PORTLAND HARBOR RI/FS

REMEDIAL INVESTIGATION REPORT

FINAL

February 8, 2016

This report was significantly revised by USEPA from the August 29, 2011 Draft Final RI Report submitted by the Respondents to the Administrative Order on Consent for Remedial Investigation and Feasibility Study U.S. EPA Docket Number CERCLA-10-2001-0240 dated and amended September 28, 2001, as amended on June 16, 2003 and April 27, 2006. This document will be part of the Administrative Record in support of EPA's selection of the remedial action for the Portland Harbor Superfund Site.

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LIST OF ACRONYMS

2-D	two dimensional
3-D	three dimensional
95 UCL	95th percentile upper confidence limit
95 UPL	95th percentile upper prediction limit
ADCP	Acoustic Doppler Current Profiler
AOC	Administrative Order on Consent
AOPC	area of potential concern
ATSDR	Agency for Toxic Substances and Disease Registry
AWQC	ambient water quality criteria
BaP	benzo(a)pyrene
BaPEq	benzo(a)pyrene equivalent
BEHP	bis-2(ethylhexyl) phthalate
BERA	baseline ecological risk assessment
BES	Bureau of Environmental Services
bgs	below ground surface
BHHRA	baseline human health risk assessment
bml	below mudline
BMP	best management practice
BNSF	Burlington Northern Santa Fe Railway Company
BOD	biological oxygen demand
BTEX	benzene, toluene, ethylbenzene, and xylenes
BTV	background threshold values
CBWTP	Columbia Boulevard Wastewater Treatment Plant
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cfs	cubic feet per second
CGF	coarse-grained flood deposits
COI	contaminant of interest[1]
COPC	contaminant of potential concern[2]
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CRAG	Columbia Region Association of Governments
CRBG	Columbia River Basalt Group
CRD	Columbia River datum
CRITFC	Columbia River Inter-Tribal Fish Commission
CSM	conceptual site model
CSO	combined sewer overflow
CSZ	Cascadia Subduction Zone
CT	central tendency

[1] Prior deliverables and some of the tables and figures attached to this document may use the term "chemical of interest," which has the same meaning as "contaminant of interest" and refers to "contaminants" as defined in 42 USC 9601(33).

[2] Prior deliverables and some of the tables and figures attached to this document may use the term "chemical of potential concern," which has the same meaning as "contaminant of potential concern" and refers to "contaminants" as defined in 42 USC 9601(33).

CWA	Clean Water Act
DDD	dichloro-diphenyl-dichloroethane
DDE	dichloro-diphenyl-dichloroethene
DDT	dichloro-diphenyl-trichloroethane
DDx	2,4′ and 4,4′-DDD, -DDE, -DDT
DEA	David Evans and Associates, Inc.
DEQ	Oregon Department of Environmental Quality
DMR	Discharge Monitoring Report
DO	dissolved oxygen
DOC	dissolved organic carbon
DNAPL	dense, nonaqueous-phase liquid
DSL	Oregon Department of State Lands
ECSI	Environmental Cleanup Site Information
EDC	ethylene dichloride
EDI	equal discharge increment
EDI-VI	vertically integrated equal discharge increment
EDI-NS/NB	near-surface and near-bottom equal discharge increment transect pair
EFC	Emergency Fleet Corporation
EFDC	Environment Fluid Dynamics Code
EOSM	Evraz Oregon Steel Mills
EPC	exposure point concentration
ERA	ecological risk assessment
ERIS	Emergency Response Information System
ESA	Endangered Species Act
FFA	fill, fine-grained facies of flood deposits, and recent alluvium
f_{oc}	fraction of organic carbon
FS	feasibility study
FSP	field sampling plan
FSR	field sampling report
gamma-HCH	gamma-hexachlorocyclohexane (Lindane)
GIS	geographic information systems
GLISP	Guild's Lake Industrial Sanctuary Plan
GPS	global positioning system
GSI	Groundwater Solutions, Inc.
GWPA	groundwater pathway assessment
HI	hazard index
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
HQ	hazard quotient
HRGC	high resolution gas chromatography
HRMS	high resolution mass spectrometry
HSP	health and safety plan
HST	hydrodynamic and sediment transport
IRIS	Integrated Risk Information System
ISA	initial study area
JSCS	joint source control strategy

K_d	solid/water partitioning coefficient
K_{oc}	organic carbon partitioning coefficient
K_{ow}	octanol-water partitioning coefficient
LISST	laser *in situ* scattering and transmissometer
LOE	line of evidence
LPAH	low-molecular-weight polycyclic aromatic hydrocarbon
LRMS	low resolution mass spectrometry
LWG	Lower Willamette Group
MCL	maximum contaminant level
MGP	manufactured gas production
mgy	million gallons per year
MHWM	mean high water mark
MNR	monitored natural recovery
MOA	memorandum of agreement
MOU	memorandum of understanding
MRL	method reporting limit
MS4	municipal separate storm sewer system
MSL	mean sea level
MTBE	methyl *tert*-butyl ether
Mw	moment magnitude
mya	million years ago
N/m^2	Newton per square meter
NAPL	nonaqueous-phase liquid
NAVD88	North American Vertical Datum of 1988
NB/NS	near bottom and near surface
NGVD29/47	National Geodetic Vertical Datum of 1929 through the Pacific Northwest Supplemental Adjustment of 1947
NJADN	New Jersey Atmospheric Deposition Network
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NTCRA	non-time-critical removal action
OC normalized	organic carbon normalized
ODFW	Oregon Department of Fish and Wildlife
ODHS	Oregon Department of Human Services
ODOT	Oregon Department of Transportation
OHW	ordinary high water
OHWM	ordinary high water mark
OLW	ordinary low water
OSSA	Oregon State Sanitary Service Authority
PAH	polycyclic aromatic hydrocarbon
PBDE	polybrominated diphenyl ether
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzo-p-dioxin
PCDD/F	polychlorinated dibenzo-p-dioxin/furan

PCDF	polychlorinated dibenzofuran
PCP	pentachlorophenol
PGE	Portland General Electric
POC	particulate organic carbon
ppm	parts per million
PRD	Portland River Datum
QA/QC	quality assurance and quality control
QAPP	quality assurance project plan
RfD	reference dose
RI	remedial investigation
RI/FS	remedial investigation and feasibility study
RM	river mile
RME	reasonable maximum exposure
SAP	sampling and analysis plan
SCRA	site characterization and risk assessment
SCSR	site characterization summary report
SEA	Stiplin Environmental Associates
SLERA	screening-level ecological risk assessment
SOP	standard operating procedure
SOW	statement of work
SPI	sediment profile imaging
SP-NB	single point, near bottom
SP-NS	single point, near surface
SP-VI	single point, vertically integrated
SQV	sediment quality value
SRM	Sandy River Mudstone
SSO	sanitary sewer overflow
STA	Sediment Trend Analysis®
SVOC	semivolatile organic compound
TBT	tributyltin ion
TCDD	tetrachlorodibenzo-p-dioxin
TCDF	tetrachlorodibenzofurans
TE	transport environment
T-EDI-NS/NB	near-surface and near-bottom equal discharge increment transect pair
T-EDI-VI	vertically integrated equal discharge increment transect
TEF	toxicity equivalency factor
TEQ	toxic equivalent concentration
TMDL	total maximum daily load
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TRV	toxicity reference value
TSCA	Toxic Substance Control Act
TSS	total suspended solids
T-VI (E, M, W)	vertically integrated, three segment (east, mid-channel, west) transect
TZW	transition zone water

UCL	upper confidence limit
UPL	upper prediction limit
UPRR	Union Pacific Railroad
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VI (E, M, W)	vertically integrated: east-middle-west
VOC	volatile organic compound
WHO	World Health Organization
WISCO	Willamette Iron and Steel Company
WQC	water quality criteria
XAD	hydrophobic polyaromatic resin

Executive Summary

This report presents the results of the remedial investigation (RI) for the Portland Harbor Superfund Site. In December 2000, the U.S. Environmental Protection Agency (EPA) identified the Portland Harbor area of the lower Willamette River as a Superfund site and placed it on the National Priorities List. The RI data collection was conducted by the Lower Willamette Group (LWG) pursuant to an Administrative Settlement Agreement and Order on Consent (AOC) with EPA to conduct the remedial investigation and feasibility study. EPA is the lead agency for investigating and selecting a remedy for the in-river portion of the Site, with support from the Oregon Department of Environmental Quality (DEQ). EPA has entered into a Memorandum of Understanding (MOU) with DEQ, six federally recognized tribes, two other federal agencies, and one other state agency,[1] who have all participated in providing support in the development of this document. The RI describes physical conditions of the site, characterizes sources of contaminants, the nature and extent of contamination and processes that affect their movement and fate, evaluates contaminant concentrations in upstream sediment, and assesses potential exposures to contaminants in Portland Harbor sediments and risks to humans and ecological receptors.

STUDY AREA

The study area is located in an urban and industrial reach of the lower Willamette River. What was once a shallow, meandering portion of the Willamette River has been redirected and channelized via filling and dredging. A federally maintained navigation channel, extending nearly bank-to-bank in some areas, doubles the natural depth of the river and allows transit of large ships into the active harbor. Much of the riverbank contains overwater piers and berths, port terminals and slips, and other engineered features (armoring such as rip rap makes up approximately half of the harbor shoreline). These extensive physical alterations have resulted in a river reach that bears little resemblance to its pre-industrialized character in terms of hydrodynamics, sediment processes, ecological habitat, and human uses.

The initial study area (ISA) as defined in the AOC extended from river mile (RM) 3.5 to RM 9.2. Ultimately, the area was expanded upstream and downstream over the course of the RI as additional site characterization data and upland source information were compiled and evaluated, and the final study area for the RI is a 10-mile stretch of the lower Willamette River. It is located north of downtown Portland between Sauvie Island at RM 1.9 and the Broadway Bridge at RM 11.8. The RI also includes data and source information from areas downstream and upstream of the final RI study area,

[1] Government parties that signed the MOU include: the Confederated Tribes and Bands of the Yakama Nation, the Confederated Tribes of the Grand Ronde Community of Oregon, the Confederated Tribes of Siletz Indians, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes of the Warm Springs Reservation of Oregon, the Nez Perce Tribe, the National Oceanic and Atmospheric Administration, the U.S. Department of the Interior, and the Oregon Department of Fish and Wildlife.

including immediately upstream in the downtown Portland reach (RM 11.9 to 15.3), and an upriver or background reach from RM 15.3 to 28.4.

Today, the Willamette River is noticeably different from the river prior to industrial development that commenced in the mid to late 18th century. Historically, the Willamette River was wider with more sand bars and shoals and flow volumes were subject to greater fluctuation. The main river now has been redirected and channelized, several lakes and wetlands in the lower floodplain have been filled, and agricultural lands converted to urban or industrial areas. The end result is a river that is deeper and narrower than it was historically with higher banks that prevent the river from expanding during high-flow events. The Willamette River navigation channel, from the Broadway Bridge (RM 11.6) to the mouth (RM 0), currently varies in width from 600 to 1,900 feet. Further, the installation of a series of dams in the upper Willamette River watershed moderate fluctuations of flow in the lower Willamette River.

Little, if any, original shoreline or river bottom exists that has not been modified by the above actions, or as a result of them. Much of the shoreline has been raised, filled, stabilized, and/or engineered and contains overwater piers and berths, port terminals and slips, stormwater and industrial wastewater outfalls and combined sewer overflows, and other engineered features. Constructed structures, such as wharfs, piers, floating docks, and pilings, are especially common in Portland Harbor where urbanization and industrialization are most prevalent. These structures are built largely to accommodate or support shipping traffic within the river and to stabilize the riverbanks for urban development.

Armoring to stabilize banks covers approximately half of the harbor shoreline, which is integral to the operation of activities that characterize Portland Harbor. Riprap is the most common bank-stabilization measure. However, upland bulkheads and rubble piles are also used to stabilize the banks. Seawalls are used to control periodic flooding as most of the original wetlands bordering the Willamette in the Portland Harbor area have been filled. Some riverbank areas and adjacent parcels have been abandoned and allowed to revegetate, and beaches have formed along some modified shorelines due to relatively natural processes.

HUMAN USE

Industrial and urban development of Portland Harbor and adjacent areas has been extensive. The majority of the shoreline in the study area is currently zoned for industrial land use and is designated by the City of Portland as an “Industrial Sanctuary,” with associated industrial and commercial worker activities. Portland Harbor also provides recreational opportunities both on the river and along the riverbanks. Additionally, there are residential areas located near the river and upstream and downstream of the study area. Recreational activities are associated with the public access areas, such as beaches and boat ramps, and may include water skiing, occasional swimming, and waterfront recreation. Fishing for salmon, sturgeon, and other species is

conducted throughout the study area, both by boaters and from locations along the banks. The lower Willamette River also provides Native American ceremonial and subsistence fisheries for Pacific lamprey (particularly at Willamette Falls) and spring Chinook salmon. In addition, transients have been observed camping at various locations within the study area.

ECOSYSTEM

Portland Harbor provides habitat for invertebrates, fishes, birds, mammals, amphibians, reptiles, and aquatic plants. Each group makes a contribution to the ecological function of the river, with its relative importance depending on its niche, its abundance, and its interaction with the physical environment. The invertebrate community living in the sediments provide important food for fish and other species in the study area. The fish species found in the harbor include numerous species of resident fish; the river also serves as an important pathway for migration of anadromous species such as salmon, lamprey, and sturgeon. The lower Willamette River has been designated by the National Marine Fisheries Service as critical habitat for several salmon species that migrate through the study area. Fish in the harbor provide an important food resource for birds, such as osprey and bald eagle, and some larger fish species like northern pikeminnow and smallmouth bass, and aquatic mammals.

Birds that use the harbor include migratory and resident species. Resident birds include bald eagle, Canada goose, mallard, spotted sandpiper, and great blue heron; other species are also found in the study area. Mammals with habitat in the study area include beaver, muskrat, raccoon, river otters, and California sea lion. Portland Harbor provides limited habitat for amphibians and reptiles, and most of the native amphibians prefer undisturbed areas that offer seasonal wetlands with emergent plants and shallow waters. Most local reptile species prefer wet vegetated upland habitats.

Aquatic plant communities are used by wildlife for refuge and for nesting and breeding habitat, and they also provide food for herbivores and play a role in the cycling of nutrients. Habitat constraints in Portland Harbor, that include muddy water, overwater obstructions that prevent the sun from reaching the bottom, and extensive bank armoring, limit the development of dense submerged and emergent plant communities in the study area.

DATA COLLECTED FOR THE REMEDIAL INVESTIGATION

The study area investigation for the Portland Harbor Superfund Site relies on data available from field investigations conducted by the LWG, with oversight by EPA, as well as data from other sources. These investigations provide information on surface features, contaminant sources, meteorology, media-specific (groundwater, surface water, fish and shellfish tissue, and sediment) chemistry, geology, hydrology (surface water and groundwater), and ecology of the study area.

The Portland Harbor RI was designed as a multi-year program involving multiple rounds of data gathering and data evaluation as chemical distributions and the factors driving risks to ecological receptors and human health were identified. Site data were collected by the LWG during four major rounds of field investigations between 2001 and 2008, often timed around varying river stages, river flows, and storm events. The field investigations first began in 2001 in the ISA as defined by the AOC, Statement of Work, and Programmatic Work Plan. Studies also included areas downriver of the study area to the confluence with the Columbia River and upriver to RM 28.4. Each sampling event was conducted under an EPA-approved Field Sampling Plan and Quality Assurance Project Plan and Health and Safety Plan. Analytical results were documented in a Field Sampling Report, a data report, and/or a Site Characterization Study Report.

In 2001 and 2002 the LWG conducted a number of studies as an initial phase of the Portland Harbor RI. These studies were necessary to scope the work plan for conducting the RI. Round 2 sampling began with multiple field efforts in 2004 and focused on the characterization of surface and subsurface sediment quality. In 2006, specialized sampling to support the hydrodynamic sediment transport model (surface sediment erosion rates) was conducted. Round 3 sampling between 2006 and early 2008 included collecting samples of surface water, biota, sediment upstream and downstream of the study area, suspended sediments (in-river sediment traps), and stormwater from selected outfalls. Round 3 sampling also filled data gaps related to site characterization, ecological and human health risks, and upriver background.

In addition to the LWG field investigations, the LWG has also reviewed numerous documents that provided information regarding Portland Harbor and the lower Willamette River in order to develop the Conceptual Site Model and guide the sampling programs for this investigation. Physical, chemical and biological data from other parties were obtained primarily from individual LWG members, EPA, Oregon DEQ, the U.S. Geological Survey, and the U.S. Army Corps of Engineers.

The sediment, water, and tissue samples discussed above were analyzed for an extensive list of environmental contaminants, including metals, tributyltin ion (TBT), polychlorinated biphenyls (PCBs), dioxins, DDT and other pesticides, semivolatile and volatile organic compounds, herbicides, phenols, and polybrominated diphenyl ethers (PBDEs). However, not every sample was analyzed for all these contaminants.

REMEDIAL INVESTIGATION RESULTS

Physical System

Physical characteristics of the site include meteorology, regional geology and hydrogeology, surface water hydrology, the physical system (which includes bathymetry, sediment characteristics, and hydrodynamics and sediment transport), habitat, and surface features.

The study area is located along the southwestern edge of a large geologic structure known as the Portland Basin, which is a bowl-like structure 40 miles long and 20 miles wide, bounded by folded and faulted uplands. The Tualatin Mountains (Portland West Hills) form a ridge that runs parallel to the Willamette River to the west from the Multnomah Channel to the City of Portland. The mountains define the western edge of the Portland Basin, and groundwater, creeks, and channels along the east face of the mountains flow downward to the Willamette River.

Precipitation falls primarily as rain, with nearly 90 percent occurring between mid-October and mid-May. Rainfall is an important component of source control as it defines stormwater and groundwater contaminant migration to the study area. It also has a significant effect on the hydrology of the river.

The Willamette River is the 19th largest river in the contiguous United States in terms of discharge, with substantial flows, averaging 33,000 cubic feet per second. Flows vary considerably by season, with the lowest flows occurring during the late-summer dry season, and typically increasing by a factor of 10 through the winter rainy season. River flows in the lower Willamette are regulated to some degree by a series of upstream dams, although high-flow events of 200,000 cubic feet per second or more still occur every few years during large storms. Although Portland Harbor is more than 100 miles from the Pacific Ocean, it is subject to tidal influence, causing the river to rise and fall up to several feet through a tidal cycle. During the dry season, when river discharge is low, rising tides can cause intermittent flow reversals throughout the harbor.

Generally, groundwater flow adjacent to the study area is toward the river. On the west side of the river, groundwater and creeks and channels along the east face of the Tualatin Mountains flow downward to the Willamette River. On the east side of the river, starting upstream of RM 4, a broad terrace divides the floodplains of the Willamette and Columbia rivers. Deep groundwater flows are influenced by the Columbia on the east side of the river, with effects increasing as distance from the Willamette River increases. Groundwater gradients are relatively flat in some areas along the east side of the river, due to both underlying geology and the influence of the Columbia River. The groundwater flow regimes bordering the river show seasonal patterns related to seasonal river stage and precipitation variations. In the absence of preferential pathways, groundwater flow to the sediments and river will tend to be heavily influenced by the location and geometry of higher and lower permeability layers in relation to the river.

The primary factors controlling river flow dynamics, sediment deposition and erosion, and riverbed character appear to be the river cross-sectional area and navigation channel width. The upstream boundary of the study area to Willamette Falls is markedly narrower, more confined by bedrock outcrops, and faster flowing than the Portland Harbor reach. The river widens as it enters the study area and becomes increasingly depositional, most notably in the western portion of the river, until RM 7. From approximately RM 5 to RM 7, the river and navigation channel narrow, and this reach is dominated by higher energy environments with little deposition. From RM 5 to

approximately RM 2 the river widens again and becomes depositional, particularly in the eastern portion of the river. Immediately downstream of the study area, the river narrows as it turns and converges with the Columbia River. Multnomah Channel exits at RM 3, considerably reducing direct discharge to the Columbia River.

Sediments in some locations may be resuspended and transported downstream during periods of high flow and from anthropogenic disturbances, such as vessel operations in the harbor. The degree of deposition and movement of sediments is controlled largely by river hydrodynamics and the sediment texture (grain size and organic matter content). Suspended fine-grained sediments (silts and clays) are typically transported farther than larger sandy sediments under all flow conditions.

Bathymetric changes from 2002 to 2009 show the greatest net sediment accumulation occurs where the channel is wide and where flow velocities are reduced; these shoals are predominantly fine-grained sediments. Some areas of natural scour and dredging are also evident. Sediments in the scour areas are predominately sand and appear to be relatively stable during low-flow conditions, but are mobilized when flow velocities are high.

Nearshore and off-channel areas, such as Swan Island Lagoon, Willamette Cove, and port terminals, also exhibit deposition. In other areas, such as RM 9-11E, areas within Swan Island Lagoon and Willamette Cove, RM 6-7W, and RM 5-7E, little elevation change and/or small-scale scour was observed. Sediment scour in some nearshore locations appears to be due to ship traffic (wakes and prop wash) and other human activities. These activities also appear to mix surface and subsurface sediments.

Sources of Contamination

Historical releases of contaminants contributed to the majority of the observed chemical distribution in sediments within the study area. Contaminants from upland areas have entered the river system as direct discharges through stormwater and wastewater outfalls, from overwater releases and spills, and indirectly through overland flow, bank erosion, groundwater, and other nonpoint sources. In addition, contaminants from regional sources have reached the study area through inputs of surface water and sediment from upstream and through atmospheric deposition. Historical and current sources responsible for the existing contamination include, but are not limited to, ship building, repair, and dismantling; wood treatment and lumber milling; storage of bulk fuels and manufactured gas production; chemical manufacturing and storage; municipal combined sewer overflows; and stormwater from industrial, commercial, transportation, and agricultural land uses.

Ongoing sources of contaminants to the study area include soil, stormwater, groundwater, and river banks. Contaminants also reach the river via direct discharge through conveyance systems, atmospheric deposition, and overwater activities. Ustream sources within the broader Willamette River Basin contribute to contamination in sediment, surface water, and biota in the study area.

Distribution of Contaminants

A subset of contaminants was selected as indicator contaminants in the RI report to facilitate the presentation of the distribution of contamination identified in the study area. The indicator contaminants are:

- Total PCBs
- Total polychlorinated dibenzo-*p*-dioxin/furans (PCDD/Fs)
- DDx (sum of 2,4´- and 4,4´- dichlorodiphenyltrichloroethane [DDT], -dichlorodiphenyldichloroethane [DDD] and -dichlorodiphenyldichloroethene [DDE])
- Total polycyclic aromatic hydrocarbons (PAHs)
- Bis(2-ethylhexyl)phthalate (BEHP)
- Total chlordanes
- Aldrin
- Dieldrin
- Arsenic
- Chromium
- Copper
- Zinc
- TBT.

Sediment

The highest concentrations of contaminants in sediments were typically found in nearshore and off-channel areas such as slips, embayments, and shallow areas, and near some known or suspected sources.

On a site-wide basis, the highest PCB sediment concentrations occur in nearshore areas and in locations proximal to local upland sources. Relatively high concentrations of PCBs are also often found in riparian sediments, sediment trap samples, surface waters, and biota samples in the areas with elevated sediment concentrations. The highest concentrations were observed at RM 11.3E, RM 8.8–10W, Swan Island Lagoon, International Slip (RM 3.7–3.8E), RM 2.1E–2.5E, and RM 4.0–4.1E. Total PCBs concentrations are generally higher in subsurface sediments, pointing to predominantly historical total PCBs sources and higher past loads, although exceptions to this trend are noted at RM 11E, Swan Island Lagoon, and Willamette Cove. Relative PCB concentrations in surface water generally align with those areas having the highest concentrations in sediment. Total PCBs concentrations in the study area sediment trap samples were 1-to-5 fold greater than upstream concentrations. Measured PCB concentrations in biota are typically found in biota samples from areas with high sediment concentrations.

Total PCDD/Fs were detected in sediments at RM 2E–8E, Swan Island Lagoon, RM 11E, RM 6W–10.3W, RM 4W–6W, and at RM 3.4W. These areas generally coincide with known or likely historical sources at RM 11E, Swan Island Lagoon,

Willamette Cove, and between RM 6.5W and 7.5W. Total PCDD/F concentrations in the subsurface are generally greater than in surface sediments, indicative of primarily historical inputs. Areas of apparent PCDD/F contamination in sediment in other locations in the study area not associated with documented sources and pathways indicate that all sources may not have been identified. There are no strong spatial or temporal gradients evident in concentrations measured in suspended sediments collected in sediment traps. PCDD/Fs were detected in all fish and invertebrate tissue samples collected from the study area, and the highest concentrations were in samples collected between RM 6.5 and 7.5.

The highest reported DDx concentrations in sediment are located in the western nearshore zone between RM 6W and 7.5W, and are proximal to known upland sources. Other areas are smaller in extent and are located at RM 8.8W, at the mouth of Swan Island Lagoon, the International Slip, and RM 4.8W (in subsurface sediment only). Concentrations are typically greater in the subsurface than in the surface layer, indicating DDx sources are primarily historical. The highest DDx concentrations observed in surface water, sediment traps, transition zone water (TZW), and biota samples were all from the area of RM 6.8W to RM7.5W.

PAHs are present at a wide range of concentrations throughout the study area in all media, and the highest concentrations in sediment occur downstream of RM 7 in nearshore areas proximal to local upland sources offshore of Siltronic, Gasco, Marine Finance, and Foss Brix. Other locations of elevated total PAH concentrations in surface sediments include Mar Com South (RM 5.5–5.6E), Terminal 4 Slip 3 and Wheeler Bay (RM 4.3–4.6E), Slip 1 (RM 4.3E), and the International Slip (RM 3.7–3.8E). Concentrations are generally higher in subsurface sediments; the most notable exception to this pattern is the navigation channel at RM 5 to 6. Another exception to the general pattern of higher subsurface total PAH concentrations is Swan Island Lagoon. The composition of different PAHs in sediment trap and high-flow surface water particulate samples were generally similar to that of sediment. Total PAH concentrations in TZW were reported in areas that correspond with elevated areas of sediment concentrations. The highest concentrations reported in biota samples also correspond with areas where the highest PAH concentrations were found in sediment.

The highest BEHP concentrations detected in sediment are located proximal to local upland sources and are observed in Swan Island Lagoon and in the International Slip (RM 3.7–3.8E), and along the riverside of Schnitzer/Calbag site RM 3.8–4.1E. RM 7.6E, RM 9.7W, RM 8.8W, RM 8.3W, RM 7.6W, and offshore of RM 7.1, and RM 10 in the navigation channel. High concentrations were less widespread in subsurface sediment. BEHP concentrations in sediment trap samples generally did not vary widely spatially or temporally. BEHP was detected in laboratory-exposed clams and worms, mussels, and fish, and was not detected in crayfish, juvenile Chinook, or carp. With the exception of the surface sediment on the east bank near RM 4 and subsurface sediment at the downstream end of Swan Island, elevated BEHP concentrations in biota do not correlate well with elevated concentrations in sediment.

The highest detected chlordane concentrations in sediment are restricted to small, widely scattered nearshore or off-channel areas, proximal to local upland sources at RM 5.8W–9W, and RM 3E, 4E, 5.5E, and 11E. Total chlordanes were detected in a majority of surface water samples. Reported concentrations in sediment trap samples were low, with no strong temporal or spatial patterns. Chlordanes were detected at low concentrations with varying frequency in all fish and invertebrate samples.

Aldrin and dieldrin contamination in sediment is generally co-located and restricted to small, widely scattered nearshore areas. The highest concentrations were detected at RM 6.8 to 7.5W and RM 8.8W. Overall, aldrin concentrations were slightly higher in subsurface than surface sediment, while dieldrin concentrations are generally greatest in surface sediment. Both were detected in particulate and dissolved surface water samples, and were infrequently detected in sediment traps.

Relatively high zinc concentrations were observed in the vicinity of Swan Island Lagoon, and at Terminal 4; high concentrations of copper were also observed in Swan Island Lagoon. With the exception of widely scattered nearshore areas where higher concentrations of arsenic, copper, and zinc were noted in sediment, concentrations of these metals are generally consistent across the site. The lack of a discernable concentration gradient between surface and subsurface is indicative of both recent and historical inputs of all three metals. Concentrations in surface water were generally consistent across the entire study area; sediment collected in traps show little spatial or temporal trends in measured concentrations. The highest reported arsenic concentrations in TZW are located at the west side of the channel at RM 6.2–6.6, and the west bank at RM 7.7. However, there are no corresponding high arsenic concentrations in sediment. The highest copper and zinc concentrations in TZW were measured offshore of the Gasco and Siltronic sites in areas where no elevated surface sediment concentrations were reported. Arsenic, copper, and zinc were detected in nearly all fish and invertebrate species and tissues analyzed from within the study area.

Areas of relatively high chromium concentrations in surface and subsurface sediments were noted at the head of the International Slip, RM 2E, RM 4E, RM 6E, Swan Island Lagoon, RM 6W, RM 7W, and RM 9W. The distribution of concentrations in surface and subsurface sediments indicate both recent and historical sources. Results from sediment trap samples show a uniform distribution of chromium concentrations. The highest concentrations in TZW were observed between RM 6.2W and 6.5W, offshore of the Gasco and Siltronic properties. It was detected in all fish and invertebrate species and tissues analyzed within the study area.

TBT contamination in sediment is primarily located in the vicinity of the Cascade General Shipyard and adjacent to Swan Island Lagoon. Concentrations in subsurface sediments exhibit slightly higher concentrations than surface sediments, suggesting that contributions from historical inputs were greater relative to current inputs. Upstream of RM 7.5, TBT was detected in sediment trap samples only in Swan Island Lagoon.

Upstream areas characterized during the RI for comparison with the study area included the downtown reach (RM 11.9 to 15.3), which is immediately above the study area, and a reach from upriver of Ross Island to Willamette Falls (RM 15.3 to 28.4). The Willamette River is narrow in these upstream areas, resulting in higher flow velocities and sandier sediments. Excluding some known or suspected source areas and cleanup sites in the downtown reach, sediment contaminant concentrations in the upstream areas are lower than found in the study area.

Locations exhibiting higher elevated contaminant concentrations in the study area appear to be physically stable over time. However, migration of some contaminants is evident in limited areas consistent with source types and general sediment transport patterns. Sediments immediately downstream of the study area in the Willamette River and Multnomah Channel showed some evidence of contaminant migration from the study area for certain contaminants.

Suspended Sediments

The areas where the highest concentrations of contaminants were detected in sediment trap samples correspond with areas with high concentrations in surface sediments, indicating the effect of erosion and resuspension of bottom sediment, the presence of current sources, or both. Concentrations of indicator contaminants collected from sediment trap samples in the study area were higher than in samples collected upstream of the study area.

Surface Water

Concentrations of contaminants in surface water within the study area are generally higher than those measured in upstream samples under all flow conditions. Elevated concentrations were observed in both transect (cross-river composite samples) and single-point surface water samples at various locations throughout the study area. The highest contaminant concentrations in surface water within the Site were found near known sources. At the downstream end of the study area and Multnomah Channel, concentrations of total PCBs, dioxin/furans, DDx, BEHP, chlordanes, and aldrin in surface water are greater than concentrations entering the study area and indicate that contamination from Portland Harbor is being transported downstream to the Columbia River.

Transition Zone Water

Currently, 120 sites have been identified with groundwater contamination. Complete or likely complete groundwater pathways have been identified at 11 sites, 51 sites have insufficient data to make a determination, and 58 sites have been identified as not having a complete pathway. As part of the groundwater pathway assessment investigation conducted for the RI, samples of TZW and pore water in surface and near-surface sediments were collected offshore of nine upland sites in the study area. Based on these efforts, a current complete groundwater pathway with influence on TZW and sediment chemistry was confirmed at four sites, groundwater migration was found to

have no significant influence at four other sites, and groundwater effects could not be determined at one site.

Fish and Invertebrate Tissue

Contaminants were detected in a majority of fish and invertebrate species collected throughout the study area. Contaminant concentrations varied within and between different species; concentrations in fish tissue were generally greater than in invertebrates. Concentrations of bioaccumulative compounds such as PCBs and DDx were often found at greater concentrations in organisms higher on the food chain and correlated with areas of elevated concentration in sediment. On a site-wide scale, biological samples from within the study area exhibited greater concentrations of most indicator contaminants than those seen in samples from upriver reaches and above Willamette Falls. Localized areas of elevated concentrations of some indicator contaminants were found in resident species, reflecting high concentrations in nearby surface sediment and biological uptake by species with small home ranges.

BASELINE HUMAN HEALTH RISK ASSESSMENT

The baseline human health risk assessment (BHHRA) evaluated the potential for adverse human health effects from exposure to contaminants within the study area. The general objective of the BHHRA was to assess the potential risks to human health from exposure to contaminants present in sediment, surface water, and groundwater seeps, or accumulating in fish and shellfish.

Approach to the Baseline Human Health Risk Assessment

Currently or potentially exposed populations were identified based on consideration of both current and potential future uses of the study area, and include populations who may be exposed to contamination though a variety of activities. The specific populations and exposure pathways evaluated were:

- Dockside workers — direct exposure via incidental ingestion and dermal contact with beach sediments.
- In-water workers — direct exposures to in-water sediment.
- Transients — direct exposure to beach sediment, surface water for bathing and drinking water scenarios, and groundwater seeps.
- Recreational beach users — direct exposure to beach sediment and surface water while for swimming.
- Tribal fishers — direct exposure to beach or in-water sediments, and consumption of migratory and resident fish.
- Recreational and subsistence fishers — direct exposure to beach or in-water sediments, consumption of resident fish, and consumption of shellfish.

- Divers — direct exposure to in-water sediment and surface water.
- Domestic water user — direct exposure to untreated surface water potentially used as a drinking water source in the future.
- Infants — consumption of human breast milk where the mother is exposed as one of the above fish-consumption populations.

The presence of uncertainty is inherent in the risk assessment process, and EPA policy calls for numerical risk estimates to always be accompanied by descriptive information regarding the uncertainties of each step in the risk assessment to ensure an objective and balanced characterization of the true risks and hazards. Additionally, it is important to note that the risks presented here are based on numerous conservative assumptions in order to be protective of human health and to ensure that the risks presented are more likely to be overestimated rather than underestimated

Results of the Baseline Human Health Risk Assessment

The major findings of the BHHRA are:

- Estimated cancer risks resulting from the consumption of fish or shellfish are generally orders of magnitude higher than risk resulting from direct contact with sediment and surface water. Risks and noncancer hazards from fish and shellfish consumption exceed the EPA point of departure for cancer risk of 1×10^{-4} and target hazard index (HI) of 1 when evaluated on a harbor-wide basis, and when evaluated on the smaller spatial scale by river mile. Consumption of resident fish species consistently results in the greatest risk estimates. Evaluated harbor-wide, the estimated reasonable maximum exposure (RME) cancer risks are 4×10^{-3} and 1×10^{-2} for recreational and subsistence fishers, respectively.

- Noncancer hazard estimates for consumption of resident fish species are greater than 1 at all river miles. Based on a harbor-wide evaluation of noncancer risk, the estimated RME HI is 300 and 1,000 for recreational and subsistence fisher, respectively. The highest hazard estimates for recreational fishers are at RM 4, RM 7, RM 11, and in Swan Island Lagoon.

  The highest noncancer hazards are associated with nursing infants of mothers who consume resident fish from Portland Harbor. When resident fish consumption is evaluated on a harbor-wide basis, the estimated RME HI is 4,000 and 10,000 for breastfed infants of recreational and subsistence fishers, respectively. Evaluated on a harbor-wide scale, the estimated RME HI for tribal consumers of migratory and resident fish is 600 assuming fillet-only consumption, and 800 assuming whole-body consumption. The corresponding HI estimates for nursing infants of mothers, who consume fish, are 8,000 and 9,000 respectively, assuming maternal consumption of fillet or whole-body fish.

- PCBs are the primary contributor to risk from fish consumption harbor-wide. When evaluated on a river mile scale, dioxins/furans are a secondary contributor to the overall risk and hazard estimates, except at RM 7 where it is the primary risk contributor. PCBs are the primary contributors to the noncancer hazard to nursing infants, primarily because of the bioaccumulative properties of PCBs and the susceptibility of infants to the developmental effects associated with exposure to PCBs.

ECOLOGICAL RISK ASSESSMENT

The baseline ecological risk assessment (BERA) evaluated the potential for adverse effects on plants, invertebrates, amphibians, fish, and wildlife from contaminants within the study area. The primary objective of the BERA was to characterize the risks of chemical effects on these aquatic and aquatic-dependent ecological receptors in the study area.

Approach to the Baseline Ecological Risk Assessment

The following complete and significant exposure pathways were quantitatively evaluated in the BERA using multiple lines of evidence:

- **Benthic invertebrates**—Direct contact with sediment and surface water, ingestion of biota and sediment, and direct contact with shallow TZW
- **Fish**—Direct contact with surface water, direct contact with sediment (for benthic fish receptors), ingestion of biota, incidental ingestion of sediment, and direct contact with shallow TZW (for benthic fish receptors)
- **Birds and mammals**—Ingestion of biota and incidental ingestion of sediment
- **Amphibians and aquatic plants**—Direct contact with surface water and shallow TZW.

The assessment endpoints for all ecological receptors are based on the protection and maintenance of their populations and the communities in which they live, with the exception of special status species (species that are protected by federal and/or state regulations or otherwise deemed culturally significant), which are assessed at the organism-level for survival, growth, and reproduction. In Portland Harbor, juvenile Chinook salmon and Pacific lamprey ammocoetes were identified as special status species. For practical reasons and to be conservative, the organism-level measurement endpoints (survival, growth, and reproduction) were used for all receptors, requiring extrapolation to assess risks to populations and communities.

Results of the Baseline Ecological Risk Assessment

The following presents the primary conclusions of the BERA:

- In total, 93 contaminants (as individual contaminants, sums, or totals) pose potentially unacceptable ecological risk. Grouping individual PCB, DDx, and PAH compounds reduces the number to 66.
- Risks to benthic invertebrates are clustered in 17 benthic areas of concern.
- Sediment and TZW samples with the highest hazard quotients for many contaminants also tend to be clustered in areas with the greatest benthic invertebrate toxicity.
- PAH and DDx compounds are the contaminants of potential concern in sediment that are most commonly spatially associated with locations of potentially unacceptable risk to the benthic community or populations.
- The most ecologically significant contaminants are PCBs, PAHs, dioxins and furans, and DDT and its metabolites. PAHs and DDx risks are largely limited to benthic invertebrates and other sediment-associated receptors. PCBs tend to pose their largest ecological risks to mammals and birds.
- The combined toxicity of dioxins/furans and dioxin-like PCBs, expressed as total TEQ, poses the potential risk of reduced reproductive success in mink, river otter, spotted sandpiper, bald eagle, and osprey.

CONCLUSIONS

The key findings of the RI include the following:

Sources of Contamination

Most of the sediment contamination at the Site is associated with known or suspected historical sources and practices, ongoing contaminated groundwater plumes, river bank soils, and upstream surface water. The distribution of contaminants in sediments in several nearshore areas appears to reflect more significant historical lateral inputs. The spatial correlation between PCBs in aquatic organisms and sediments indicate that contamination in bottom sediments are an ongoing source of persistent bioaccumulative contaminants such as PCBs, DDx, and dioxin/furans contamination to biota.

Nature and Extent of Contamination

- Sediments in Portland Harbor reflect the industrial, marine, commercial, and municipal practices for over 100 years in this active industrial, urban, and trade corridor, as well as agricultural activities in the Willamette Basin.
- Higher concentrations of contaminants in sediments occur in nearshore and off-channel areas that are generally associated with known or likely historical or current sources.
- Contaminant concentrations in sediment are generally higher at depth than in the surface layer, indicating that past contaminant inputs were greater than current

inputs, and that surface sediment quality has improved over time. The few exceptions include areas where higher surface sediment concentrations appear to be associated with ongoing local sources, low rates of sediment deposition, and physical sediment disturbance (e.g., from boat scour).

Fate and Transport

The major internal fate and transport processes are:

- Erosion from the sediment bed
- Deposition to the sediment bed
- Dissolved flux from the sediment bed (pore water exchange)
- Groundwater advection
- Degradation (for some contaminants)
- Volatilization
- Downstream transport of either particulate-bound or dissolved phase contaminants.

These processes interact to create complex patterns of contaminant redistribution that vary over space, time, and by contaminant. Patterns of contamination in bedded surface sediment suggest some redistribution of contaminants over time. In some areas this is limited by re-burial of much of the source area contamination, as indicated by higher subsurface sediment concentrations in these areas. In other areas, periodic erosion may temporarily expose buried contamination and disburse contaminants downstream.

Groundwater plume advection and release has been observed in several areas along with dissolved phase flux from surface sediments to the water column. Limited sampling of groundwater effects on pore water in the study area has been conducted and further sampling will need to be conducted in Remedial Design.

Based on results of surface water data collected during the RI, resuspension and/or dissolved phase flux from the sediment bed are contributing to contaminant concentrations in surface water, particularly in quiescent areas where surface water mixing and dilution is minimal. Loading estimates are consistent with this concept, indicating that the mass flux of some contaminants exiting the downstream end of the study area in surface water (either directly to the Columbia River or via Multnomah Channel) is greater than the flux entering the study area. Contaminant concentrations in loads entering the study area from adjacent upland sources and pathways (such as stormwater) are generally greater than concentrations in the upstream loads (upriver surface water and sediments). Stormwater input is the most important current source pathway within the study area for many contaminants, including PCBs and DDx.

Finally, empirical tissue contaminant data and food web modeling indicate that persistent contaminants (particularly PCBs and dioxin/furans) in sediments and surface water bioaccumulate in aquatic species tissue.

All the data taken together (surface water, sediment, sediment traps), provide evidence that contaminants from the study area are transported downstream to either the Columbia River or Multnomah Channel.

Estimates of Risk

There is unacceptable risk to both human and ecological receptors (cancer risk and noncancer hazard greater than those defined as acceptable by the National Contingency Plan).

The greatest risk to humans is through consumption of contaminated fish and shellfish. Contaminants that contribute to the unacceptable risk estimates to humans include:

- Aldrin
- Arsenic
- BEHP
- Chlordanes
- DDx Compounds
- Dieldrin
- Hexachlorobenzene
- Mercury
- Pentachlorophenol
- PBDEs
- PCBs
- Carcinogenic PAHs
- Dioxins and furans.

There are 20 contaminants posing ecologically significant risk:

- PCBs
- Dioxins and furans
- PAHs
- DDT and metabolites
- Total chlordanes

- Mercury
- Lead
- Cadmium
- Copper
- Zinc
- Dieldrin
- Lindane
- BEHP
- TPH (C_{10}-C_{12} aliphatic)
- Tributyltin
- Cyanide
- Ethylbenzene
- Perchlorate
- Manganese
- Vanadium.

1.0 INTRODUCTION

This report presents the results of the remedial investigation (RI) for the Portland Harbor Superfund Site (Site) conducted by the Lower Willamette Group (LWG). Portland Harbor encompasses the downstream portion of the lower Willamette River and has served as the city of Portland's major industrial corridor since the mid 1800s[1]. The study area for the RI extends from river mile (RM) 1.9 [upriver end of the Port of Portland's Terminal 5] to RM 11.8 [near the Broadway Bridge], and data collection for the RI report extends from RM 0.8 to 26.4 [above Willamette Falls near Oregon City] (Map 1.0-1).

Portland Harbor was evaluated and proposed for inclusion on the National Priorities List (NPL) pursuant to Section 105 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund), 42 U.S.C. §9605, by the U.S. Environmental Protection Agency (USEPA) and formally listed as a Superfund site in December 2000.

This RI report evaluates the environmental data collected and compiled by the LWG since the inception of the Portland Harbor Remedial Investigation and Feasibility Study (RI/FS) in 2001[2]. The LWG is performing the RI/FS for the Portland Harbor Superfund Site pursuant to a USEPA Administrative Settlement Agreement and Order on Consent for Remedial Investigation/Feasibility Study (AOC; USEPA 2001a, 2003b, 2006a). Oversight of the Portland Harbor RI/FS is being provided by USEPA with support from the Oregon Department of Environmental Quality (DEQ). EPA has entered into a Memorandum of Understanding (MOU) with DEQ, six federally recognized tribes, two other federal agencies, and one other state agency[3], who have all participated in providing support in the development of this document.

The content and organization of this RI report adhere to CERCLA's *Guidance Document for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final* (USEPA 1988). In accordance with these requirements, this report assembles data collected by the LWG and others, characterizes the physical characteristics and nature and extent of contamination in the study area based on those data, identifies sources of contaminants to the study area, provides an analysis of the fate and transport of contaminants, discusses background contaminant concentrations,

[1] In this RI report, the term "Portland Harbor" means the portion of the Willamette River containing the federal navigation channel, from RM 0 to 11.6. The term "lower Willamette River" means the portion of the Willamette River from its confluence with the Columbia River to Willamette Falls, or RM 0 to approximately RM 26.5.

[2] Upland source control efforts, including site-specific upland source control studies and implementation of source control measures, are performed under the oversight of DEQ and are not within the scope of the AOC and statement of work (SOW) for the in-water portion of the Site.

[3] Government parties that signed the MOU include: the Confederated Tribes and Bands of the Yakama Nation, the Confederated Tribes of the Grand Ronde Community of Oregon, the Confederated Tribes of Siletz Indians, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes of the Warm Springs Reservation of Oregon, the Nez Perce Tribe, the National Oceanic and Atmospheric Administration, the U.S. Department of the Interior, and the Oregon Department of Fish and Wildlife.

presents the baseline human health risk assessment (BHHRA) and baseline ecological risk assessment (BERA), and provides a revised conceptual site model (CSM). Information collected during the RI will be used to help identify areas requiring cleanup. The feasibility study (FS) report will analyze and compare alternatives or approaches to remediate those areas that need cleanup to reduce or eliminate risks.

1.1 SITE BACKGROUND

1.1.1 Site Description

The Willamette River originates within Oregon in the Cascade Mountain Range and flows approximately 187 miles north to its confluence with the Columbia River. The lower reach of the Willamette River from RM 0 to approximately RM 26.5 is a wide, shallow, slow moving segment that is tidally influenced with tidal reversals occurring during low flow periods as far upstream as RM 15. The river segment between RM 3 and 10 is the primary depositional area of the Willamette River system. The lower reach has been extensively dredged to maintain a 40-ft deep navigation channel from RM 0 to 11.6. This segment of the lower reach includes a highly industrialized area known as Portland Harbor, which contains a multitude of facilities and both non-municipal and municipal outfalls.

Portland Harbor is located along an 11.6-mile dredged reach of the lower Willamette River in Portland, Oregon (Map 1.0-1). While the harbor area is heavily industrialized, it occurs within a region characterized by commercial, residential, recreational, and agricultural uses. Land use along the lower Willamette River in the harbor includes marine terminals, manufacturing, and other commercial operations, as well as public facilities, parks, and open spaces. Information regarding land use zoning within the lower Willamette River, as well as waterfront land ownership, is provided in Section 3 of this report.

1.1.2 Site History

The Willamette River is the 19th largest river in the United States and is one of 14 American Heritage Rivers in the country. During its 309-mile course, which ends by emptying into the Columbia River, it drains 11.7 percent of the state of Oregon.

In 1891, the Oregon State Legislature created the Port of Portland. By 1930, following a period of railroad and riverfront development, shipping tonnage for the Port increased to 4.1 million tons. The Port of Portland is now the largest wheat exporting port in the country (Port of Portland 2011). Cargo from more than 40 U.S. states passes through Portland as part of the approximately $15 billion in goods that travel the Columbia River system. As Oregon's major port and population center, the lower Willamette River sees a great variety of uses. For example, shipping, industrial, fishing, recreational, natural resource, and other interest groups all use the lower Willamette River.

Since the late 1800s, the Portland Harbor section of the lower Willamette River has been extensively modified to accommodate a vigorous shipping industry. Modifications include redirection and channelization of the main river, draining seasonal and permanent wetlands in the lower floodplain, and relatively frequent dredging to maintain the navigation channel. Constructed structures, such as wharfs, piers, floating docks, and pilings, are especially common in Portland Harbor where urbanization and industrialization are most prevalent. These structures are built largely to accommodate or support shipping traffic within the river and to stabilize the riverbanks for urban development. Riprap is the most common bank-stabilization measure. However, upland bulkheads and rubble piles are also used to stabilize the banks. Seawalls are used to control periodic flooding as most of the original wetlands bordering the Willamette in the Portland Harbor area have been filled. Detailed aerial photographs showing constructed structures are provided in Section 3 of this report

Today, the Willamette River is noticeably different from the river prior to industrial development that commenced in the mid to late 18th century. Historically, the Willamette was wider, had more sand bars and shoals, and fluctuated greatly in volume. In contrast, the main river now has been redirected and channelized, several lakes and wetlands in the lower floodplain have been filled and agricultural lands converted to urban or industrial areas. The end result is a river that is deeper and narrower than it was historically with higher banks that prevent the river from expanding during high-flow events. Further, the installation of a series of dams moderates fluctuations of flow in the lower Willamette River. Little, if any, original shoreline or river bottom exists that has not been modified by the above actions, or as a result of them. Some riverbank areas and adjacent parcels have been abandoned and allowed to revegetate, and beaches have formed along some modified shorelines due to relatively natural processes.

Numerous municipal and non-municipal outfalls, including storm drains and combined sewer overflows (CSOs), are located along both shores of the lower Willamette River in the metropolitan area. In the early 1900s, rivers in the United States were generally used as open sewers, which was also true for the Willamette (Carter 2006). The growing city's untreated sewage, as well as process water from a variety of industries, including slaughterhouses, chemical plants, electroplaters, paper mills, and food processors, was discharged directly into the river. The long history of industrial and shipping activities in the Portland Harbor, as well as agricultural, industrial, and municipal activities upstream of Portland Harbor, has contributed to chemical contamination of surface water and sediments in the lower Willamette River. Potential sources of chemical releases to the river are described in Section 4 of this report.

Development of the river has resulted in major modifications to the ecological function of the lower Willamette River. However, a number of species of invertebrates, fishes, birds, amphibians, and mammals, including some protected by the Endangered Species Act (ESA), use habitats that occur within and along the river. The river is also an important pathway for migration of anadromous fishes, such as salmon and lamprey. Various recreational fisheries, including salmon, bass, sturgeon, crayfish, and others,

use the lower Willamette River. A detailed description of ecological communities in Portland Harbor is presented in the BERA discussion in Section 9 and Appendix G of this report.

1.1.3 Navigational Channel Authorization History

A federal navigation channel, with an authorized depth of -40 ft, extends from the confluence of the lower Willamette River with the Columbia River to RM 11.6. Container and other commercial vessels regularly transit the river. Certain parts of the river require periodic maintenance dredging to keep the navigation channel at its authorized depth. In addition, the Port of Portland and other private entities periodically perform maintenance dredging to support access to dock and wharf facilities. Dredging activity has greatly altered the physical and ecological environment of the river in Portland Harbor.

The lower Willamette federal navigation project was first authorized in 1878 to deepen and maintain parts of the Columbia River and lower Willamette with a 20-ft minimum depth. The channel for both rivers has been deepened at various intervals since that time. The navigation depth for both rivers was increased to 25 ft in 1899 and to 30 ft in 1912. Between 1930 and 1935, the navigation channel depth was again increased to 35 ft, and in 1962 the authorized depth was increased to 40 ft. The current project authorization, as modified by Congress in 1962, encompasses 11.6 miles of the Willamette River below Portland and 103.5 miles of the Columbia River below Vancouver, Washington. Work on the authorized 40-ft-deep channel from Portland and Vancouver to the Pacific was completed in 1976. The Willamette River channel, from the Broadway Bridge (RM 11.6) to the mouth (RM 0), varies in width from 600 to 1,900 ft.

1.1.4 Previous Investigations

There have been numerous investigations of the Portland Harbor site dating back to the 1920s; however, most studies have been conducted from the late 1970s through the 1990s. Some investigations have been conducted on a larger scale (e.g., several river miles) while others have been conducted on a smaller scale (e.g., less than one river mile). Larger scale investigations have typically been conducted by or for federal or state agencies, such as the U.S. Army Corps of Engineers (USACE), the U.S. Geological Survey (USGS), the Oregon Department of State Lands (DSL), the Oregon Department of Fish and Wildlife (ODFW), the DEQ Water Program, and USEPA, to assess the health of the river system. Smaller scale investigations have typically been conducted by private parties for the purposes of maintenance dredging, construction and maintenance of in-river structures, or assessment of fate and transport of contamination from upland or in-water releases.

Nearly 700 documents and data sets were obtained that address conditions in the lower Willamette River. This information was used to develop an initial understanding of the

physical, chemical, and biological processes at the site and to assist in the development of the CSM for the study area. Appendix A discusses which of these data sets were included in the final RI report.

1.2 REPORT ORGANIZATION

This document is organized as follows:

- **Section 1. Introduction.** This section describes the purpose of the report and presents site background information.
- **Section 2. Study Area Investigation.** This section presents summaries of the field activities associated with site characterization, the process used to assess data quality, and removal actions already completed.
- **Section 3. Environmental Setting.** This section discusses the results of activities to determine physical characteristics and human use of the study area.
- **Section 4. Identification of Sources.** This section describes the types of known and potential contaminant sources that affect the study area.
- **Section 5. In-River Distribution of Contamination.** This section presents the results of site characterization of contamination in various media within the Willamette River.
- **Section 6. Loading, Fate, and Transport for Select Contaminants.** This section presents an overview of the primary known sources of contaminants to the river, describes the processes affecting the release, transport, and fate of contaminants within the study area, and presents estimates of current pathway-specific mass-loading rates. Historical contributions to the study area are discussed qualitatively in this section.
- **Section 7. Determination of Background Concentrations for Indicator Contaminants.** This section provides an evaluation of the concentrations and distributions of contaminants in sediment samples collected from upstream reference locations (i.e., background) for use in development of remedial alternatives in the FS. .
- **Section 8. Baseline Human Health Risk Assessment Summary.** This section provides a summary of the BHHRA conducted for this site. The BHHRA is provided in Appendix F of this document.
- **Section 9. Baseline Ecological Risk Assessment Summary.** This section provides a summary of the BERA conducted for this site. The BERA is provided in Appendix G of this document.
- **Section 10. RI Conceptual Site Model Summary.** This section presents a study area-wide overview of the physical setting; contaminant distribution in sediments; contamination sources identified to date; external loading and

internal fate and transport mechanisms; and human health and ecological receptors, and exposure pathways and scenarios. For selected contaminants, this section also presents integrated, chemical-specific evaluations of nature and extent in abiotic and biotic media in the study area, and the relationships between the observed distribution in the system and known or likely historical and current sources of contamination.

- **Section 11. References.** Citations noted in the RI are found in this section.

Nine appendices are included with this document:

- **Appendix A. Data Sources and Site Characterization/Risk Assessment Database.** This appendix briefly summarizes the studies from which data in this RI report were obtained and includes the complete database in Access® files on compact disc. Data rules for the site characterization and risk assessment (SCRA) database for the RI data set and the BHHRA and BERA data sets are provided. Further, this appendix includes the process for calculating chemical concentrations from whole-body bass and carp samples.
- **Appendix B. DEQ September 2010 Milestone Report Table 1.** This appendix presents Table 1 from DEQ's Joint Source Control Strategy (JSCS) Milestone Report (DEQ 2010a).
- **Appendix C. Stormwater Statistics and Groundwater Characterization.** Summary statistics for stormwater collected by the LWG and other parties are included in this appendix. Details of the LWG's groundwater pathway assessment work, including identification of potential upland groundwater source areas and transition zone water (TZW) investigation results, are also provided.
- **Appendix D. In-River Distribution of Contaminants in Biotic and Abiotic Media.** Summary statistics of the chemical and physical data for all media are provided. The appendix includes constituent concentrations used in each summed analyte group for all media. Scatter plots, histograms, and maps of distribution of contaminants not included in the main report are also included in this appendix. A technical memo, *Comparison and Use of PCB Aroclor and Congener Data*, is included in this appendix.
- **Appendix E. Loading, Fate, and Transport Supporting Information and Calculations.** This appendix provides the analyses used to develop loading estimates for upstream surface water, stormwater, permitted point source discharges, atmospheric deposition, groundwater plumes, and advection through sediments.
- **Appendix F. Baseline Human Health Risk Assessment.** This appendix provides the final BHHRA conducted for this site.
- **Appendix G. Baseline Ecological Risk Assessment.** This appendix provides the final BERA conducted for this site.

- **Appendix H. Background Supporting Information.** This appendix contains the sediment background data set, information supporting the background calculations, and background statistics for contaminants not included in Section 7.
- **Appendix I. Interactive Map Application of Section 10 Panels.** This appendix provides an interactive map application of the three-section panel analyte-specific series included in Section 10 that present cross-media contaminant distributions and available source information for each of the 13 CSM contaminants. The panels show the entire study area, upland site property boundaries, outfall locations, historical industries, and river mile markers, and these layers can be turned on and off to display different combinations of information (e.g., subsurface sediment and biota polychlorinated biphenyl [PCB] distributions).

2.0 STUDY AREA INVESTIGATION

The study area investigation for the Portland Harbor Superfund Site (see Map 1.0-1) relies on data available from field investigations conducted by the LWG, with oversight by USEPA, as well as data from other sources. These investigations provide information on surface features, contaminant sources, meteorology, media-specific (e.g., groundwater, surface water, fish and shellfish tissue, and sediment) chemistry, geology, hydrology (surface water and groundwater), and ecology of the study area. This section discusses the field investigations conducted by the LWG and information/data collected from other sources (Section 2.1 and Appendix A1). The data quality assessment process for these studies is summarized in Section 2.2 and supporting details are presented in Appendices A2 and A3. Section 2.3 describes removal actions that have already taken place within the Portland Harbor Superfund Site.

The Portland Harbor RI was designed as a multi-year program involving multiple rounds of data gathering and data evaluation as chemical distributions and the factors driving risks to ecological receptors and human health were identified. Site data were collected by the LWG during four major rounds of field investigations between 2001 and 2008, often timed around varying river stages, river flows, and storm events. The field investigations first began in 2001 in the initial study area (ISA) as defined by the AOC, SOW, and Portland Harbor RI/FS Programmatic Work Plan (Programmatic Work Plan) as RM 3 to 9. As the studies proceeded, the study area was expanded from RM 1.9 to 11.8. Studies also included areas downriver of the study area to the confluence with the Columbia River at RM 0 and upriver to RM 28.4.

Each subsection of Section 2.1 describes the sample collection, and the maps presented in this section show the location of data collected from each sampling event by media (e.g., surface sediment, biota, surface water, etc.). Each sampling event was conducted under an USEPA-approved field sampling plan (FSP) and quality assurance project plan (QAPP) and health and safety plan (HSP). Analytical results were documented in a field sampling report (FSR), data report, and/or site characterization summary report (SCSR). Table 2.0-1 provides a list of the LWG FSPs, FSRs, and data reports submitted to USEPA for each major round of sampling.

In addition to the LWG field investigations, the LWG has also reviewed numerous documents that provided information regarding Portland Harbor and the lower Willamette River in order to develop the CSM and guide the sampling programs for this investigation. Physical, chemical and biological data from other parties were obtained primarily from individual LWG members, USEPA, Oregon DEQ, the USGS, and USACE. These investigations are summarized in Table 2.0-2. Section 2.1.5 and Appendix A1 provide additional information on the data collected by other parties.

2.1 REMEDIAL INVESTIGATION FIELD INVESTIGATION SUMMARIES

The Programmatic Work Plan (Integral, Windward, Kennedy/Jenks, Anchor, and GSI 2004) describes the activities to be undertaken by the LWG as it developed this RI for the Portland Harbor Superfund Site. The Programmatic Work Plan complies with the requirements of the AOC and SOW (USEPA 2001a) between the LWG and USEPA for conducting the RI/FS. This section of the RI discusses the preliminary and RI field investigations conducted by the LWG in accordance with the Programmatic Work Plan, AOC, and SOW. These field investigations include preliminary studies (Section 2.1.1), Round 1 RI field investigations (Section 2.1.2), Round 2 RI field investigations (Section 2.1.3), and Round 3 RI field investigations (Section 2.1.4).

2.1.1 Preliminary Studies (2001–2002)

Under a legal agreement with USEPA (2001a), the LWG conducted a number of studies as an initial phase of the Portland Harbor RI. These studies were necessary to scope the work plan for conducting the RI. This phase of studies included a multibeam bathymetric survey of the lower Willamette River (DEA 2002a), a juvenile salmonid residence time survey (Ellis Ecological Services 2002), and a Sediment Trend Analysis® (STA) survey (GeoSea Consulting 2001; SEA 2002a). On December 5, 2001, USEPA also approved performance of a sediment profile imaging (SPI) survey of the lower Willamette River (SEA 2002b). In spring 2002, an Acoustic Doppler Current Profiler (ADCP) survey was conducted to measure current velocities at several transects in the river (DEA 2002b).

2.1.1.1 Bathymetric Survey

A multibeam bathymetric survey conducted by David Evans and Associates, Inc. (DEA) took place in the lower Willamette River from the confluence with the Columbia River at RM 0 to 15.6 in accordance with the Multibeam Bathymetry Work Plan (DEA 2001). The bathymetric survey was conducted between December 13, 2001 and January 14, 2002, during a period of high water in the river. The methods used to collect and post-process the riverbed elevation data are provided in a field report (DEA 2002a). There were no deviations from the work plan. The results of the survey are shown in both hill-shade format and contours in the field report (DEA 2002a) and discussed further in Section 3 of this RI report. Water depths are referenced to the North American Vertical Datum of 1988 (NAVD88).

2.1.1.2 Juvenile Salmonid Residence Time Survey

A reconnaissance-level (pilot) survey was conducted in spring 2001 by Ellis Ecological Services, Inc. on the residence time of subyearling juvenile Chinook salmonids in Portland Harbor (Ellis Ecological Services 2002). This study was conducted in the lower Willamette River between RM 3.5 and 18.5. A comprehensive discussion of the methodologies and results is provided in the Technical Memorandum: Juvenile Salmonid Residence Time in Portland Harbor (Ellis Ecological Services 2002). This study was conducted to evaluate the feasibility of using miniature radio-tags (nanotags) for estimating residence time of the larger subyearling Chinook salmon (107–125 mm

fork length) in Portland Harbor. Emphasis was placed on testing the methodology and approach rather than trying to develop definitive estimates of residence time for subyearling Chinook salmon. Specific objectives of the study were as follows:

- Test, evaluate, and refine proposed techniques for estimating residence time of subyearling Chinook salmon in Portland Harbor
- Develop a preliminary estimate of median residence time for radio-tagged subyearling Chinook salmon in Portland Harbor, particularly between RM 3.5 and 9.5, during the period of peak downriver migration
- Monitor ambient water quality (temperature, dissolved oxygen, conductivity, and turbidity) and flow conditions in conjunction with collection of fish movement and distribution data.

Only a small number of fish were measured during the capture efforts to minimize the effects associated with handling of fish. Therefore, no specific efforts targeted the quantification of fish size. However, fish captured during beach seine operations were noticeably smaller than those captured at the bypass facility. Fish captured in the beach seine ranged in size from approximately 55 mm (2.2 inch) to 110 mm (4.3 inch) fork length while fish captured at the bypass facility ranged in size from approximately 80 mm (3.1 inch) to 150 mm (5.9 inch) fork length.

A total of 43 Chinook salmon were successfully radio-tagged and released in the lower Willamette River upriver of Portland Harbor in May and June 2001. Of these 43 fish, 28 were located 266 times during the mobile tracking effort. None of the released fish was recorded on the Oregon Department of Fish and Wildlife (ODFW) fixed telemetry receivers. Fifteen fish were not located after release. Therefore the mobile tracking efforts were determined to be 65 percent effective in locating released fish. Sixteen subyearling fall Chinook were selected and used to obtain a preliminary determination of mean rate of downriver movement. These 16 fish were located 147 times during the mobile tracking effort. Ten of these 16 fish were from release two, 2 fish were from release three, and 4 fish were from release four. Six out of the 16 selected fish had adequate telemetry to allow calculation of a residence time estimate for the study area.

Map 2.1-1 shows the radio telemetry locations for the radio-tagged fish representing the median rate of downriver movement. Travel rate among the 16 fish was highly varied. Rates of travel ranged from 0.9 km per day (0.6 miles per day) to 15.3 km per day (9.5 miles per day). Residence time in the study area from RM 3.5 to RM 18.5 averaged 6.0 days (SD = 6.1 days, n = 16), ranging from 1.6 days to 26.9 days. The median residence time between RM 3.5 and RM 18.5 was 4.8 days.

No preference by fish for shallow water habitat was observed between the Multnomah Channel (RM 3.5) and the Broadway Bridge (RM 11.7). All of the 16 fish selected were observed in this reach of the river during mobile tracking operations and located a total of 54 times. Only four of these 54 observations were located in shallow water rearing

habitat (Figure 2.1-1). In addition, there was no correlation identified between fish size and rate of downriver movement and no diurnal effects were observed.

2.1.1.3 Sediment Trend Analysis® Survey

STA® is a unique technique developed by GeoSea Consulting whereby patterns of net sediment transport in a waterbody are determined from relative changes in the grain-size distributions of bottom sediments in the waterbody. In addition, the technique enables the dynamic behavior of the bottom sediments to be assessed (i.e., net erosion, net accretion [erosion], dynamic equilibrium [stability], etc.).

The specific objectives of the STA® (GeoSea Consulting 2001; SEA 2002a) for this site were the following:

- Collect approximately 850 sediment grab samples from the Willamette River from the mouth to the Willamette Falls (RM 26) downstream to the confluence with the Columbia (RM 0) and in the Columbia River approximately 1 mile upstream and downstream of the confluence of the Willamette with the Columbia River
- Analyze each of the sediment samples for its complete grain-size distribution and establish, using the STA® technique, the present patterns of sediment transport
- Determine areas of sediment erosion, stability, and deposition as inferred by this technique.

Sediment grab samples were collected during the period September 15, 2000 through September 29, 2000 using a van Veen type grab sampler. This device samples the top 10 to 15 cm of sediment. In most instances, samples were obtained at predetermined locations; however, where shoreline structures (e.g., docks and marinas) and moored vessels interfered with navigation, samples were collected as close as practicable to the planned position. A total of 935 sample sites were visited, of which 99 samples were found to be “hard ground” (i.e., cobbles or bigger, or scoured bottom, or wood debris covering the bottom) and no sample could be taken. A site was designated as “hard ground” after three separate drops of the grab sampler failed to retrieve sediment.

The sediments of the Willamette River (summarized in Table 2.1-1) vary widely, from coarse sand in the upstream portions of the river near its confluence with Clackamas River, to mainly sandy mud near the mouth where it enters the Columbia River. To facilitate presentation and discussion of the results, the river was divided into seven reaches or segments, starting from Reach 1 near Willamette Falls. The most common sediment types were sand, muddy sand, and sandy mud, which account for 83.5 percent of all the samples (Table 2.1-1). Approximately 10 percent of the samples were “hard ground,” where no sample could be obtained after three attempts with the grab. Most of these samples were found in the upstream part of the river, but there were a few locations (e.g., in Multnomah Channel) where wood debris covered the bottom.

A total of 154 transport lines were selected to provide a pattern of sediment transport in the river. The transport lines were grouped into sixteen transport environments (TEs), starting from TE1 at the upstream end of the survey area (i.e., near Willamette Falls). A Transport Environment is defined as an area within which transport lines are associated both geographically and "behaviorally". Generally, transport lines cannot be continued from one TE into another, because to do so decreases the statistical significance of the line (samples in the new TE are not related through transport to the samples in the line). Thus, a region in which transport lines naturally end (and begin) is a boundary between TEs. Map 2.1-2a–b shows the sediment types and sample locations in each of the seven reaches sampled in the survey.

2.1.1.4 Sediment Profile Image Survey

A SPI survey was conducted by SEA (2002b) in the lower Willamette River from RM 0 (the Willamette's confluence with the Columbia River) upstream to RM 15.7 (the upstream edge of Ross Island) from November 26, 2001 through December 11, 2001. Prior to the start of the survey, a complete sampling and analysis plan (SAP), QAPP, and HSP were submitted to USEPA (SEA 2001). This survey was completed in accordance with those plans.

The purpose of this study was to provide reconnaissance information on physical and biological features of surface sediments in the lower Willamette River from Ross Island to the Columbia River. These data, in addition to information from other preliminary sampling efforts (e.g., bathymetric survey, STA® survey), provided information needed to develop an effective approach to the RI/FS for sediments in the lower Willamette River.

Specifically, the objectives of the SPI survey were to generate and supplement area-wide information on the following:

- Grain-size distributions in sediments
- Patterns in physical disturbance of sediments
- Benthic community distributions in sediments
- Gradients in benthic habitat conditions, both in the main river channel and in nearshore areas.

SPI images were obtained from 478 stations in the lower Willamette River from RM 0 to 15.7. In general, stations were located along regularly spaced cross-river transects (Map 2.1-3).

Along each transect, the greatest number of stations were placed in the nearshore areas (those areas having water depths of 20 ft or less, Columbia River Datum [CRD]). It was anticipated that the nearshore areas would exhibit the greatest heterogeneity of sediment types, and potential land uses and habitats. Nearshore stations accounted for about two-thirds of the total number of stations sampled. The remaining stations were located within the federally maintained navigation channel or the main river stem.

Because of its more uniform depths and physiography, benthic conditions in the channel were considered likely to be less variable than nearshore, off-channel areas.

The study area was also divided into three upstream-downstream subareas with different sampling densities as described below. The most dense station grid was located between RM 3.5 and 9.2. SPI data from this area contributed to the development of RI sampling strategies and assisted in the interpretation of other data types. The river segments located downriver between RM 0 and 3 and upriver between RM 9.7 and 15.7 were sampled at a lower station density. These data catalog general bottom conditions and habitats in these river segments and helped locate reference areas for the RI in upstream areas.

A total of 523 images from 478 stations were analyzed. Replicate images were analyzed at 45 stations (9 percent replication). Physical parameters measured include prism penetration depth and sediment grain size. Biological parameters measured include apparent redox potential discontinuity, methane, and benthic infaunal succession stage. The complete results of the SPI survey are detailed in SEA (2000b).

2.1.1.5 Acoustic Doppler Current Profiler Survey

ADCP data were collected in the river by DEA during a high water event on April 19, 2002 (DEA 2002b). The ADCP was mounted on a 30-ft survey vessel, and transects were taken at RM 1, 2, 2.5, and 3.1 (Multnomah Channel), RM 4 and 4.6 (into Port of Portland Terminal 4 Slip 3), RM 5.8 (St. Johns Bridge), RM 6.3 (offshore GASCO), RM 6.8 (into Willamette Cove), RM 7.8 (offshore Willbridge Terminal), RM 8 (from Coast Guard Station, across Portland Shipyard to the west bank), Swan Island Lagoon (two short transects—one across mouth, one at the upper end), and RM 9.6, 10, and 11 (see Map 2.1-4). The river stage at the time of the data collection was approximately 11.6 ft CRD at the Morrison Street Bridge.

Water velocities obtained from the ADCP survey ranged from an upstream velocity of nearly 1 ft/second (upstream flow in back eddy) to a downstream velocity of 2 ft/second. Flows across the transects were computed at approximately 70,000 cubic feet per second (cfs) above Multnomah Channel and approximately 35,000 cfs below Multnomah Channel. The Willamette River flow on April 19, 2002 was roughly double the average Willamette discharge rate of about 32,000 cfs.

2.1.2 Round 1 RI Field Investigations (2002–2004)

Round 1 data collection for the Portland Harbor RI was conducted from June 2002 through February 2004 and results were presented in the Round 1 SCSR (Integral 2004a) and in the following study-specific FSRs:

- Aquatic plant and amphibian/reptile reconnaissance (Windward 2003a)
- Epibenthic invertebrate sampling using multiplates (Windward 2003b)
- Lamprey harvest reconnaissance survey (Kennedy/Jenks 2003)

- Nearshore deposition/erosion monitoring using sediment stakes (Anchor 2004a)
- Summer 2002 river-wide bathymetric survey (DEA 2003a).
- May 2003 multibeam bathymetric survey (SEA and DEA 2003; DEA 2003b)
- February 2004 multibeam bathymetric survey (DEA 2004a)
- Juvenile lamprey reconnaissance (SEA and Windward 2003)
- Benthic infaunal biomass reconnaissance survey (SEA and Windward. 2003)
- Soft-bottom benthos tissue reconnaissance (SEA and Windward 2003)
- Seep reconnaissance survey (GSI 2003a)
- May 2003 ADCP survey (DEA 2003c)
- January 2004 ADCP survey (DEA 2004b).

Except where noted in the FSRs or as modified by subsequent correspondence between the LWG and USEPA, all sample collection activities followed the procedures described in the Round 1A and Round 1 FSPs (SEA, Windward, Anchor, and Kennedy/Jenks 2002a, 2002b) and the Fish Tissue Sampling Standard Operating Procedure (SOP) (SEA, Windward, and Kennedy/Jenks 2002a). Fish tissue sample processing, including compositing, homogenization, and shipping, followed the procedures detailed in the Fish Tissue Compositing and Homogenization SOPs (SEA 2002c; SEA, Windward, and Kennedy/Jenks 2002b). All laboratory analyses follow the USEPA-approved Round 1 QAPP (SEA 2002d).

2.1.2.1 Summary of Round 1 Field Activities

The following tasks were carried out according to the Round 1A FSP, which was approved by USEPA on May 5, 2002 (SEA, Fishman, Ellis, Windward, Anchor, and Kennedy/Jenks 2003):

- Juvenile salmonid mark/recapture pilot study
- Collection of fish tissue for chemical analysis
- Epibenthic invertebrate sampling using multiplates
- Aquatic plant and amphibian/reptile reconnaissance survey
- Adult lamprey harvest reconnaissance survey
- Nearshore deposition/erosion monitoring using sediment stakes
- Summer 2002 multibeam acoustic bathymetric survey.

Round 1 field activities included the following tasks, which were approved by USEPA in a letter dated September 20, 2002 (SEA, Fishman, Ellis, Windward, Anchor, and Kennedy/Jenks 2003):

- Beach sediment chemistry

- Sediment chemistry at sculpin, crayfish, and benthic infauna stations (collocated sediments)
- Benthic infauna survey
- Clams for tissue analysis
- Juvenile salmonids and resident fish tissue analysis

In addition, the following activities were performed:

- Seep reconnaissance survey
- Juvenile lamprey and benthic infaunal biomass reconnaissance surveys
- Soft-bottom benthos reconnaissance survey
- May 2003 multibeam acoustic bathymetric survey
- February 2004 multibeam acoustic bathymetry survey
- May 2003 ADCP survey
- January 2004 ADCP survey.

Each of these activities is described in more detail in the following section. Water column chemistry and subsurface sediment radioisotope studies were not conducted in this phase of the project. Both of these studies were conducted later in Round 2 and are discussed further in Section 2.1.3.

2.1.2.1.1 Juvenile Salmonid Mark/Recapture Pilot Study

A pilot study to gather information on mark/recapture methods for juvenile salmonids was conducted July 8-9, 2002. The study of residence time of subyearling Chinook salmon was originally scheduled to begin in May 2002 and continue through the peak period of downstream migration (i.e., late May through June). However, between the submission of the Section 10 fishing permit and research startup, the proposed research was required to be reviewed and approved by USEPA. USEPA decided that instead of emphasizing residence time of subyearling Chinook in the 2002 season, emphasis should be placed on the collection of fish for tissue analysis. The scope of the residence time study was reduced to a pilot study to evaluate the efficacy of using fluorescent elastomer tags for marking subyearlings and developing an estimate of recovery efficiency. These changes in priorities were discussed with National Oceanic and Atmospheric Administration (NOAA) Fisheries Service in May 2002.

Due to the time required for the USEPA review and approval, startup of the pilot study was delayed until mid-July. By that time, water temperature in the study area had increased to levels that were stressful to juvenile salmonids. Juvenile Chinook salmonids were captured by beach seine on July 8 and 9, 2002. Field personnel found that the stress of handling at the ambient water temperatures was too high to allow meaningful results for a tag-recovery-efficiency estimate. Therefore, sampling for these

purposes was discontinued, and no information was developed in 2002 on the residence time of subyearling Chinook. There were no agency representatives present as observers during the brief study.

2.1.2.1.2 Collection of Fish Tissue for Chemical Analysis

The fish tissue collection program was approved as part of Round 1A. Collection of fish and crayfish tissue from the study area followed guidelines outlined in the Fish Tissue Sampling SOP (SEA, Windward, and Kennedy/Jenks 2002a). Eleven fish species and one crayfish species were identified for tissue analyses to obtain data for the BERA and BHHRA. The target species for the BERA were:

- Northern pikeminnow (*Ptychocheilus oregonensis*)
- Smallmouth bass (*Micropterus dolomieui*)
- Sculpin (*Cottus* sp.)
- Subyearling Chinook salmon (*Oncorhynchus tshawytscha*)
- Peamouth (*Mylocheilus caurinus*)
- Largescale sucker (*Catostomus macrocheilus*)
- Lamprey ammocoetes
- Crayfish.

Of these species, only lamprey ammocoetes could not be found in sufficient numbers for tissue analyses.[1]

The target species for the BHHRA were:

- Carp (*Cyprinus carpio carpio*)
- Black crappie (*Pomoxis nigromaculatus*)
- Brown bullhead (*Ameiurus nebulosus*)
- Smallmouth bass (*Micropterus dolomieui*)
- Crayfish.

In addition, walleye and largescale sucker were collected as alternative species for brown bullhead and carp, respectively. These alternate species were not used for tissue analyses because adequate numbers of bullhead and carp were caught.

Before fish tissue sampling began, the LWG established a fish sample processing field laboratory and field equipment storage area, located in former laboratory space at the

[1] A concerted effort was made to locate lamprey ammocoetes in the ISA by the LWG and tribal biologists over 4 days in September and October 2002 without success. Methods tested and observations made during this effort are reported in SEA and Windward (2003).

decommissioned ATOFINA plant (RM 7W) in Portland. This field laboratory was outfitted with a water de-ionizing unit, venting hood, two sinks, and all laboratory safety equipment listed in the SOP. USEPA visited and approved the use of the field laboratory space. In addition, he observed a "dry run" of the fish processing procedures and approved the methodology being used. USEPA project managers conducted a final visit to the laboratory, where the fish processing team from Fishman Environmental Services clarified any additional questions about fish processing procedures.

During the Round 1A collection of subyearling Chinook salmon from June 24 through June 27, 2002, beach seining and dip netting were the only fishing techniques used. The beach seining procedure was observed by representatives from USEPA, NOAA, and the United States Fish and Wildlife Service (USFWS). As noted above, the intended mark and recapture pilot program for subyearling Chinook salmon was halted after signs of heat stress were observed in fish held in buckets prior to marking.

During the Round 1 collection of all remaining species from July 22 through November 10, 2002, six fishing techniques were used. These included beach seining, boat electrofishing, backpack electrofishing, trot line, angling, and crayfish traps. At the beginning of the Round 1 field program, fishing techniques, sample handling, and fish processing were observed in the field by USEPA and Oregon DEQ. Subsequent visits were made by USEPA and NOAA, who, along with LWG consultant field managers and field crew, helped clarify issues such as station definitions and appropriate fishing methods.

The LWG field teams collected fish in the study area, both day and night, over 79 days (Maps 2.1-5 through 2.1-11). A total of 1,870 fish were collected, including 863 sculpin, 419 crayfish, 128 largescale sucker, 90 smallmouth bass, 78 carp, 92 subyearling Chinook salmon, 64 brown bullhead, 35 northern pikeminnow, 48 black crappie, 30 peamouth, 18 yellow bullhead, 3 lamprey ammocoetes, and 2 walleye. Forty-two individuals participated in the fish tissue collection effort. Striplin Environmental Associates (SEA) staff coordinated the effort, which was carried out by personnel from Ellis Ecological Services, Fishman Environmental Services, Windward Environmental, Kennedy/Jenks Consultants, and Anchor Environmental. All people directly involved with the fishing effort were authorized to collect fish under the scientific taking permit granted by ODFW to Ellis Ecological Services. With the exception of juvenile lamprey, the 2002 fish sampling program was successful in collecting all target species at all target locations in the study area to satisfy the Round 1 data needs of the BHHRA and BERA.

Fish samples were processed at the field laboratory by laboratory staff led by Fishman Environmental Services personnel. Fish specimen sample handling and processing procedures followed those detailed in USEPA-approved project SOPs and QAPP. Following final agreement with USEPA on fish sample compositing schemes, frozen samples were shipped to Axys Analytical Services Ltd. (Sidney, B.C., Canada) for tissue homogenization.

2.1.2.1.3 Epibenthic Invertebrate Sampling Using Multiplates

The objectives of the Portland Harbor multiplate invertebrate sampling were to characterize the epibenthic organisms settling on multiplates placed in the study area and measure chemical constituents in tissue samples from these invertebrate epibenthic organisms for use in the fish, bird, and mammalian exposure models. It was anticipated that the multiplate biomass would represent accumulation via the surface water pathway.

Multiplate samplers were placed at 10 locations within the study area (Map 2.1-5) between July 26 and 28, 2005 (Windward 2005b). Members of the regulatory agencies and trustees were present on July 26, 27, 28, and September 7, 2005, to oversee field operations. Observers were representatives from Oregon DEQ and USEPA.

The multiplate samplers were deployed at the 10 locations. At each location, 4 arrays of 6 multiplate samplers (total of 24 multiplate samplers per station) (Figure 2.1-2) were deployed based on field determination of the most suitable location for each array. At most stations, 21 multiplate samplers were processed for invertebrate tissue analyses and 3 multiplate samplers were processed for taxonomic evaluation. At MIT002, 10 multiplate samplers were processed for invertebrate tissue analyses and 2 multiplate samplers were processed for taxonomic evaluation. At MIT007, 16 multiplate samplers were processed for invertebrate tissue analyses and 1 multiplate sampler was processed for taxonomic evaluation. Factors included in the suitability evaluation included water depth (at least 5 m to ensure adequate water depth later in the summer), tie-up point for the rope connected to the array, avoiding high traffic areas and prop-wash areas, and avoiding the dredge operation near Gasco.

Forty-four taxa representing 6 phyla, 10 classes, 16 orders, and 24 families were collected in sediments from the 21 multiplate samplers processed from the 10 locations in the study area. Dipterans (true flies) and oligochaetes were the most diverse taxonomic groups represented, with 10 and 12 taxa, respectively. All dipterans present were members of the chironomid family (midges) while two orders and four families of oligochaetes were present. Other taxa found were bivalves, crustaceans, arachnids (mites and water mites), nematodes, polychaetes, and trichopterans (caddisflies). Chironomids, oligochaetes, and bivalves were the most common taxonomic groups found. Chironomids were found in all 21 multiplate samplers while oligochaetes and bivalves were present in 20 and 19 samples, respectively. Abundance varied greatly between samples, but oligochaetes, on average, were the most abundant. Taxonomic richness varied by more than a factor of 3.

2.1.2.1.4 Aquatic Plant and Amphibian/Reptile Reconnaissance Survey

An aquatic plant and amphibian/reptile reconnaissance level survey was conducted between June 26 and 28, 2002 to determine the presence or absence of these species throughout the study area. As specified in the Round 1A FSP (SEA 2002e), this reconnaissance survey was designed to determine whether aquatic plants and amphibians/reptiles should be included in the BERA. The study was designed to be a

qualitative survey to determine presence/absence of amphibians/reptiles and plants in the study area. However, the presence of some amphibians may not have been recorded due to the survey being performed in late June after the hatching of egg masses. This study was not meant to be a quantitative estimation of amphibian/reptile or plant abundance or a quantitative survey of available amphibian/reptile or plant habitat.

Aquatic plant and amphibian/reptile surveys were conducted at 21 sampling sites located throughout the study area (Map 2.1-12). Sampling locations were selected based on river bank type and amphibian/reptile habitat quality. Most of the sampling locations were selected before going into the field to ensure that all representative bank types in the study area were sampled at least twice. The most common bank types occurring in the study area were riprap, unclassified fill, natural bank and river beach, and seawall. Many sampling sites coincided with the presence of in-water or shoreline structures that were considered to represent possible habitat. In addition, all designated habitat areas in the study area identified by the Willamette River Inventory (Adolfson et al. 2000) were included in the survey (e.g., Harborton Forest and Wetlands and Willamette Cove). Approximately one-third of the sample locations were selected while in the field based on visual observations of potential aquatic plant and amphibian/reptile habitat.

In general, the four bank types on which the majority of the sampling sites were located included riprap, unclassified fill, natural bank, and river beach due to the occurrence of available habitat in these areas. Other more developed bank types such as seawall and overwater structures were also visited, but did not support aquatic plant communities and, therefore, did not provide suitable amphibian or reptile habitat. Results of the plant and amphibian/reptile surveys are presented in Table 1 of the FSR (Windward 2003a). This table includes a physical description of each site and the plants, amphibians, and reptiles observed. The survey looked for evidence of salamanders but none was found. It was not possible to identify the species of the egg masses.

The aquatic plant survey identified 26 plant species, most of which were obligate and facultative wetland plant species, as defined by the National List of Plant Species That Occur in Wetlands (Reed 1996). The aquatic plant community was dominated by emergent hydrophytes that are able to live with their roots in water or muddy substrates. No submersed plants were found offshore in waters 2.4–3 m deep; however, a few submersed plants were identified close to the waterline near shore. These submersed plants included water moss, grasses, and sedge species.

The 21 sites sampled in this survey can be separated into three major types of aquatic plant habitat: 1) rocky or riprapped banks dominated by scrub-shrub wetland vegetation; 2) sandy beach where no emergent macrophytes were present in the water; and 3) sandy or rocky banks with emergent macrophytes present in the water.

Evidence of amphibian presence was observed at 6 of the 21 sampling locations. No reptiles were found at any sampling locations. In addition, frogs were heard calling in

multiple habitat types, but not in response to the frog call recordings. Because no responses to the frog call recordings were heard, the nighttime frog call survey was terminated after the first night (June 26, 2002). However, surveying primarily during the day may have excluded evidence of the presence of adult amphibians. While this survey supports the presence of amphibian species in the study area in general habitat types, specific exposure areas were not defined in the study area.

Representatives from USEPA, NOAA, and USFWS observed the nighttime frog call procedures at one sampling location on the evening of June 26, 2002.

2.1.2.1.5 Adult Lamprey Harvest Reconnaissance Survey

Reconnaissance surveys of the lamprey harvest at Willamette Falls were conducted on June 26, 2002 and July 22, 2002 (Kennedy/Jenks 2003). The objective of the surveys was to observe the harvest and to identify the lamprey species harvested. LWG consultants observed lamprey harvests by the Confederated Tribes of Siletz on June 26, 2002, and by the Yakama Nation on July 22, 2002. Because these harvest dates were not fixed in advance and required attendance on very short notice, neither Oregon DEQ nor EPA technical staff were able to observe.

Three lamprey species are native to the Columbia River basin, the Pacific lamprey (*Lampetra tridentata*), the river lamprey (*L. ayresi*), and the western brook lamprey (*L. richardsoni*). The Pacific and river lamprey are both anadromous, and the adults of both species are parasitic. The western brook lamprey is a resident species and nonparasitic. Pacific lamprey is the species used by Tribes; adults are caught at Willamette Falls. River lamprey are extremely rare, although historically were known from the Willamette River. Western brook lamprey adults are considerably smaller than Pacific lamprey (4–6 inches long as adults vs. 1.5–2 ft long for Pacific lamprey).

All of the collected lampreys that were observed during the reconnaissance surveys were adult Pacific lamprey. The collected lampreys ranged in size from 400 to 650 mm (approximately 16–26 inches) indicating that they could not be the resident western brook lamprey. Only Pacific lampreys were collected during the harvest; tribal members were not familiar with the river lamprey. The western brook lamprey does not appear to be harvested for consumption by Native American tribal members.

2.1.2.1.6 Nearshore Deposition/Erosion Monitoring Using Sediment Stakes

A study using sets of index stakes placed in the intertidal regime at eight locations between RM 2 and 9 was conducted to evaluate potential changes in the beach elevation and to relate those changes to offshore/subtidal sediment elevation changes in the river channel determined by the bathymetric surveys (DEA 2002a). The nearshore data and possible relationship to erosion/deposition farther offshore are potentially useful in assessing various approaches, such as capping and attendant stability, for addressing sediment contamination problems. The duration of the study was from July 17, 2002 to December 20, 2002.

Sediment stakes were successfully deployed at eight of nine proposed locations in the study area (Map 2.1-13). At proposed location 2 (Schnitzer Steel), no suitable area for deployment and monitoring was available and stakes were not deployed. At each of eight sample locations, three 3-ft-long polyvinyl chloride (PVC) stakes were placed along a transect perpendicular to the shoreline. The 3-ft stakes were installed so that the top of each was approximately 1 ft above the sediment surface. The target mudline elevations for the locations of the stakes along each transect were the 10th percentile (low stakes), 50th percentile (median stakes), and 90th percentile (high stakes) of the river stage measured at the USGS gage station 14211720. The distribution of stakes at different elevations along a given transect allowed measurement of sediment changes under a variety of water level/river flow conditions.

Sediment levels relative to the tops of the stakes were recorded approximately once per month over the duration of the study from July 17 to December 20, 2002. The sediment levels were determined by measuring the distance from the top of each stake to the level of the surrounding unaffected sediment surface. Any debris, such as trash, sticks/branches, weeds, and leaves that accumulated around the stakes was removed prior to making sediment level measurements. Local scour around the stakes was insignificant in all cases.

The relationship between changes in beach mudline elevation and changes in mudline elevation farther offshore in the study area were investigated by comparing stake measurement data with data from bathymetric surveys in December 2001 and July 2002. Over the study interval, the river stage varied from 5.97 ft (gage datum) on July 22 to a low of 1.54 ft on October 13, after which a general increasing trend ensued, and the stage reached a high of 6.07 ft on December 17. Tidal excursions influence the river stage at Portland, so instantaneous surface elevations would consist of the fluctuating tidal elevation superposed on daily-average values. The tidal range varies throughout the year, but for the purposes of this study was assumed to be approximately 4 ft. Thus, the range of surface elevations over a given day would be approximately the daily-average value plus and minus a 2-ft tidal signal.

The lowest river discharge recorded was 8,080 cfs on August 18. No river discharge data are available after September 30, but the general trend apparent from 28 years of record (Figure 2.1-4) is for increasing discharge volume after the summertime lows.

Sediment erosion and accretion in the study area are dynamic processes that respond to the shape of the shoreline, width of the river channel, and the stage and speed of the river. Because fluctuations in river stage and discharge are highly seasonal, it follows that sediment processes will also be seasonal. The sediment stake study spanned 5 months, and while it included the low-flow portion of the year and portions of the transitions before and after, it did not include the portion of the year when flows are typically highest. For example, the general trend among sediment measurements when river stage and discharge began increasing from the summertime lows was one of increasing erosion, which is what would be expected. Because the period when the

highest stage and discharge conditions occurred was not captured, there is no information about how much more erosion may have occurred during that period. Thus, observations and resulting conclusions made during the study interval are not representative of typical annual conditions that can be expected to occur year after year. Similarly, sediment level changes determined from changes in bathymetry between December 2001 and July 2002 and changes indicated by the sediment stake measurements are not strictly comparable because they do not span the same interval.

2.1.2.1.7 Multibeam Bathymetric Surveys

DEA performed three bathymetric surveys from 2002 to 2004 to support sediment sampling during the RI, to define shoaling and scour areas relative to the previous survey conducted in December 2001/January 2002 as part of the preliminary studies, and to support future site investigations.

Summer 2002

The summer 2002 bathymetric survey was conducted in two phases. RM 2 to 11 was surveyed between July 3 and 18, 2002. Following a review of these data, RM 0 to 2.5 and RM 10.5 to 15.6 were surveyed between September 16 and 20, 2002. This bank-to-bank survey was conducted during the low-water season to obtain summertime riverbed elevations for comparison with the riverbed elevation data collected during December 2001 and January 2002. No regulatory agencies were present during the surveys.

DEA, under contract with SEA, conducted two additional bank-to-bank multibeam bathymetric surveys of the lower Willamette River during the summer of 2002. The primary goal of these surveys was to create a data set that depicts summertime riverbed elevations for 2002 that could be directly compared to the prior, January 2002, survey to determine areas of erosion and accretion within the study area. The survey was conducted from RM 0 (at the confluence with the Columbia River) to RM 15.6 (at the upper end of Ross Island), which was the same extent as the January 2002 survey (DEA 2002a). DEA also provided geographic information system (GIS) grids of the bathymetry and difference grids that depict the change in riverbed elevation from January 2002 to summer 2002.

The results from this survey were used to support sediment sampling during the RI, to define shoaling and scour areas relative to previous surveys, and to support future site investigations. Survey operations were conducted in two stages. The initial survey was conducted from July 3, 2002 to July 18, 2002, and data were collected from RM 2.0 to 11.0. After processing the data, significant changes were identified. The LWG determined that it would be beneficial to document the extent of changes for the remainder of the 15-mile study area. A second survey included the remainder of the 15-mile stretch of the Willamette with a 0.5-mile overlap at each end to identify any short-term change during the summer of 2002. From September 16, 2002 to September 20, 2002, data were collected between RM 0.0 and 2.5 (overlapping the July survey between RM 2.0 and 2.5) and from RM 10.5 to 15.0 (overlapping the July survey between RM 10.5 and 11.0).

In order to determine erosional and depositional areas of the river, the values of the grid nodes for the summer 2002 survey were subtracted from the grid node values for the January 2002 survey to produce the difference grids. A color scale was applied to the difference grids to aid in the analysis of the riverbed change. The color palette was designed to accentuate various levels of riverbed change that were defined by the scope of the project. All areas that changed ±0.25 ft, which is the approximate vertical error budget of the survey, were colored gray. Areas of accretion (or shoaling) were given red and orange hues while those areas that eroded were given blue hues. The color values correspond to the magnitude of the difference. For example, areas shaded with dark blues signify changes greater than light blues. An example of the results of this difference analysis is illustrated in Figure 2.1-3. This process is known as sun-illumination. Sun-illuminated images provide a more detailed presentation of the high-resolution multibeam bathymetric data than contouring and aid in the interpretation of river bedforms.

Differences were detected along steep slopes that may be the result of minor positioning differences between surveys. Slight differences may also be observed as long linear streaks in the difference images. Some of these minor differences, less than 0.50 ft, may be the result of lower quality outer beam measurements from the multibeam sonar. Extreme differences were defined in the color palette by purple (greater than 10 ft) and brown (greater than −30 ft). These extreme values are present at and around bridge piles throughout the survey area. Most of these areas do not represent change, but rather differences in depths collected along the vertical structure of the bridge piles or bulkheads at piers from the two surveys. Some of these areas represent actual change and are the result of dredging operations. An example of such an area is at the northeast end of Ross Island.

During the differing analysis, erroneous soundings were identified on sheets 6 and 7 in the original January 2002 data set. These soundings were removed from the January 2002 bathymetry grids, and new versions of these grids were issued as a revision with the difference grids on November 22, 2002. The revisions to the winter survey were used to produce the difference grids to keep erroneous soundings from creating invalid differences for the summer 2002 analysis as well as for future surveys. Results of the multibeam survey were presented as bathymetric contours and sun-illuminated imagery. Difference analysis was presented as a color-coded image.

The survey data were processed using a grid size of 1 m by 1 m to generate a digital terrain model. The results of the summer 2002 survey are shown in both contour and hill shade formats in the field report (DEA 2003a). Water depths are referenced to NAVD88. In addition, bathymetric survey difference maps, which show areas of riverbed shallowing and deepening, were generated in the report (DEA 2003a).

May 2003

DEA conducted a bank-to-bank multibeam bathymetric survey of the lower Willamette River from May 6 through May 28, 2003. The primary goal of this survey was to create

a data set that depicts riverbed elevations for 2003 during high river flow that can be directly compared to prior surveys to determine areas of erosion and accretion within the study area. The survey was conducted from RM 0 (at the confluence with the Columbia River) to RM 15.6 (at the upper end of Ross Island), which was the same extent as previous surveys, summer 2002 and January 2002. The control used for the survey, data acquisition methodology, and data processing procedures are discussed in the field report (DEA 2003b).

DEA also provided GIS grids of the bathymetry and difference grids that depict the change in riverbed elevation from January 2002 to May 2003 and from summer 2002 to May 2003. The results from this survey were used to support sediment sampling during the RI, to define shoaling and scour areas relative to previous surveys, and to support future site investigations. The results of the May 2003 survey are shown in both contour and hillshade formats in the field report (DEA 2003b). Water depths are referenced to NAVD88. In addition, bathymetric survey difference maps, which show areas of riverbed shallowing and deepening were generated in the field report (DEA 2003b).

February 2004

DEA also conducted a bank-to-bank multibeam bathymetric survey of the lower Willamette River during February and March of 2004. The survey was a continuation of an ongoing sediment transport study in support of the RI. The primary goal of the February-March survey was to create a data set containing riverbed elevations for 2004 following a high river flow event (over 120,000 cfs) that can be directly compared to prior surveys to determine areas of sediment erosion and accretion within the study area. The survey was conducted from RM 0 to 15.6, which is the same extent as previous surveys in May 2003, summer 2002, and January 2002.

The results from this survey were used to support sediment sampling during the RI; to define shoaling and scour areas relative to previous surveys; and to support future site investigations. Survey operations were conducted from February 6, 2004 to March 6, 2004, with an additional day of acquisition required on March 26. The control used for the survey, data acquisition methodology, and data processing procedures are discussed in the field sampling report (Integral and DEA 2004; DEA 2004a). Included with the FSR was a set of full size drawings and project DVD-ROMs containing digital data, Arc/Info GRID files, AutoCAD drawing files, and plot files of final maps.

The results of the February 2004 survey are shown in both contour and hillshade formats in the field sampling report (Integral and DEA 2004; DEA 2004a). Water depths are referenced to NAVD88. In addition, bathymetric survey difference maps, which show areas of riverbed shallowing and deepening, were generated in the field sampling report (Integral and DEA 2004; DEA 2004a).

2.1.2.1.8 Seep Reconnaissance Survey

A seep reconnaissance survey was conducted between RM 2 and 10.5 on October 7 and 8, 2002. Representatives from SEA, Groundwater Solutions Inc. (GSI), and

Kennedy/Jenks Consultants conducted the seep reconnaissance. Representatives from Oregon DEQ and USEPA accompanied representatives of the LWG on a subsequent tour of the identified seep areas on October 24, 2002.

For the purposes of the survey, a seep was defined as a location where water discharges from the ground either above or below the river surface. The definition of seep does not imply that the water from the seep is contaminated in any way absent some other obvious indicator of contamination (e.g., sheen or chemical odor). Seeps were identified during the survey based on at least one of the following criteria:

- Locations where seepage of water was directly observed
- Known past and current locations of petroleum, creosote, and other types of nonaqueous-phase liquid (NAPL)-containing seeps
- Locations where water was observed discharging from the backfill surrounding an outfall
- Locations where extensive iron (ferric hydroxide) staining of the bank materials was observed; these locations were considered potential seasonal seep locations.

Locations where healthy and/or phreatophyte vegetation also were noted as potentially indicating the presence of groundwater near the surface.

The scope of the approved seep reconnaissance work included:

- Perform a boat reconnaissance survey to identify bank seeps within the study area.
- Photograph, describe, and record the location of each seep with a global positioning system (GPS) instrument.

The objective of the seep survey was to inventory readily identifiable groundwater seeps present between RM 2 and 10.5 to support development of the BHHRA and groundwater CSM. The intended uses of the seep survey include the following:

- Identify groundwater seeps in areas where potential human contact could occur in order to identify beaches as a potential human use area to evaluate potential human health risks associated with exposure to groundwater
- Provide information to describe shallow groundwater interactions with the river for development of a groundwater conceptual model within the study area.

The seep locations and navigation waypoints illustrating the route of the survey are shown on Map 2.1-14. The locations of beaches that were identified as potential human use areas at or near where seeps were identified are shown on Map 2.1-14, which does not include other beaches identified as potential human use areas where seeps were not observed.

The reconnaissance survey was conducted during a low-stage period on the Willamette River after a drier than normal summer and fall. Each seep identified during the survey was visually examined for indications of contamination including discoloration, sheen, or obvious odor. Many seeps observed during the survey were characterized by the presence of reddish-orange staining from iron mineral precipitates interpreted to be ferric hydroxide. Iron bacteria slime growth also was commonly observed associated with seeps. The presence of iron-related staining and bacterial growth in the vicinity of seeps is considered diagnostic of the presence of groundwater except in a few situations where the obvious source of the staining is corrosion of steel pipes.

The locations where water was observed discharging directly from outfall pipes were not classified as seeps because of the uncertainty as to whether or not the source of the water was directly from groundwater or was surface drainage from upland areas. Descriptions of general types of seeps observed during the reconnaissance survey are provided in the following section. The seep reconnaissance survey report (GSI 2003a) provides the locations and descriptions of specific seeps catalogued during the reconnaissance survey; brief descriptions of the riverbank along the reconnaissance survey route between seep locations, and the seep category, as defined in the following section, for the catalogued locations. Digital photographs of the seep locations were taken and are available in the seep reconnaissance survey report (GSI 2003a).The types of seeps and potential seeps observed during the survey were categorized according to one or more of the following five types:

- Seepage line at the base of embankments
- Linear and point seeps at the foot of beaches
- Seeps from backfill surrounding outfalls
- Seepage of NAPL
- Potential seasonal seep locations.

These seep types are intended to be generalized descriptors of the types and occurrences of seeps observed and are not an exact and definitive classification as several of the seeps observed during the survey could be considered to have characteristics of more than one of these categories.

The seeps catalogued during this survey are limited to those that could be directly observed or were previously known at the time of the survey. There are likely areas of seepage that were not observed during the survey because of the presence of piers, bulkheads, riprap, dense vegetation, and other access constraints. Also, while the observed seeps are visible expressions of groundwater flow, the discharge represented by the seeps is likely to comprise only a small percentage of the total groundwater discharge to the Portland Harbor, with most of the groundwater discharging to the river probably occurring as submerged seepage.

2.1.2.1.9 Juvenile Lamprey and Benthic Infaunal Biomass Reconnaissance Surveys

On September 16 and 17, 2002, a field team consisting of SEA, Windward Environmental, Ellis Ecological, and Fishman Environmental personnel visited 21 of the 22 collocated sediment and tissue sampling stations, originally identified in the June 2002 LWG FSP (SEA, Windward, Anchor, Kennedy/Jenks 2002b) and as modified during the subsequent fishing efforts. On October 8 and 9, 2002, a field team consisting of two lamprey biologists from the Umatilla tribe, a NOAA representative, and LWG consultants visited 11 lower Willamette sites for a follow-up reconnaissance using specialized lamprey electroshocking equipment (SEA and Windward 2003).

The main objective of this reconnaissance survey was to determine whether juvenile lamprey (ammocoetes) could be collected using backpack electroshockers or surface grab samplers in adequate numbers to allow for tissue chemical analyses. Also, because lamprey collection techniques included sediment grab sampling, an ancillary objective was to assess the apparent biomass and composition of the soft-bottom, benthic infaunal community to determine whether adequate biomass of infauna were present to allow for tissue chemical analysis.

Sampling was conducted on foot (backpack electrofishing) and from a boat. As warranted based on each station's physical setting, shoreline habitats, and accessibility, beach electroshocking for lamprey ammocoetes and beach and subtidal sediment sampling (hand-held spoons, Ekman and van Veen grab samplers) for lamprey ammocoetes, soft-bottom benthos, and bivalves were conducted. Sediments were sieved through both 1.0 mm and 0.5 mm screens at a subset of stations, and representative benthic infauna specimens were retained for later examination in the laboratory, although no attempt was made to quantitatively sample the benthos. Infaunal organisms were identified to major taxonomic categories following the survey and bivalves were identified to the genus level.

The juvenile lamprey reconnaissance field report (SEA and Windward 2003) provides descriptions and locations of the stations visited during the September 2002 reconnaissance in chronological order, details on the lamprey ammocoetes electrofishing efforts and results at each station, and the major site-specific observations. The field report also provides a summary of the benthic infauna data, and conclusions on whether adequate benthic biomass might be collected at a given location to allow for chemical analyses of composite invertebrate tissue samples.

Lamprey

The backpack electroshocking was only successful at collecting lamprey ammocoetes at one (04R004) of the 16 stations sampled. Two lamprey ammocoetes were collected at this site and one specimen was released and subsequently re-found with the electroshocker. This suggests that the electroshocking approach is successful at finding lamprey ammocoetes when they are present. Electroshocking was not attempted at several stations without apparent suitable habitat, i.e., steep-sloped riprapped shorelines.

Other methods evaluated for catching lamprey ammocoetes included grab sampling and hand-scooping of beach sediments in areas that appeared to be suitable habitat. Beach and/or subtidal sediments were collected and sieved at 15 of the target stations. No lamprey ammocoetes were collected in the sediment grab samples. A small epibenthic dredge was mobilized for this reconnaissance but nearshore sediment dredging was not attempted at any station because of the shallow water levels, uneven bottom terrain, and nearshore structures (e.g., dolphins, piers, etc.). Given the apparent low abundance of lamprey ammocoetes in the area surveyed in mid-September, the probability of collecting lamprey ammocoetes in a sediment grab sample seemed quite low.

Overall, because numerous, apparently high quality habitat locations were sampled with both standard electro-backpacking and sediment sampling equipment without finding lamprey, it is doubtful that other methods would yield sufficient quantities of lamprey at this time of the year to allow tissues analyses.

Benthos

Sediments were collected and sieved at 15 of the target collocated stations. Soft-bottom benthos observed consisted of oligochaetes, bivalves, chironomids, and amphipods. Oligochaetes and chironomids were present in low abundances in most fine-grained (silts) areas. Amphipods were observed only at downriver locations (RM 2–3). The bivalve, *Corbicula* sp., was widespread in areas with an obvious sand fraction. With the exception of these bivalves at certain locations (where there were individual clams equal to or greater than about 3 cm in length), the tissue biomass of the soft-bottom infaunal assemblage appeared to be extremely low as a result of both relatively low abundances and the small size of individuals (e.g., most specimens passed through the 1.0-mm screen but were retained on the 0.5-mm screen).

Based on this reconnaissance effort, the only soft-bottom benthic organism that could potentially provide sufficient biomass for laboratory tissue analyses is the exotic bivalve, *Corbicula* sp. At several locations (02R001, 03R001, 05R001, 06R002, 07R003), *Corbicula* sp. were abundant and large enough to provide sufficient biomass for tissue chemical analyses with a reasonable effort (e.g., 1–2 days per site). In addition, large specimens of the mussel, *Margaritifera* sp., were collected at Station 05R002, but their origin at this location is uncertain because it is just off a public boat ramp and these specimens may have been transported and disposed there from elsewhere on the river.

2.1.2.1.10 Composite Beach Sediment and Collocated Surface Sediment Sampling

Composite surface beach sediment samples were collected at 20 beaches in the study area (Map 2.1-15) from October 9 through 14, 2002. At each beach, samples were generated by combining randomly selected, individual 0- to 15-cm beach sediment samples into a single composite. All beach sediments were collected using stainless steel hand corers. An Oregon DEQ reprentative participated in the beach sediment

collection and modified the definition (start or end point) of some target beaches during the field sampling event.

In-river surface sediments (0–15 cm) for chemical analyses to support the BERA were collected at two types of stations. First, as described in the FSP, collocated sediments were collected at 27 nearshore sculpin and crayfish tissue sampling stations (12 of these stations also included benthic infauna sampling stations). Second, surface sediments for chemical analysis were also collected at 10 additional benthic infauna stations to provide additional information on the distribution of benthic infauna in the study area. These stations were situated in both nearshore areas and in the navigation channel to supplement the distribution of the 27 sculpin/crayfish collocated stations. The collocated surface sediment samples were collected from October 16 through 25, with an additional sampling day on November 12, 2002. All surface sediments were collected using either a 0.1-m^2 van Veen grab sampler provided by SEA or a 0.3-m^2 hydraulic power grab sampler provided by Marine Sampling Systems. Collocated surface sediment sample collection procedures were observed by USEPA), NOAA, and Oregon DEQ representatives.

2.1.2.1.11 Benthic Infauna and Clam Sampling

Soft-bottom benthic samples were collected from 22 stations in the study area (Map 2.1-16) from October 22 through 25, 2002. Benthic infauna samples were collected at 12 of the sculpin/crayfish collocated sediment stations and at 10 additional stations in both nearshore areas and in the navigation channel. Infauna were collected with a 0.1-m^2 van Veen grab sampler and sieved through a 0.5-mm sieve box. For the BERA, a single replicate was collected at each location to provide a qualitative indication of the benthic infaunal assemblages throughout the harbor.

During the juvenile lamprey/benthic infauna reconnaissance survey conducted in September 2002 (see Section 2.1.2.1.9), it was determined that the non-native bivalve species *Corbicula fluminea* was the largest and most widespread benthic invertebrate in the study area. In some locations, *Corbicula* appeared to be abundant enough to allow for the collection of sufficient biomass for tissue chemical analyses. Between October 29 and November 5, with an additional day on November 12, 2002, clam collection was attempted by repeated casts of a 0.1 m^2 van Veen grab sampler at five target locations. Also, at one location, an unsuccessful attempt was made to rake clams from a shallow subtidal beach. Clam collection was attempted over multiple sampling days at each location. After considerable total effort (over 500 casts with the van Veen grab sampler), two locations near the center of the study area yielded more than 150 grams of tissue, which is the minimum biomass required to conduct tissue analyses for a full suite of target analytes. Fifty-three grams were collected at a third station, while the remaining two stations yielded only nominal amounts of tissue.

2.1.2.1.12 Acoustic Doppler Current Profiler Surveys

DEA conducted two ADCP surveys of the lower Willamette River in May 2003 and January of 2004 in support of the sediment transport assessment for the RI (DEA 2003c, 2004b). Survey methods and results are discussed in these reports.

On May 13, 2003, DEA conducted an ADCP survey along four transects in the vicinity of Multnomah Channel at RM 3 (Map 2.1-4) during relatively low river levels. Six observations were conducted over a 14-hour period from high tide to high tide, through one low tide event. The transect profiles are presented in the 2003 ADCP survey report (DEA 2003c).

On January 31, 2004, DEA conducted an ADCP survey over a 9-hour period during a relatively high-flow event along 17 transects in the lower Willamette River between RM 0 and 11 (Map 2.1-4). The primary goal of the January 2004 ADCP survey was to measure current velocities within the study area during a high river flow event (over 100,000 cfs). The transect profiles are presented in the 2004 ADCP survey report (DEA 2004b).

2.1.3 Round 2 RI Field Investigations (2004–2006)

The Round 2 field investigations were performed from fall 2004 through spring 2006. Round 2A includes those investigations conducted in 2004, and Round 2B includes investigations conducted in 2005 and in the spring of 2006. Round 2 field investigations are discussed in the following FSRs or data reports:

- Shorebird foraging area and beach sediment chemistry (Integral 2005a)
- Surface sediment chemistry (Integral 2005a, 2006a)
- Subsurface sediment chemistry (Integral and Anchor 2005; Integral 2005b, 2006b,c, 2008a)
- Surface water chemistry (Integral 2005c,d,e, 2006d)
- Benthic sediment toxicity (bioassays) (Windward 2005a)
- Physical system information (Integral 2006e,)
- Natural attenuation (radioisotope cores) (Anchor 2005a,b)
- Groundwater pilot study—mapping tools and sampling methods (Integral 2005f)
- Groundwater pathway assessment (GWPA; Integral 2006f,g)
- Subyearling Chinook tissue (Integral and Windward 2005a, 2006a)
- Multiplate epibenthic invertebrate tissue (Windward 2005b; Integral 2006h)
- Benthic invertebrates and clam tissue (Windward and Integral 2005a, 2006; Integral and Windward 2006b)
- Mussel and lamprey ammocoetes tissue (Windward and Integral 2006, 2007)

- Cultural resources analysis (AINW 2005).

Except where noted in the FSRs, the data reports, or as modified by subsequent correspondence between the LWG and USEPA, all sample collection activities followed the procedures described in the following Round 2 FSPs and SAPs:

- Shorebird foraging area and beach sediment chemistry (Integral, Kennedy/Jenks, and Windward 2004)
- Surface sediment chemistry, subsurface sediment chemistry, and benthic sediment toxicity (Integral, Anchor, and Windward 2004; Integral 2005g; Anchor and Texas A&M University 2004)
- Surface water chemistry (Integral 2004b)
- Physical system information (Integral and West 2006; Anchor and Texas A&M University 2004)
- Groundwater pilot study—mapping tools and sampling methods (Integral 2004c)
- GWPA (Integral, Kennedy/Jenks, and Windward 2005; Integral 2005f,h,i,j,k,l, 2006i)
- Subyearling Chinook tissue (Integral, Windward, and Ellis 2005)
- Benthic invertebrate tissue (Windward and Integral 2005b,c).

All field sampling was conducted in accordance with the following HSPs:

- Round 2 HSP (Integral 2004d)
- Round 2 GWPA HSP (Integral 2005m).

All laboratory analyses follow the following USEPA-approved Round 2 QAPP:

- Round 2 QAPP (Integral and Windward 2004)
- Round 2 QAPP Addendum 1: Surface Water (Integral 2004e)
- Round 2 QAPP Addendum 2: PCB Congener Analysis in Sediment (Integral 2004f)
- Round 2 QAPP Addendum 3: GWPA Pilot Study (Kennedy/Jenks and Integral 2004)
- Round 2 GWPA QAPP Supplement to Addendum 3 (Integral 2005n)
- Round 2 QAPP Addendum 4: Subyearling Chinook Tissue Collection (Integral 2005o)
- Round 2 QAPP Supplement to Addendum 4: Subyearling Chinook Tissue Collection – Semivolatile Organic Compounds (Integral 2005p)

- Round 2 QAPP Addendum 5: Benthic Invertebrate Multiplate Tissue Collection (Integral 2005q)
- Round 2 QAPP Supplement to Addendum 5: Invertebrate Tissue Collection Using Multiplate Samplers (Integral 2005r)
- Round 2 QAPP Addendum 6: Sampling of Benthic Invertebrate Tissue (Integral and Windward 2005b).

2.1.3.1 Summary of Round 2 Field Activities

The purpose of Round 2A sampling was to collect sediment data for the RI and risk assessments and initiate data collection for the FS. The specific objective of the Round 2 sediment sampling program was to collect the following types of data:

- Beach sediment chemistry to support the BHHRA
- Shoreline and riverbed surface sediment chemistry to characterize chemical distributions in surface sediments and potential source effects to the river, and to support the human health and ecological risk assessments
- Subsurface sediment chemistry and physical data to characterize chemical distributions in subsurface sediments and potential source effects to the river, to support the FS and groundwater impacts assessment tasks, and to confirm the physical CSM
- Preliminary sedimentation samples (e.g., radioisotope cores of subsurface sediments) in areas that may have depositional processes to support development of the FS.

The purpose of Round 2B sampling was to fill in data gaps from previous studies to support then the remedial investigation, baseline risk assessments, and the FS.

2.1.3.1.1 Shorebird Area and Beach Sediment Sampling

Surface sediment sampling activities were conducted in shorebird foraging areas and human use beach areas accordance with the Round 2 FSP (Integral, Kennedy/Jenks, Windward 2004), the Round 2 QAPP (Integral and Windward 2004), and the Round 2 HSPs (Integral 2004f). Composite shoreline sediment samples were collected from July 26 through 30, and on November 5, 2004 at 21 shorebird foraging areas from RM 2 to 10, and 4 collocated shorebird foraging areas and potential human use beaches between RM 2 and 3. As described below, all of the Round 2A shoreline samples were collected close to waterline; these samples are generally referred to as “beach” samples in this report. The 25 Round 2A shoreline samples are indicated by a “B” (e.g., B001) in the station identification code on Map 2.1-15. The four collocated shorebird and human beach area locations stations are B001, B002, B003, and B005. For presentation purposes, Map 2.1-15 depicts the shoreline samples as a point only. The Surface and Beach FSR (Integral 2005a) provides a detailed description of the collection effort and a map that more accurately displays the actual shoreline area sampled.

At each beach sampling location, sediments were collected to a depth of 15 cm using a stainless-steel, hand-held coring device. A total of 28 composite beach sediment samples (including two field replicate samples and one homogenate split sample) were collected and submitted to the analytical laboratories for chemical testing. Similar to the beach composite samples, the replicate beach samples were composed of subsamples and were collected contemporaneously alongside each primary beach subsample. The replicate subsamples were composited and processed separately from the primary sample.

2.1.3.1.2 Surface Sediment Sampling

Surface sediment sampling activities were conducted in accordance with the Round 2 FSP (Integral, Anchor, Windward 2004), the Round 2 QAPP (Integral and Windward 2004), and the Round 2 HSP (Integral 2004d). Surface riverbed sediment grab samples (0–30 cm) were collected in the lower Willamette River from July 19 through November 5, 2004, at a total of 523 target locations distributed from about RM 2 to 25. All but 8 of these stations (i.e., 515 stations) were locations identified in the sediment FSP (Integral, Anchor, and Windward 2004) and were located in Portland Harbor from about RM 2 to 11 (Map 2.1-15). These Round 2A surface sediment stations are indicated by a "G" in the station identification code (e.g., G001). Six upstream stations (between RM 16 and 25) and two downstream (between RM 2 and 3) stations were added for chemical and toxicity sampling in October 2004 based on discussions between USEPA and the LWG. These stations are indicated by a "U" (upstream stations) or a "D" (additional downstream stations) on Map 2.1-15.

Five stations (G124, G126, G161, G411, and G431) could not be accessed directly by boat due to water depth or in-water obstructions (e.g., pilings). These stations were sampled from the shoreline below the high-water mark using a hand-held GPS unit for positioning.

Including field replicates and homogenate splits, a total of 576 surface sediment grab samples from 523 stations were submitted to analytical laboratories for chemical testing. Field replicate grabs were collected by targeting the primary grab sample coordinates. The distances between the primary and duplicate sample locations ranged from 3 to 29 ft. A detailed description of the Round 2 surface sediment collection effort is included in the Round 2 Surface and Beach FSR (Integral 2005a). Additional information is provided in the Round 2A PCB Congeners in Archived Round 2A Surface Sediment Data Report (Integral 2006a).

2.1.3.1.3 Subsurface Sediment Sampling

Subsurface riverbed sediment cores were collected at 200 locations within the lower Willamette River between RM 2 and 10 from September 20 to October 8 and from October 18 to November 11, 2004. Samples from these cores are generally referred to as subsurface samples in this report. Subsurface sediment station locations are indicated by a "C" in the station identification code (e.g., C009) on Map 2.1-17. Most of these locations were sampled to support chemical distribution in subsurface

sediments; however, 49 locations also supported FS purposes, 11 locations were sampled to further support the physical CSM studies and hydrodynamic modeling effort, and 4 locations were sampled to evaluate sedimentation processes in the river.

Subsurface sediment cores were collected and processed in accordance with the Round 2 FSPs (Integral, Anchor Windward 2004; Anchor and Texas A&M 2004), the Round 2 QAPP (Integral and Windward 2004), and the Round 2 HSP (Integral 2004d). A total of 218 subsurface sediment cores were collected from the 200 stations. A total of 717 sediment samples from the cores were submitted for chemical and/or physical analyses, including 30 replicate core samples and 19 homogenate split samples. Unlike field replicate grab samples, the locations of replicate cores were deliberately shifted from the initial sampling location in order to avoid the area disturbed during the collection of the initial core. The distances between the initial and replicate core locations ranged from 1 to 43 ft. A more detailed description of the field sampling effort, including core logs, the field screening values, and photographs of the cores, is included in the Round 2A Subsurface Sediment FSR (Integral and Anchor 2005), the Round 2B Subsurface Sediment FSR (Integral 2005b), the Round 2A Archived Core Sediment Data Report (Integral 2006b) and the Round 2B Subsurface Sediment Data Report (Integral 2006c).

A subset of core segments was frozen and archived during Rounds 2A and 2B core processing for possible future chemical analysis. The Round 2B FSP Addendum for analysis of archived sediment samples (Integral 2006j) describes the process used to select for analysis of PCB congeners to supplement the paired PCB Aroclor/congener data set generated in Round 2A. A total of 53 archived Round 2 sediment samples were initially selected for PCB congener analysis. The analysis of one sample, LW2-D1-1, was subsequently canceled because it was determined that PCB congeners had previously been analyzed in this sample. Except where noted in the data report (Integral 2008a), all activities, including sample handling, processing, and data management, followed guidelines specified in the Round 2 QAPP (Integral and Windward 2004), and the Round 2 QAPP Addendum 10 (Integral and Windward 2007b).

2.1.3.1.4 Surface Water Sampling

Surface water sampling was conducted in accordance with the Round 2A FSP (Integral 2004b), the Round 2 QAPP (Integral and Windward 2004), the Round 2 QAPP Addendum 1 (Integral 2004e), and the Round 2 HSP (Integral 2004d). Surface water samples were collected in three separate events at 23 target locations from RM 2 to 11 in the Willamette River during the following time periods: November 8–December 2, 2004, March 1–17, 2005, and July 5–20, 2005. The 23 target locations included 12 amphibian habitat stations, 2 amphibian habitat/source area stations, 3 source area stations, 3 human-use contact areas, and 3 site characterization cross-sectional river transects. Map 2.1-18 shows the geographical locations for all Round 2A surface water sampling stations.

Reconnaissance Survey

Due to seasonal variations in river water levels, many overwater structures, and numerous operational waterfront industrial and port facilities in Portland Harbor, the target surface water sample locations required verification during a reconnaissance trip on the river before sampling was initiated. A reconnaissance survey took place on October 29, 2004, prior to initiation of the Round 2 surface water sampling program.

The purposes of the reconnaissance survey were to verify sampling locations, determine whether the sampling vessel could physically access each station, and to confer with agency personnel (USEPA and USFWS) on the sample locations that were selected based on the presence of amphibian habitat. Based on this reconnaissance, several target locations were modified; these changes were incorporated into the maps and tables of positional data used in the field during the fieldwork. The final sample locations are shown in Map 2.1-18.

Representatives from both the LWG and USEPA and its partners were present during the field reconnaissance survey. As indicated above, based on the reconnaissance, USEPA and the LWG agreed to modifications to the sampling approach and/or to selected sample locations, and the field crews incorporated these changes into the sampling effort. The reconnaissance survey effort was reported in the Round 2A Surface Water FSR (Integral 2005c).

Fall 2004

Surface water samples were collected at 23 target locations from RM 2 to 11 in the Willamette River from November 8 through December 2, 2004. This sampling period was targeted to coincide with the early fall rainy season. The lower than normal rainfall during the 3-week sample collection event resulted in decreasing discharge during this sample collection event and lower than historical average (1975–2003) and recent historical average (1998–2003) discharge [15,400 to 24,700 cfs] of the Willamette River for the early rainfall season. All stations identified in the FSP, including 14 amphibian habitat stations, 3 cross-sectional river transects, 3 human-use contact areas, and 3 source area stations were sampled using a peristaltic pump. Two stations (W013 and W016) were occupied twice to generate field replicates for this sampling method. In accordance with the surface water FSP and QAPP, surface water samples from all 23 target stations were submitted to analytical laboratories for chemical testing.

High-volume surface water sampling using an Infiltrex™ 300 system connected to XAD-2 resin columns was also conducted to collect hydrophobic organic compounds for analysis by ultra-low analytical methods. Sample volumes of approximately 1,000 L were collected at seven target locations in the Willamette River from November 8 through November 30, 2004. All high-volume stations identified in the FSP were sampled. One station (W013) was occupied twice to generate a field replicate for this sampling method. In accordance with the FSP and QAPP, surface water samples from all seven target stations were submitted to analytical laboratories for extraction and

chemical testing. The fall 2004 surface water sampling event was reported, along with the reconnaissance survey event, in the Round 2A Surface Water FSR (Integral 2005c).

Winter 2005

The winter 2005 sampling event, conducted in early March 2005, was selected by USEPA to coincide with release of amphibian egg masses. The discharge for this event (8,390–11,900 cfs) was significantly lower than the historical average or recent historical average. From March 1 to 17, 2005, a second round of surface water samples was collected at the reoccupied stations from the fall 2004 sampling event. All 23 target stations were sampled using the peristaltic pump method. Four stations (W002, W004, W0013 and W016) were occupied twice to generate field replicates for this sampling method. Between March 1 and March 17, 2005 high-volume samples were also obtained from the seven target locations sampled during the first round. One station (W013) was occupied twice to generate a field replicate for this sampling method. Further details of the winter 2005 sampling event are documented in the Round 2A Winter 2005 Surface Water FSR (Integral 2005d).

Summer 2005

The summer 2005 surface water samples were collected from July 5 to 20, 2005 at the same stations sampled during the fall 2004 and winter 2005 sampling efforts. This low-flow sampling event was representative of typical low-flow conditions (5,720–11,300 cfs) and was consistent with historical average and recent historical average conditions for low-flow conditions. All 23 target stations were sampled using the peristaltic pump method. Two stations (W002 and W016) were occupied twice to generate field replicates for this sampling method. High-volume samples were also obtained from the seven target locations previously sampled. One station (W013) was occupied twice to generate a field replicate for this sampling method. The summer 2005 surface water sampling event is described in the Round 2A Summer 2005 Surface Water FSR (Integral 2005e).

2.1.3.1.5 Benthic Sediment Toxicity (Bioassays)

Sediment toxicity testing of Round 2 surface sediment samples (see Section 2.1.3.1.2) was performed to support the development of a predictive model(s) characterizing the relationship between sediment chemistry and benthic invertebrate toxicity in the study area. The 10-day *Chironomus tentans* and the 28-day *Hyalella azteca* sediment toxicity tests were conducted on 215 sediment samples collected between RM 2 and 10, and 18 sediment samples collected at stations upstream of Ross Island (~RM 16).

Surface (0–30 cm) sediment grab samples were collected at 215 stations in nearshore areas within the Portland Harbor study area using a power grab sampler deployed from a sampling vessel. In addition, 18 surface sediment samples were collected at six stations upstream of the Portland Harbor study area. A total of 11 batches of 20 sediment samples each and one batch of 13 samples for a total of 233 surface sediment samples (Map 2.1-15) were collected during Round 2 and tested in accordance with the

FSP (Integral, Anchor, and Windward 2004), the Round 2 HSP (Integral 2004d), and QAPP (Integral and Windward 2004).

Field deviations from the FSP included modifications to station locations and elimination of six stations from the sampling program. There were no deviations from field procedures presented in the QAPP. Detailed descriptions of station location modifications and the USEPA approval process are presented in the Round 2 Surface and Beach Sediment FSR (Integral 2005a). Test methods and results are described in the Portland Harbor RI/FS Round 2A Data Report, Sediment Toxicity Testing (Windward 2005a).

2.1.3.1.6 Physical System Information

As part of the CSM, it is necessary to understand sediment transport regimes within the river and how they are affected under differing flow regimes. The purpose of collecting physical system information is to refine the understanding of hydrodynamic and sediment transport (HST) processes in the lower Willamette River.

There are five physical processes that may significantly affect sediment transport in the study area: tides, river flows, sediment inflows, sediment bed composition and dynamics (such as deposition and erosion), and wind. Density (salinity and temperature) and groundwater discharges are not included, because these processes are not expected to have a significant effect on sediment transport in the study area. The critical data needs for Round 2 were for sediment bed composition and sediment dynamics. Data were collected on total suspended solids (TSS) concentrations in water, suspended sediment particle-size fractions (to allow for calculation of site-specific settling velocities), and sediment bed properties (Sedflume Study). In the Sedflume Study, sediment cores were collected to measure erosion rates, critical erosion velocities, and sediment bed properties with depth. Data were collected as three major activities: TSS sampling, grain size distribution and settling velocities, and surface sediment bed properties (Sedflume Study) that are discussed below.

Except where noted in the FSR (Integral 2006e) or in the sections below, this sampling effort followed the procedures specified in the HST Modeling FSP (Integral and WEST 2006), the Round 2 QAPP (Integral and Windward 2004), the Round 2 QAPP Addendum 1 (Integral 2004e), and the Round 2 HSP (Integral 2004d). The contingent, event-based, short-term riverbed elevation surveys were not conducted because a relatively high-flow event (>100,000 cfs) did not occur following FSP approval. More detailed information regarding sampling events and results are discussed in the Round 2 HST Modeling Data Collection FSR (Integral 2006e).

Total Suspended Solids

TSS data from water samples were collected upstream over a range of flows and within the study area over a tidal cycle to support the hydrodynamic modeling. TSS sampling was conducted from late November 2005 to early April 2006.An upstream time series of vertically and horizontally integrated composite water samples were collected for

TSS analysis to support verification of the sediment inflow–river flow rating curve (WEST and Integral 2005). Upstream TSS samples were collected from November 22, 2005 to April 5, 2006. Sampling was targeted for an upstream location well above the study area but below the confluence of the Clackamas and Willamette rivers (~RM 24.7) (Map 2.1-19). A total of 10 upstream TSS samples were collected at intervals triggered by changes in river flow: at 5,000-cfs intervals between 15,000 and 30,000 cfs; at 10,000-cfs intervals between 30,000 and 70,000 cfs; and, as logistically feasible, at flows exceeding 70,000 cfs, specifically at 109,000, 145,000, and 170,000 cfs. Figure 2.1-4 shows the hydrograph for the lower Willamette River (Morrison Street Bridge gauge at RM 12.8) for the November 2005 through April 2006 time period, annotated with the TSS sampling dates and associated daily mean discharge levels (cfs).

Additional study area TSS data were targeted to supplement TSS data previously collected as part of the Portland Harbor surface water sampling program and to support hydrodynamic model calibration and validation. Vertically integrated TSS samples were collected along four transects in the study area, RM 11, 6.3, and 2, and in the Multnomah Channel (Map 2.1-19), over a 2-day period on April 3 and 4, 2006. Three vertically integrated samples (west side, mid-channel, and east side) were collected along each transect. One sampling event was conducted for these locations during flows less than 30,000 cfs. During this sampling effort, two sets of TSS samples were collected over one tidal cycle, one at mid-flood and one at mid-ebb.

Suspended Sediment Grain-Size Distribution and Calculation of Settling Velocities

Measurements of *in situ* suspended sediment particle-size fractions were made to allow site-specific settling velocities to be calculated for input to the model. As described in the FSP, suspended sediment measurements were made using a laser *in situ* scattering and transmissometer (LISST)-100 system (Sequoia Scientific, Inc., Redmond, WA). The LISST-100 was deployed from a vessel and measured *in situ* suspended sediment grain-size distributions over depth and time at five target locations (Map 2.1-19). These samples were collected during the same sampling period as the study area TSS sampling in early April 2006.

Four of the five suspended sediment particle size stations were located in the study area between RM 2 and 11 and were distributed in the mid-channel as well as along both the west and east banks. The fifth station was located in a narrow portion of the river upstream of Ross Island at approximately RM 18 (Map 2.1-19) in an effort to sample an area with potentially higher internal water shear forces.

Surface Sediment Bed Properties–Sediment Cores

Surface sediment bed properties (i.e., critical erosion velocities and erosion rates and physical sediment characteristics) were studied throughout the study area to provide site-specific data on these critical parameters.

Between March 28 and 31, 2006, 17 Sedflume cores (10 × 15 × 60 cm) were collected at locations throughout the study area (Map 2.1-19). All cores were collected by divers.

Sedflume sampling locations were proximal to Round 2A core locations so that, in addition to providing site-specific erosion data for the model, these data can potentially be empirically coupled with the bulk chemistry data from each location as part of the data evaluation process. These cores were collected for the analysis of bulk sediment properties (i.e., grain size, total organic carbon [TOC], specific gravity) for comparison with the Sedflume erosion data.

2.1.3.1.7 Natural Attenuation (Radioisotope Cores)

Of the total 717 subsurface sediment core samples (see Section 2.1.3.1.3), 60 core samples were collected from sedimentation cores and submitted for 210Pb and bulk metals analyses. An additional 72 sedimentation core samples were analyzed exclusively for radioisotopes 7Be and 137Cs. Twelve samples were submitted for conventional and organics analyses in ancillary cores taken immediately adjacent to the sedimentation core at each station. The results of the sedimentation core analyses are presented in Natural Attenuation Evaluation FSR (Anchor 2005a).

The natural attenuation coring was conducted at four locations (Map 2.1-19) on October 20 and 21, 2004 using coring equipment and procedures identical to those used for the much larger Round 2 sediment sampling event that is described in the Portland Harbor RI/FS Round 2 FSP for Sediment Sampling and Benthic Toxicity Testing (Integral, Anchor, Windward 2004).

At each sampling location, two cores were taken: these cores were taken as close together as possible, while ensuring that the sediments disturbed by one core were not sampled by the second core. The first core was used for radioisotope analyses, and was termed the "radioisotope core." The second core was sampled for ancillary information on sediment bulk chemistry and physical characteristics, and was termed the "ancillary core." Field log forms from the core collection are contained in Appendix B of the Round 2A FSR (Integral and Anchor 2005).

The cores (in intact sections) were provided to Anchor Environmental for onshore processing (e.g., splitting and subsampling of cores) and delivery of samples to the laboratories. Core processing occurred on October 20, 21, and 22, 2004. Deviations from the FSP are discussed in the FSR (Integral and Anchor 2005).

2.1.3.1.8 Groundwater Pilot Study – Mapping Tools and Sampling Methods

From November 11, 2004 through February 8, 2005, a pilot study was performed to evaluate groundwater discharge mapping tools and transition zone sampling methods for possible use in the Round 2 GWPA. The mapping tools and sampling methods were tested offshore at three study areas: ARCO/BP Terminal 22T, Arkema Acid Plant, and Arkema Chromate Plant. The technical approach for the pilot study is presented in the GWPA Pilot Study Data Report (Appendix B in Integral 2005f). The pilot study results, in conjunction with guidance available from technical literature sources, formed the basis for the identification of methods presented in the discharge mapping FSP (Integral 2005h) and TZW FSP (Integral 2006i). All sampling was conducted in

accordance with the pilot study FSP and QAPP Addendum (Integral 2004c; Kennedy/Jenks and Integral 2004). Replicate samples were also collected by each method (except the UltraSeep system) from three of the nine sampling locations (one at each study area).

The following TZW sampling tools were evaluated in the pilot study:

- Trident probe
- UltraSeep system
- Diffusion-based samplers (large- and small-volume peepers)
- Power grab sediment sampling, followed by centrifugation
- Geoprobe®.

A total of nine sampling locations were planned for collection using these methods. These sampling stations were to be distributed three per study area, with specific locations determined based on preliminary review of Trident probe discharge mapping results. To the extent practicable, collocated sampling was planned for each of the nine locations via each of the sampling methods, with the exception of the UltraSeep system. (Due to limited equipment availability and time requirements for UltraSeep sampling, the UltraSeep system was only planned for a single deployment at each of the three study areas.) The Geoprobe® was only used at the ARCO sampling location.

For groundwater discharge mapping in the study area, a combined application of two methods was recommended based on the pilot study results: temperature difference mapping using the Trident probe plus direct seepage measurements using the UltraSeep system. For TZW sampling, two of the evaluated sampling methods were recommended: push-point sampling using the Trident probe and diffusion-based sampling using small-volume peepers. A detailed discussion of discharge mapping method selection is provided in the pilot study FSP (Integral 2004c).

Thermal Infrared Imaging

Thermal infrared imaging was planned for consecutive low-tide periods, to capture daytime and nighttime images of RM 2 through 11.5. Images were successfully collected over the entire flight range for the daytime flight. For the nighttime flight, fog formed over the Willamette River downstream of the Multnomah Slough, precluding data acquisition downstream of the slough. This affected nighttime images for RM 2 and 3. A complete set of images from the thermal infrared imaging survey and a discussion of the survey results are presented in Attachment 1 to the Round 2 GWPA SAP (Integral, Kennedy/Jenks, and Windward 2005).

Trident Probe

The Trident probe groundwater discharge mapping and sampling activities were implemented as planned, with some minor deviations in response to field observations

and field conditions. Trident probe groundwater discharge mapping data and samples were collected on the following dates in November 2004:

- ARCO—Mapping: November 17, 18, 22, 23; sample: November 23
- Arkema Acid Plant—Mapping: November 15–16; sample: November 19
- Arkema Chlorate Plant—Mapping: November 16, 17, 22; sample: November 20–21.

Trident groundwater discharge mapping data were collected at 64 sampling locations over the 15 transects specified in the pilot study FSP (Integral 2004c). A total of 60 locations were identified during the field planning effort for temperature and conductivity measurements with the Trident probe system (five four-point transects at each study area). All but 3 of the 60 proposed Trident probe measurements of TZW temperature and conductivity for groundwater discharge mapping were collected successfully. Additionally, seven locations were added to the scope based on real-time analysis of data. Maps 2.1-20a-l identify the Trident probe groundwater discharge mapping locations for each study area. The three points where measurements were not taken (CP08A, AP04A, and ARC01A) were all located nearshore in gravel or cobble areas. At these locations, the Trident probe could not be advanced into sediment. In each case, at least three attempts were made to deploy the probe before the location was abandoned.

Based on real-time review of field data, seven supplemental point discharge mapping measurements were made with the Trident probe system—three measurements offshore of the Arkema Chlorate Plant area and four measurements offshore of the ARCO site. In the former Chlorate Plant area, the southernmost planned transect (CP10) indicated increased subsurface conductivity measurements relative to the previous transect to the north (CP09). In response, an additional transect was added to the south (measurement locations CP11AA, CP11A, and CP11B on Map 2.1-20j) in an effort to spatially bracket the higher conductivity values. Offshore of the ARCO site, additional Trident probe measurements were obtained in the central dock area (ARC06B and ARC06C) and staggered between the northern transects in the deeper water (ARC04E and ARC05E). This was done to better characterize the apparent change in temperature trends observed between transects moving from the area south of the main dock structure to the area north of the central dock structure.

Based on a preliminary review of Trident results, a total of nine locations were selected for TZW sampling (Maps 2.1-20a-l): three from offshore of the ARCO site (ARC02B, ARC03B, ARC06B), three from offshore of the Arkema Acid Plant area (AP03B, AP04B, AP04D), and three offshore of the Arkema Chlorate Plant area (CP06C, CP07B, CP08D). An additional Chlorate Plant sampling location was added (CP10A) for the Trident sampling effort to investigate the high conductivity results in the CP10 transect; all sampling locations were at a depth of 30 cm. Additionally, a sample was collected at CP07B at 60 cm. A discussion of the basis for selection of sampling

locations is presented in Attachment 2 to the Round 2 GWPA SAP (Integral, Kennedy/Jenks, and Windward 2005).

Trident Sampling Probe – Manometer

In accordance with the pilot study FSP, several attempts were made to measure groundwater head relative to surface water head by linking the manometer to the Trident sampling probe, filling the system with water, and then allowing the system to equilibrate for a reading. Five attempts were made during the pilot study to test the manometer at a variety of water depths and sediment textures. Several persistent problems prevented successful data collection. To begin, in many of the test areas, degassing from the sediment was apparent in the tubing extending to the Trident probe sampling point. In cases where degassing was present, occasional bubbles moved through the line for the entire test period (up to 1 hour). The introduction of a compressible gas moving slowly through the tubing in the closed system invalidated the head measurements.

Additionally, in areas of fine sediments, significant suction from the peristaltic pump was needed to draw water up from the sediment to fill the manometer. As a result, fine sediment often packed around the intake, thereby changing the local hydraulic conductivity of the surrounding sediments and likely obscuring the reading. Furthermore, with the high suction required, leaks in the system arose at connections on the manometer, requiring frequent seal replacement.

In coarser sediments, where there were no complications from leakage or degassing, the pressure differential signal was still not clear. Motion of the boat and the float leading to the surface water line caused the readings to fluctuate, overwhelming the signal, and suggesting the signal was probably small.

UltraSeep System

During the pilot study, the UltraSeep system was programmed to collect continuous flow data and multiple samples from each sample station over the course of 24 hours. A W.S. Ocean Systems (now EnviroTech) ESM data logger/controller unit was used to monitor data from the flow meter.

All operational activities relating to the UltraSeep systems were performed by Coastal Monitoring Associates with oversight by Integral Consulting personnel. The UltraSeep system could not be deployed at the ARCO site due to conflicts with barge schedules, which precluded two consecutive days of assured access for deployment and retrieval. The system was deployed at three Trident probe groundwater discharge mapping locations at the Arkema site: one in the Chlorate Plant area (CP07B; Map 2.1-20j) and two in the Acid Plant area (AP04B and AP04D; Map 2.1-20j).

Following deployment, the UltraSeep was left in place for approximately 24 hours. The system was pre-programmed to continuously log flux measurements at 5-minute intervals at station AP04D, and 12-minute intervals at AB04B and CP07B. The system was also programmed to collect samples in time-series sampling bags, in response to

positive flux measurements. Sample grab volumes matched the positive flux measurements, producing a sample equal in volume to the observed positive flux over the deployment period.

The UltraSeep unit was deployed and retrieved on the following dates:

- Arkema Acid Plant (AP04D)—Deployed November 10 and retrieved November 20, 2004
- Arkema Acid Plant (AP04B)—Deployed November 23 and retrieved November 24, 2004
- Arkema Chlorate Plant (CP07B)—Deployed November 21 and retrieved November 22, 2004.

Groundwater level data were also collected at 15-minute intervals by pressure transducers deployed in two nearshore wells at the Arkema site during deployments of the UltraSeep (MWA-10i and MWA-32i, see Appendix A-7 of the SAP, Figure 3). These measurements allowed for contemporaneous monitoring of upland groundwater levels and groundwater discharge rates in response to the tidal cycle.

Due to the low groundwater discharge rates, sample volumes were small, limiting analyte lists. At AP04D, the discharge was consistently negative or zero, thereby producing no sample for analysis. At AP04B, a total of 100 mL were collected (80 mL submitted to lab in two volatile organics vials). At CP07B, a total of 754 mL were collected. Analytical results for sampling stations CP07B and AP04B, including field and laboratory replicates, are presented in the Pilot Study Data Report (Appendix B of Integral 2005f).

Diffusion-Based Samplers – Peepers

Both large- and small-volume diffusion-based samplers (i.e., peepers) were deployed at the nine TZW sample locations selected during the discharge mapping phase. For the most part, sample collection with the diffusion-based samplers followed the pilot study plans specified in the FSP.

A total of 30 small-volume peepers were available for the pilot study, and one peeper was damaged during attempted deployment; the number of samplers deployed at each location depended on the desired analyte list (volume constraints), whether a replicate was being collected, and other constraints on the number of sampling devices. All samplers were positioned in the upper 30 cm of the sediments, and left in place for a period of 3 weeks to allow for equilibration with TZW.

Deployment and retrieval occurred on the following dates:

- ARCO—Deployed December 20, 2004 and retrieved January 10, 2005
- Arkema Acid Plan—Deployed December 21–22, 2004 and retrieved January 11–12, 2005

- Arkema Chlorate Plant—Deployed December 21, 2004 and retrieved January 11, 2005.

Power Grab Sediment Sampling and Centrifugation

The power grab sampler was used to collect bulk sediment samples from the upper 30 cm of sediment. TZW samples were extracted from the power grab bulk sediment samples by centrifugation. The remaining, uncentrifuged sediment subsamples were used for analysis of bulk sediment chemical concentrations.

Bulk sediment samples were collected from the upper ~30 cm of sediment at each of the nine sampling locations using a power grab sampler. Bulk sediment sample collection was completed on the following dates at each site:

- ARCO—January 21, 2005
- Arkema Acid Plant—January 18–19, 2005
- Arkema Chlorate Plant—January 19, 2005.

Geoprobe

Direct-push sampling of shallow groundwater was performed at three sampling stations at the ARCO site using a barge-mounted Geoprobe® drill rig on February 7–8, 2005. The purpose of this sampling was to assist in the validation and interpretation of the findings of the pilot study groundwater discharge mapping and TZW sampling by 1) determining whether contaminants of interest (COIs) are present in groundwater within the groundwater discharge zone targeted for TZW sampling, and 2) assisting in the determination of the origin of COIs detected in the TZW (i.e., transported to TZW via discharge of contaminated groundwater versus desorbed into TZW from contaminated sediments). Borehole total depths were 40 ft for ARC02B and 15 ft for both ARC03B and ARC06B (Map 2.1-20e).

2.1.3.1.9 Groundwater Pathway Assessment

The Round 2 GWPA was performed to support evaluation of the potential risk to in-water receptors resulting from groundwater plume discharges to the study area.

The objective of Round 2 TZW sampling was to collect and analyze samples of TZW to quantify concentrations of groundwater-related COIs in areas of plume discharge identified during the groundwater discharge mapping field effort. Additionally, sediment samples were collected at a subset of locations to support sediment–water partitioning analysis.

The Round 2 GWPA sample collection by the Trident probe, small-volume peeper, and power grab sampling techniques was performed between October 3 and December 2, 2005. Except where noted in Section 4 of the FSR (Integral 2006f), all Round 2 GWPA sampling activities, including navigational positioning, sample collection, sample handling and processing, and data management, followed guidelines specified in the following planning documents:

- Round 2 GWPA SAP (Integral 2005f)
- SAP Attachment 2, TZW FSP (Integral 2005i)
- TZW FSP Addendum 1 (Integral 2005j)
- TZW FSP Addendum 2 (Integral 2005k)
- TZW FSP Annotated Cross Sections (Integral 2005l)
- Round 2 QAPP Addendum 3 (Kennedy/Jenks and Integral 2004)
- Round 2 QAPP Supplement to Addendum 3 (QAPP supplement; Integral 2005n)
- Round 2 GWPA HSP (Integral 2005m).

Deviations from these documents in the field were primarily limited to access issues at the Gasco site and anticipated volume limitations in TZW sampling.

As described in the SAP (Integral, Kennedy/Jenks, and Windward 2005), the following nine sites were included in the Round 2 TZW sampling effort:

- ExxonMobil Oil Terminal
- Gasco
- Siltronic
- Arkema Acid and Chlorate Plant
- Kinder Morgan Linnton Terminal
- ARCO Terminal 22T
- Rhone Poulenc (Bayer)
- Willbridge Bulk Fuels Terminal
- Gunderson.

A total of 191 TZW samples, including replicate samples and paired filtered samples, were successfully collected at 80 locations using the Trident probe and small-volume peepers. Of these 191 samples, 155 samples were collected by the Trident probe and the remaining 36 samples were collected by small-volume peepers. Of the Trident probe samples, 117 were collected at 30 cm depth below the mudline (bml) and 38 were collected at 90 to 150 cm depth bml. Paired filtered samples were collected at 78 percent of the target Trident samples, resulting in 57 percent collection of paired filtered samples across the target TZW sampling effort. Sampling of TZW by small-volume peepers was performed at all study sites except ExxonMobil, where the Trident successfully collected all targeted samples.

The 36 sets of small-volume peepers were deployed in two mobilizations and, following equilibration, were retrieved in two subsequent mobilizations. The first peeper

deployment took place October 17 through 20, 2005. Seventeen sets of peepers (a total of 89 individual small-volume peeper devices) were installed during this first deployment offshore of the ARCO, Siltronic, and Arkema (former Acid Plant and Chlorate Plant areas) sites. The peepers were allowed to equilibrate for 3 weeks, and then retrieved between November 14 and 18, 2005. The second deployment mobilization took place October 31 through November 3, 2005. Nineteen sets of peepers (a total of 78 individual small-volume peeper devices) were deployed during this phase offshore of the Kinder Morgan, Gasco, Rhone Poulenc, Willbridge, and Gunderson sites. The peepers were allowed to equilibrate for 3 weeks, and then retrieved between November 28 and December 1, 2005. Of the 36 sets of small-volume peepers deployed, nine were replicates (one replicate pair was deployed at each site where peeper sampling was performed).

At total of 38 bulk sediment samples were collected from 34 locations using the power grab sampler across the nine study sites, with two to six locations sampled at each site. Of these, four were replicate samples. An overall summary of samples collected at each site, and tabular and graphical summaries of all collected samples and requested analyses are presented by site in of the FSR (Integral 2006f).

2.1.3.1.10 Subyearling Chinook Salmon Tissue

This sampling effort was intended to supplement the baseline ecological data related to potential exposure of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) to site-related contaminants. The objectives of this study were to 1) determine the extent to which subyearling Chinook salmon in the Portland Harbor area may accumulate COIs, and 2) estimate exposure of subyearling Chinook by characterizing COI concentrations in stomach contents.

Two site reconnaissance surveys were undertaken on April 11 and May 9, 2005, prior to initiation of the Round 2 subyearling Chinook salmon tissue collection. While the results of the first reconnaissance trip determined that the subyearling salmon collected would not meet the minimum size requirements, the second reconnaissance trip confirmed the presence of fish that met the target size requirements, and sampling was initiated the following day.

Subyearling Chinook tissue samples were collected at four target locations from May 10 to 12, 2005, including three stations within the ISA and one station upriver, along with one field replicate. A detailed description of the fish sample collection, dissection, and sample processing is provided in the FSR (Integral and Windward 2005a). The Round 2 Subyearling Chinook Tissue Data Report summarizes the results from this sample collection effort (Integral and Windward 2006a).

Except where noted in the FSR (Integral and Windward 2005a), all Round 2 subyearling Chinook tissue collection field activities, including navigational positioning, sample collection, sample handling and processing, and data management, followed guidelines specified in the following documents:

- Portland Harbor RI/FS Field Sampling Plan for Subyearling Chinook Tissue Collection (Chinook Tissue FSP; Integral, Windward, and Ellis 2005)
- Round 2 QAPP (Integral and Windward 2004)
- Round 2 QAPP Addendum 4: Subyearling Chinook Tissue Collection (Integral 2005o)
- Round 2 QAPP Supplement to Addendum 4: Subyearling Chinook Tissue Collection – Semivolatile Organic Compounds (Integral 2005p)
- Round 2 HSP (Integral 2004d).

Subyearling Chinook tissue samples were collected at four target locations in the Willamette River from RM 2 to 18 (Map 2.1-10). All stations identified in the FSP, including three stations within the study area and one station upriver from the ISA, were sampled. One station (T03) was occupied twice on subsequent days to collect enough fish to generate field replicates for chemical analyses.

Only target subyearling Chinook salmon (i.e., fish within the 50- and 80-mm target length) were retained for sampling; all other fish were returned to the river. A total of 95 fish were captured, to obtain three 30-fish composite sample replicates for chemical analyses, and at least five additional fish for taxonomical analyses of stomach contents.

The live juvenile subyearling Chinook were transported to the LWG's Portland field laboratory for further sample processing. The standard chemical suite for whole-body fish tissue included percent lipids, percent moisture, total metals, butyltin compounds, organochlorine pesticides, polycyclic aromatic hydrocarbons (PAHs), semivolatile organic compounds (SVOCs), dioxins and furans, and PCB congeners (full list of 209 congeners). The stomach (gut) contents of five to eight individuals from each fish composite were separated for identification and enumeration of prey species. The remaining stomach contents were analyzed for PAHs, PCB congeners (full list of 209 congeners), and organochlorine pesticides. In addition to the fish tissue samples collected by the LWG, NOAA collected fish at Stations T01 and T02 for stomach content analysis. NOAA performed the dissection and provided LWG with the stomach contents for analysis. The FSR (Integral and Windward 2005a) summarizes the results for taxonomical analyses of 20 fish stomach samples collected at the three sampling stations, T01, T02, and T04 (Map 2.1-10). A total of 36 prey organisms were identified in the 20 subyearling chinook stomachs. The most commonly identified prey organisms belonged to six taxonomical groups. Cladocera (daphnids) accounted for 57.5 percent of all prey organisms identified in the stomachs. The high percentage was to a large extent driven by one juvenile Chinook having eaten 358 daphnids out of 906 identified prey organisms. Daphnids were found in 30 percent of the 20 stomachs. Chironomids (blood worms) were identified in 60 percent of the stomachs and accounted for 8.9 percent of all identified organisms. The other four commonly identified organisms included Coleoptera (beetles, 12.6 percent of all identified organisms), Nematocera (long-horned flies, 5.1 percent of all identified organisms), and Psocoptera (wood lice, 2.8 percent of

all identified organisms). The developmental stages of the insects identified in all stomach contents samples were 73 percent larvae, 2 percent pupae, and 25 percent adults.

2.1.3.1.11 Multiplate Epibenthic Invertebrate Tissue

Epifaunal invertebrates were collected using multiplate samplers in the spring/summer of 2005 to provide information on invertebrate exposures in the water column. Invertebrates were collected at surface water sampling locations distributed throughout the study area. The multiplate samplers were located in a variety of habitats adjacent to riprap, on sandy beaches, and in soft-bottom quiescent areas.

The specific objectives of the Portland Harbor invertebrate sampling using multiplate samplers were as follows:

- Measure constituents in invertebrate tissue samples that represent epibenthic organisms within the study area for use in the BERA fish, bird, and mammalian exposure models.
- Measure constituents in invertebrate tissue samples that represent epibenthic organisms within the study area for use in the tissue-residue line-of-evidence for benthic risk in the BERA.
- Measure constituents in invertebrate tissue samples that represent epibenthic organisms within the study area for use in the food web model to develop risk-based cleanup goals. It was anticipated that the multiplates biomass would represent accumulation via the surface water pathway.

Multiplate samplers were placed at 10 locations (Map 2.1-5) within the study area between RM 2 and 11, between July 26 and 28, 2005. Members of the regulatory agencies and trustees were present on July 26, 27, 28, and September 7, 2005, to oversee field operations. Observers were representatives from Oregon DEQ and USEPA.

Sampling procedures for collection of invertebrates using multiplate samplers followed those detailed in the FSP (Windward and Integral 2005b,c), the Round 2 QAPP (Integral and Windward 2004), and QAPP Addendum 5 (Integral 2005q). The Round 2 Multiplate Invertebrate Tissue Data Report (Integral 2006h) summarizes the results from the July through September 2005 sample collection effort designed to supplement the Round 1 multiplate tissue data set.

The multiplate samplers were deployed at the 10 stations. At each station, 4 arrays of 6 multiplate samplers (total of 24 multiplate samplers per station) (Figure 2.1-2) were deployed based on field determination of the most suitable location for each array. Factors included in the suitability evaluation included water depth (at least 5 m to ensure adequate water depth later in the summer), tie-up point for the rope connected to the array, avoiding high traffic areas and prop-wash areas, and avoiding the dredge operation near Gasco. Six of the stations were placed at a distance of 92 m or less from

the proposed locations. The remaining 4 stations where placed further away (148 to 236 m) from the proposed locations because of the reasons mentioned above. Prior to deployment the multiplate samplers were washed with a brush and Alconox™.

On Monday, August 15, two of the sampler arrays at station MIT005 were reported damaged near the Rhone Poulenc outfall diffuser. The damaged arrays were retrieved on August 15 and 17 and replacement samplers were deployed just downstream of the remaining two samplers at MIT005 on Thursday, August 18. On August 31, one sampler array from station MIT002 was observed on the shore without anchors, and buoys from another array were observed at the surface of the water. On September 1, the array on the shore was attached to new anchors and redeployed in the original location. The other array with buoys at the surface was left untouched. The multiplate samplers were retrieved at all locations between September 6 and 15, 2005.

The multiplate samplers were retrieved approximately 6 weeks later. All sampler arrays were retrieved at all stations except at stations MIT007 and MIT002. At MIT007, 1 array of 5 samplers and 1 single sampler on another array were missing (a total of 17 samplers were retrieved for analysis). At MIT002, 1 array of 6 samplers was missing and another array of 6 samplers was lying in shallow water on the sediment with the weights cut off (a total of 12 samplers were retrieved for analysis).

At all stations, except MIT002 and MIT007, 21 multiplate samplers were sent to a laboratory and processed for invertebrate tissue analyses. At MIT002 and MIT007, only 10 and 16 multiplate samplers, respectively, were processed for tissue analyses. The remaining 3 multiplate samplers from each station (only 1 from MIT002 and 2 from MIT007) were processed for taxonomic evaluation.

Following retrieval, the 14 tempered hardboard plates were removed from each sampler in the laboratory and the organisms from each plate were picked or scraped off using stainless steel forceps and placed either in a small stainless steel sieve or into a clean glass jar filled with site water. (Some of the organisms were retained in a clean jar with site water because they were very lively and would crawl out of the sieve before all the plates from one station were processed.) The organisms were sorted into the following major groups: crustaceans (predominately *Corophium sp.*), insect larvae (predominantly chironomids), bryozoans and sponges, mollusks, invertebrate eggs, and miscellaneous taxa (worms and others), and fish eggs. After all the retrieved multiplate samplers from one station were processed, the remaining debris/mud in the glass jar(s) was examined under a dissecting microscope and missed organisms were picked out. Daphnids swimming in the water phase were strained out by pouring the water through a small stainless steel sieve. Then, each major invertebrate group was weighed, except Daphnids, because they were too small and there was a likelihood of losing a significant portion of them in the weighing process.

Because of the limited number of tissue samples from all stations, a revised chemical analytical approach was developed in cooperation with USEPA and its partners. This

revised analytical approach is described in a supplement to the multiplate tissue QAPP Addendum 5 (Integral 2005) and includes combining tissue samples from several stations to achieve sufficient mass for chemical analysis. The tissue samples were homogenized and analyzed for PCBs, DDTs, PAHs, phthalates, metals, lipids, and moisture.

A detailed description of the Round 2 multiplate tissue collection effort is included in the FSR (Windward 2005b).

2.1.3.1.12 Reconnaissance for Benthic Invertebrates and Clam Tissue

The specific objectives of the Portland Harbor Round 2 benthic invertebrate and clam tissue sampling effort were as follows:

- Measure constituents in benthic invertebrate tissue samples that represent benthic invertebrate prey organisms within the study area for use in the BERA fish, bird, and mammalian dietary exposure models. It was expected that clams would be the predominant biomass and would be a surrogate for other species.
- Measure constituents in benthic invertebrate tissue samples that represent benthic organisms within the study area for use in line-of-evidence in the BERA.
- Measure constituents in benthic invertebrate tissue samples that represent benthic organisms within the study area for use in calibrating the food web model.
- Use information from both field-collected and laboratory bioaccumulation tests to calculate a site-specific biota-sediment accumulation factor.

The benthic sledge, bongo net, diaphragm pump, and Schindler trap were all evaluated as potential sampling approaches for collecting sufficient tissue for invertebrates predominantly exposed through sediment (Windward 2005c). Based on this effort, it was determined that the use of the benthic sledge in locations throughout the study area for collecting clams (*Corbicula sp*.) would provide the best opportunity to collect the mass of tissue required to meet analytical goals. Bioaccumulation testing would be conducted on freshwater oligochaetes (*Lumbriculus variegatus*) to estimate tissue concentrations for other common sediment-exposed benthic invertebrates. Bioaccumulation testing would also be conducted using *Corbicula fluminea* to facilitate the evaluation of the two difference exposure regimes (field and lab) and the subsequent tissue concentrations.

Using a benthic sledge, clams (*Corbicula* sp.) were sampled at 33 sample locations (Map 2.1-21) between RM 2 and 10 between November 28 and December 14, 2005. Sampling procedures for the collection of clams followed those detailed in the Portland Harbor RI/FS FSP: Round 2 Sampling of Benthic Invertebrate Tissue (Windward and Integral 2005b), the Round 2 QAPP (Integral and Windward 2004), the Round 2 QAPP Addendum 2: PCB Congener Analysis in Sediment Samples (Integral 2004f) and the

Round 2 QAPP Addendum 6: Sampling of Benthic Invertebrate Tissue (Integral and Windward 2005b). As stated in the FSP, all mussels and lamprey ammocoetes collected at the 33 stations were retained for possible chemical analysis. The Round 2 Benthic Tissue and Sediment Data Report (Integral and Windward 2006b) summarizes the results from the November through December 2005 sample collection effort designed to supplement the Round 1 benthic invertebrate tissue chemistry data set. A detailed description of the Round 2 benthic invertebrate and sediment collection effort is included in the Round 2 Sampling of Benthic Invertebrate Tissue FSRs (Windward and Integral 2005a, 2006). Except where noted in the FSR, all Round 2 benthic invertebrate collection field activities, including navigational positioning, sample collection, sample handling and processing, and data management, followed guidelines specified in the approved FSP and QAPPs. Members of the regulatory agencies and trustees were present on November 28, 29, and 30, 2005, and on December 1, 5, 6, 7, 8, 9, 12, 13, and 14, 2005, to oversee field operations. Observers included representatives from the Oregon DEQ, USEPA, the USFWS, Environmental International Ltd., and Parametrix, Inc.

Of the 33 sampling locations, 20 were located along the shoreline of the main lower Willamette River channel and 12 were located in off-channel slips or embayments. The remaining station was located in Multnomah Channel. Twenty-three of the sampling locations were also within sandpiper foraging habitat. All sampling locations were in areas where elevated concentrations of at least one chemical were measured in the Round 2 surface sediment sampling effort.

The benthic invertebrate tissue sampling effort was conducted as a series of sampling events. The first event was the field collection of clams. The collection was initiated November 28, 2005. A week later, on December 5, 2005, sediment collection was initiated by sampling at stations where the collection of clams had been completed. The sediment sampling at each station used a location-specific sampling approach, which was based on locations where clams had been successfully collected. Sediment was collected for both chemical analysis and bioaccumulation testing with two organisms, the clam *Corbicula fluminea* and the worm *Lumbriculus variegatus*. The clam sampling effort at the 33 locations (Map 2.1-21) was completed on December 14; and the sediment sampling effort was completed on December 20, 2005.

Sufficient amounts of tissue were collected for a full suite of chemical analyses, including percent lipids, PCB congeners, PAHs, organochlorine pesticides, butyltin compounds, phthalates, SVOCs, metals, and dioxins and furans. Laboratory bioaccumulation testing was conducted with the sediments using freshwater oligochaetes (*Lumbriculus variegatus*) to estimate tissue concentrations for other common sediment-exposed benthic invertebrates. Bioaccumulation testing was also conducted using *Corbicula fluminea* to allow evaluation of the two different exposure regimes (field-collected and laboratory-exposed) and the subsequent tissue concentrations.

2.1.3.1.13 Mussel and Lamprey Ammocoete Tissue

Sampling of lamprey ammocoetes and mussels was conducted concurrently with the sampling for clams (*Corbicula* sp.) discussed in the previous section. The sampling was conducted at 33 locations within the study area (Maps 2.1-5 and 2.1-11) between RM 2 and 10 in November and December 2005.

In accordance with the Round 2 Sampling of Benthic Invertebrate Tissue FSP (Windward and Integral 2005b), all lamprey ammocoetes and mussels collected at the 33 locations (Maps 2.1-5 and 2.1-11) were retained for possible chemical analysis. The mussel and lamprey ammocoete samples were handled in a manner similar to that of the clam samples. One to two lamprey ammocoete individuals were collected at nine locations; a total of 10 lamprey ammocoetes were collected. A total of 40 mussels were collected at 19 locations with numbers ranging between 1 and 7 individuals. The majority of the mussels were tentatively identified as Western pearlshell mussels (*Margaritifera falcata*); only a few individuals (5) collected at BT007 and BT009 were tentatively identified as winged floaters (*Anodonta nuttalliana*).

Chemical analysis was performed on the composite lamprey ammocoete sample and seven mussel tissue samples collected at stations BT001, BT004, BT006, BT009, BT021, BT025, and BT033. Chemical analysis was not conducted on two of the mussel samples because the sample collected at BT017 consisted of one mussel that turned out to be an empty shell and the other sample collected at BT015 consisted of only one mussel. The Round 2 Mussel and Lamprey Ammocoete Tissue Data Report (Windward and Integral 2007) summarizes the results from the Round 2 sample collection effort.

2.1.3.1.14 Cultural Resources Analysis

According to CERCLA and its implementing regulations, USEPA is required to comply with federal statutes that provide protection for archaeological and historical resources, including Native American burials and places of traditional religious and cultural significance. In 2001, USEPA and Oregon DEQ signed a Memorandum of Understanding (MOU) with six tribal governments and three federal and state agencies that identified cultural resources as an area of special concern to the signatory tribes. Also in 2001, USEPA signed an AOC with the LWG to perform a cultural resource survey as part of the RI/FS. The survey included the in-water portion of the Site from the confluence of the Willamette and Columbia rivers to Willamette Falls, including upland areas adjacent to this stretch of the river. Results of the survey are documented in Cultural Resource Analysis Report for the Portland Harbor Superfund Site, Portland, Oregon (AINW 2005). A comprehensive cultural resource analysis, including procedures for protecting and addressing cultural resources before, during, and after the RI/FS and remedial design is complete, will be provided in consultation with the tribes at a later date.

2.1.4 Round 3 RI Field Investigations (2006–2008)

Round 2 sampling focused on sediment and surface water chemistry, benthic toxicity, and ongoing work related to site characterization within the currently identified

Portland Harbor study area. The Round 3 sampling needs included collection of additional data to complete the site characterization, refine the CSM, complete the BERA and BHHRA, and support the FS. The data gaps that needed to be completed in Round 3 sampling were identified in the Round 3 SOW (USEPA 2006b) and the Comprehensive Round 2 Site Characterization Summary and Data Gaps Analysis Report (Integral, Windward, Kennedy/Jenks, and Anchor 2007).

Round 3 field investigations were performed from January 2006 through January 2008. Round 3 field investigations are discussed in the following FSRs or data reports:

- Surface water (Integral 2006k,l,m , 2007a,b,c,d)
- Groundwater – Gunderson Site (Integral 2007e)
- Stormwater (Anchor and Integral 2007a, 2008a,b)
- Lamprey ammocoete tissue (Windward 2006a, 2007a, 2008a; Integral and Windward 2007a)
- Sturgeon tissue (Windward 2007b; Windward and Integral 2008)
- Fish and invertebrate tissue and collocated surface sediment (Integral and Windward 2008; Integral 2008b,c)
- Sediment – Willamette Cove (Integral 2008d)
- Sediment and sediment toxicity bioassays (Integral 2008e,f; Windward 2008b)
- Sediment trap (Anchor 2007a,b,c, 2008a; Anchor and Integral 2008a,b,c)
- Upstream/downstream surface and subsurface sediment (Integral 2007f,g)
- Natural attenuation (radioisotope subsurface sediment cores) (Integral 2007f,h)
- Sediment chemical mobility testing (Anchor and Integral 2008d; Integral 2009)
- Side-scan sonar (Anchor QEA 2009a).

Except where noted in the FSRs, the data reports, or as modified by subsequent correspondence between the LWG and USEPA, all sample collection activities followed the procedures described in the following Round 3 FSPs and SOPs:

- Surface water (Integral 2004b, 2006n,o,p)
- Groundwater – Gunderson Site (Integral 2007i)
- Stormwater (Anchor and Integral 2007b,c)
- Lamprey ammocoete tissue (Windward 2006b,c; LWG 2006)
- Sturgeon tissue (Windward 2007c; Integral 2007j)
- Fish and invertebrate tissue and collocated surface sediment (Integral 2007k)
- Sediment – Willamette Cove (Integral, Anchor, and Windward 2004)

- Sediment and sediment toxicity bioassays (Windward 2007d; Integral, Windward, and Anchor 2007a,b; Integral 2007l; Integral and Anchor 2007)
- Sediment trap (Anchor 2006b)
- Upstream/downstream surface and subsurface sediment (Integral 2006q)
- Natural attenuation (radioisotope cores) (Integral 2006q)
- Sediment chemical mobility testing (Anchor 2008b)
- Side-scan sonar (Anchor 2008c).

All field sampling was conducted in accordance with the following HSPs:

- Round 2 HSP (Integral 2004d)
- Round 2 GWPA HSP (Integral 2005m).

All laboratory analyses follow the following USEPA-approved Round 2 QAPPs:

- Round 2 QAPP Addendum 1: Surface Water (Integral 2004e)
- Round 2 QAPP Supplement 1 to Addendum 1: Round 3A Surface Water Sampling (Integral 2006r)
- Lamprey Ammocoete (*Lampetra* sp.) Toxicity Testing QAPP (Windward 2006d)
- Round 2 QAPP Addendum 7: Round 3 Chemical Analysis of Lamprey Ammocoete Toxicity Test Water (Integral 2006s)
- Round 2 QAPP Addendum 8: Round 3A Stormwater Sampling (Integral 2007m)
- Round 3 Lamprey Ammocoete (*Lampetra* sp.) Toxicity Testing QAPP Addendum: Phase 2 Lamprey Ammocoete Collection and Testing (Windward 2007e)
- Round 2 QAPP Addendum 9: Fish and Invertebrate Tissue and Co-located Sediment Sampling for Round 3B (Integral 2007n)
- Round 2 QAPP Addendum 10: Round 3B Comprehensive Sediment and Bioassay Testing (Integral and Windward 2007b)
- Round 2 QAPP Addendum 11: Sediment Chemical Mobility Testing (Integral 2008g).

2.1.4.1 Summary of Round 3 Field Activities

The purpose of the Round 3 sample collection was to provide greater specificity regarding the nature and scope of data collection efforts necessary to address the existing data gaps, and to support the RI/FS and subsequent cleanup decisions.

The specific Round 3A objectives can be related to specific data analyses within the RI/FS as follows:

- **Nature and Extent of Surface Water Chemicals**. Acquire additional low detection limit data under specific flow and runoff conditions to augment the Round 2A data. Refine the CSM, and support the fate and transport modeling effort, which is currently under development.
- **Food Web Model**. Consider additional surface water chemistry data for use with Round 2A data, as appropriate, to characterize average chemical concentrations in surface water for use in the food web model. In addition, data for a wider range of flow conditions will be considered for characterizing seasonal and event-specific (e.g., storm) variability of chemical concentrations.
- **Background Conditions/Site Boundary**. Collect water quality data upstream of the ISA to assist in characterization of background conditions and, along with other information, help define the boundaries of the Site.
- **Source Identification**. Collect data to help understand the regional impact of any ongoing sources to the Site and to differentiate between sediment resuspension and other potential sources.
- **Feasibility Study**. Collect water quality data to support development of the FS objectives, including evaluation of remedial alternatives as they relates to fate and transport of chemicals, background conditions, source characterization/recontamination issues, and the potential for monitored natural recovery.
- **Hydrodynamic/Sediment Transport Model**. Collect TSS data to further refine and calibrate the HST model.

The 2006/2008 Round 3 Portland Harbor RI field sampling efforts include collection of the following information:

- Surface water
- Groundwater – Gunderson Site
- Stormwater
- Lamprey ammocoete tissue
- Sturgeon tissue
- Fish and invertebrate tissue and collocated surface sediment
- Sediment – Willamette Cove
- Sediment and bioassay
- Sediment trap
- Upstream/downstream surface and subsurface sediment

- Natural attenuation (radioisotope cores)
- Sediment chemical mobility testing
- Side-scan sonar.

2.1.4.1.1 Surface Water

The Round 3A surface water investigation was conducted to supplement the results of the Round 2A surface water investigation. Surface water chemistry was measured under various flow conditions and at additional locations upstream and downstream of the study area in Round 3A. The primary objectives of the Round 3A surface water sampling effort were as follows:

- Assess water quality conditions in the study area and adjacent areas under various flow conditions
- Collect data to support the FS evaluation of remedial alternatives, including monitored natural recovery, potential recontamination of sediment surface from surface water, and background conditions
- Continue to evaluate nature and extent of chemicals in surface water
- Refine the CSM
- Provide additional water quality data to further support the food-web modeling effort for the ecological and human health risk assessments.

These surface water field activities were conducted in accordance with the Round 3A Surface Water FSP (Integral 2006n), the Addendum to Round 3A FSP Summer Low-Flow Surface Water Sampling (Integral 2006o), Round 3A FSP Surface Water Sampling Addendum 2 (Integral 2006p), the Round 2A Surface Water FSP (Integral 2004b), the HSP (Integral 2004d), the QAPP (Integral and Windward 2004), the Round 2 QAPP Addendum 1 for Surface Water Sampling (Integral 2004e), and the Round 2 QAPP Supplement 1 to Addendum 1: Round 3A Surface Water Sampling (Integral 2006r). Deviations from the planned approaches are described in the FSRs (Integral 2006k,m, 2007b,c) and were generally coordinated with the USEPA team prior to their implementation.

For Round 3A, both transect and single-point samples were collected, and both peristaltic and hydrophobic polyaromatic resin (XAD) methods were used at selected stations (Map 2.1-18). Round 3A sampling locations included three Round 2A transect stations (RM 11, 6.3, and 4), three additional transects (RM 16, 2, and at the inlet to the Multnomah Channel), and 12 single-point locations between RM 2 and 10. At RM 2 and 11, transects were subdivided into three lateral segments across the river as follows: east shoreline to navigational channel, navigational channel, and navigational channel to west shoreline, resulting in a total of six stations for these two transects. Surface water was collected at the Round 3A surface water locations during the following four sampling events. The sample collection for each of the four events is described below:

January 2006 High-flow Event

This event, conducted January 19–21, consisted of the collection of single-point mid-river peristaltic and XAD samples at two Round 2A stations (W023 at RM 11, W005 at RM 4) and one Round 3A location (W024 at RM 16) during flood conditions (Q>160,000 cfs).

Surface water samples were collected using a peristaltic pump at three mid-channel target locations at RM 4, 11, and 16 in the Willamette River (Map 2.1-18) using an Infiltrex 300 system connected to XAD-2 resin columns to collect hydrophobic organic compounds for analysis by ultra-low analytical methods. All stations identified in the FSP (Integral 2006m) were sampled. One station (W023) was occupied twice to generate a field replicate for the peristaltic sampling method. A field replicate was not collected during this sampling event for the XAD method.

River stage and river flows on the Willamette River at Portland as well as local precipitation levels that occurred during the surface water sampling period (January 19–21, 2006) are shown in the FSR (Integral 2006k).

September 2006 Low-flow Event

Surface water samples were collected September 4–13 from six transect locations between RM 2 and 16 (Map 2.1-18). This event was conducted during low-flow conditions (Q<20,000 cfs) by collecting near-bottom and near-surface (NB/NS) peristaltic and XAD samples at four transect locations (W005 at RM 4, W011 at RM 6.3, W024 at RM 16, and W027 in Multnomah Channel), and by collecting vertically integrated samples at three stations spaced laterally across the river at two Round 3A transect locations (W023 at RM 11 and W025 at RM 2). All stations identified in the Round 3A Surface Water FSP were sampled; however, the field replicate transect sample (W011) scheduled for September 15, 2006 was not collected because rain had fallen the day before (0.13 inch on September 14, 2006).

Vertically integrated water column samples were collected using both peristaltic pump and Infiltrex pump methods at two transect locations (W025 at RM 2 and W023 at RM 11). Each transect was subdivided into three lateral segments across the river as follows: east shoreline to navigational channel, navigational channel, and navigational channel to west shoreline. These lateral segments were sampled at the midpoint of each segment; the navigation channel sample was collected as close to mid-channel as feasible. At the midpoint of each segment, a vertically integrated water column sample was collected. Details on the sampling approach for transects are provided in Appendix G of the Round 3A Surface Water FSP (Integral 2006n).

River stage and river flows on the Willamette River at Portland, as well as local precipitation during the surface water sampling period (September 4–13, 2006), are shown in the FSR (Integral 2006m).

November 2006 Stormwater Event

This event was conducted November 2–5 during a stormwater runoff event when the river discharge is in low-flow conditions (Q<20,000 cfs) by collecting NB/NS peristaltic samples and XAD samples at 18 Round 3A locations (Map 2.1-18) during an active stormwater event(s).

Cross-sectional near-bottom and near-surface peristaltic and high-volume samples were collected at four transect locations (W005 at RM 4, W011 at RM 6.3, W024 at RM 16, and W027 at the mouth of the Multnomah Channel). At each transect the river was divided into equal discharge increments (EDIs) using existing bathymetry and river flow data.

Six vertically integrated water column samples were collected using both peristaltic pumps and high-volume sample methods at two transect locations (W025 at RM 2 and W023 at RM 11). Each transect was subdivided into three lateral segments across the river as follows: east shoreline to navigational channel, navigational channel, and navigational channel to west shoreline. At the midpoint of each segment, a vertically integrated water column sample was collected. Details on this transect sampling approach are provided in Appendix G of the Round 3A Surface Water FSP (Integral 2006k).

Single-point NB/NS peristaltic and high-volume samples were collected at 12 locations (W026 at RM 2, W028 at RM 3–4, W029 at RM 4–5, W030 at RM 5–6, W031 at RM 6–7, W032 at RM 6–7, W033 at RM 7, W034 at RM 7–8, W035 at RM 8–9, W036 at RM 8–9, W037 at RM 9–10, and W038 at RM 9–10). High-volume XAD samples were collected only for PCB congeners at eight locations (W026, W028, W029, W030, W034, W036, W037, and W038).

River stage and river flows on the Willamette River at Portland, as well as local precipitation levels that occurred during the surface water sampling period (November 2–5, 2006), are shown in the FSR (Integral 2007b).

Winter 2007 High-flow Event

This event was conducted during a high-flow event (Q>50,000 cfs) by collecting NB/NS peristaltic samples and XAD samples at 16 Round 3A locations (Map 2.1-18). In addition, three vertically integrated peristaltic and XAD samples spaced laterally across the river at two Round 3A transect locations (W023 at RM 11 and W025 at RM 2) were collected during high-flow conditions.

The high-flow surface water sampling event was split into two phases because of a sudden drop in precipitation after the first 3 days of sampling. The first phase took place January 15–18, 2007. On January 18, 2007, the high-flow surface water collection program was cancelled due to the flow of the Willamette River dipping below 50,000 cfs. The second phase resumed on February 21 through March 10, 2007.

Cross-sectional NB/NS peristaltic and high-volume samples were collected at four Round 3A transect locations (W005 at RM 4, W011 at RM 6.3, W027 at the mouth of the Multnomah Channel, and W024 at RM 16). At each transect the river was divided into EDIs using existing bathymetry and river flow data (Integral 2006n, Appendix A). During the first phase of the high-flow sampling event, sampling at transect W024 started on January 15, it was then interrupted by a snow storm on January 16, and resumed from January 17–18, 2007. This station was not resampled with the remaining sampling stations during the second phase. All other cross-sectional NB/NS transects were sampled from February 21 through March 10, 2007.

Eight vertically integrated water column samples were collected using both peristaltic pumps and high-volume sample methods at two transect locations (W025 at RM 2 and W023 at RM 11). Each transect was subdivided into three lateral segments across the river as follows: 1) east shoreline to navigational channel, 2) navigational channel, and 3) navigational channel to west shoreline. At the midpoint of each segment, a vertically integrated water column sample was collected. Details on this transect sampling approach are provided in Appendix G of the Round 3A Surface Water FSP (Integral 2006k). During the first phase, the sampling stations located in the middle of the navigational channel at W023 and W025 were sampled on January 15, 2007, and were sampled again during the second phase on March 2 and March 10, 2007, respectively.

During the second phase of the high-flow sampling event, single-point NB/NS peristaltic and high-volume samples were collected at 12 locations (W026 at RM 2, W028 at RM 3–4, W029 at RM 4–5, W030 at RM 5–6, W031 at RM 6–7, W032 at RM 6–7, W033 at RM 7, W034 at RM 7–8, W035 at RM 8–9, W036 at RM 8–9, W037 at RM 9–10, and W038 at RM 9–10). High-volume XAD samples were collected for PCB congeners only at eight locations (W026, W028, W029, W030, W034, W036, W037, and W038). All samples were collected from February 21 through March 10, 2007.

River stage and river flows on the Willamette River at Portland, as well as local precipitation levels that occurred during the surface water sampling period (January 15–18, 2007 and February 22 through March 10, 2007), are shown in the FSR (Integral 2007c).

2.1.4.1.2 Groundwater – Gunderson Site

The Gunderson site is an industrial facility located between RM 8.5 and 9.2 on the west bank of the Willamette River. A volatile organic compound (VOC) groundwater plume is present in the upland groundwater of Area 1 at the Gunderson site, resulting from a historical spill of 1,1,1-trichloroethane (1,1,1-TCA). The primary objective of this effort was to gather information to allow evaluation of the stratigraphic trend of the deep conductive (gravel/sand) zone offshore of the Gunderson Area 1 site. The goal was to determine whether possible discharge areas could be identified where TZW sampling might be used to evaluate such discharges, and to focus that sampling, if needed.

Stratigraphic cores were collected offshore of the Gunderson Area 1 at nine locations between October 16 and October 19, 2007 (Map 2.1-22). Sampling was conducted in accordance with the Round 2 GWPA SAP (Integral, Kennedy/Jenks, and Windward 2005), Round 3 GWPA HSP Addendum II (Integral 2007o), and the Round 3 GWPA FSP (Integral 2007i). The nine stratigraphic core locations are shown on Map 2.1-22. Table 3-1 of the FSR (Integral 2007e) lists the stations, core lengths, and number of field flame ionization detector reading intervals. Complete field notes are presented in Appendix B of the FSR (Integral 2007e). Core log description forms for the nine stratigraphic cores are presented in Appendix C of the FSR and a comparison of target and actual core locations is presented in Appendix D of the FSR (Integral 2007e).

2.1.4.1.3 Stormwater

The objectives of the RI/FS stormwater sampling program were to evaluate stormwater contribution to in-river fish tissue chemical burdens and determine the potential for recontamination of sediment (after cleanup) from stormwater inputs. In summary, the planned sampling approach described by the FSP (Anchor and Integral 2007b,c) included the following:

- Flow-weighted composite storm water samples using automated Teledyne ISCO samplers from three storm events, including whole water for organic compound analyses and filtered/unfiltered pairs for metals analyses
- One additional set of grab stormwater samples at 10 of the 23 planned sampling locations for sampling of filtered/unfiltered pairs and analysis of selected organic compounds and associated conventional analytes
- Sediment trap deployment (to collect suspended sediment from stormwater and analyze for sediment chemistry) for a minimum duration of 3 months.

The LWG sampling activities are described in detail in the Round 3A Stormwater Sampling FSP (Anchor and Integral 2007b), Round 3A Stormwater Sampling FSP Addendum (Anchor and Integral 2007c); and the Round 2 QAPP Addendum 8 (Integral 2007m). The FSP, FSP Addendum, and QAPP are companion documents to the Round 3A Stormwater Sampling Rationale (Anchor and Integral 2007d), which describes the reasoning behind the overall sampling approach.

The first round of stormwater sampling, Round 3A, was conducted from February through July 2007 and included collection of composite stormwater samples, grab stormwater samples, and sediment trap stormwater samples. During Round 3A, flow-weighted stormwater samples were collected at 33 locations (including LWG, Terminal 4, and GE Decommissioning Facility sites), grab samples were collected at 10 LWG locations, and sediment samples were collected from 24 LWG locations plus 6 additional locations in the vicinity of Terminal 4 (Map 2.1-23). The Round 3A sampling resulted in less than the total number of desired samples, as described in the Round 3A FSP (Anchor and Integral 2007b) so a second round of sampling was planned to commence in the fall of 2007.

The second round of sampling, Round 3B, was conducted from November 2007 through February 2008. Round 3B consisted of collection of flow-weighted stormwater samples by an ISCO sampling device from 17 locations (including LWG, Terminal 4, and GE Decommissioning Facility sites) and sediment trap samples from 12 LWG locations plus six additional locations in the vicinity of Terminal 4 (Map 2.1-23). A detailed description of field efforts associated with the Round 3A and 3B Stormwater Sampling Field Data Report is included in the respective FSRs (Anchor and Integral 2007a; Anchor and Integral 2008d; Ash Creek Associates/Newfields 2008).

Rainfall data for Round 3A and 3B stormwater sampling were obtained from five established rain gages in the City of Portland Hydra Rainfall Network. These rain gages included Albina, Swan Island, Terminal 4, WPCL, and Yeon. The rainfall data obtained from each gage were used to make sampling decisions throughout the course of the sampling and to understand the flow results for data reporting. Complete rainfall data for the duration of the project and the locations of the gages relative to stormwater sampling locations are included in Appendix C of the Data Report (Anchor and Integral 2008a).

In order to prevent sampling water from the Willamette River, stormwater sampling stations were specifically chosen to be at locations/elevations unlikely to experience a backup of river water into the junction or adjoining pipes. During the Round 3A and 3B sampling events, the gage height during the sampling periods was reviewed to verify that the sampling locations were not inundated by river water. The gage height of the Willamette River at the Morrison Street Bridge, USGS Station 14211720, was obtained from the USGS on a half-hour basis for the duration of the stormwater sampling. The records of gage height elevations for the duration of the sampling periods are included in Appendix D of the Data Report (Anchor and Integral 2008a).

2.1.4.1.4 Lamprey Ammocoete Tissue

A total of 23 stations were sampled for lamprey ammocoetes (*Lampetra* sp.) between September 20 and October 16, 2006 (Map 2.1-11). These included 21 sampling stations within the study area between RM 2 and 11 and two locations upstream of the study area. Sampling procedures for the collection of ammocoetes followed those detailed in the FSP (Windward 2006b).

The specific objectives of the Portland Harbor Round 3 lamprey ammocoete tissue sampling effort were as follows:

- Obtain site-specific empirical lamprey ammocoete whole body tissue data
- Measure concentrations of chemicals in lamprey ammocoetes from the study area for use in evaluating risks from hazardous substances to out-migrating lamprey larvae

- Determine whether lamprey ammocoetes from the study area have elevated concentrations of site-related contaminants compared with upstream reference areas
- Collect incidental information on lamprey habitat preference based on catch success.

Representatives of the regulatory agencies and trustees were present throughout the sampling effort, to oversee field operations. Observers were representatives from the Oregon DEQ, USEPA, the USFWS, Environmental International Ltd., the Grand Ronde Tribe, and the Siletz Tribe. Representatives from USFWS (Marquette Biological Station) were present September 20 through September 27, 2006, to provide sampling equipment training and troubleshooting.

The FSR (Windward 2006a) further discusses the field procedures and presents the number of casts conducted and estimated lamprey biomass collected at each sampling station. The FSR also provides figures showing the cast locations at the sampling stations.

2.1.4.1.5 Sturgeon Tissue

Five areas (i.e., reaches) of the river within the study area were sampled for pre-breeding white sturgeon (*Acipenser transmontanus*) between February 19 and March 6, 2007 (Map 2.1-10). The sampling and processing procedures followed those detailed in the FSP (Windward 2007c) and *Procedure for Sampling Fish, Collecting Tissues, and Conducting an External Fish Health Assessment* (USFWS 2007), also referred to as the SOP.

The specific objective of the Portland Harbor Round 3 pre-breeding white sturgeon tissue sampling effort was to obtain site-specific pre-breeding white sturgeon whole-body tissue samples for use in determining whether COIs in field-collected white sturgeon tissue from the Portland Harbor Site potentially pose unacceptable ecological risks to the sturgeon themselves.

Representatives of the regulatory agencies and trustees were present throughout the sampling effort to oversee field operations. Observers were representatives from USEPA, USFWS, ODFW, NOAA, Oregon DEQ, Ridolfi Inc., Environment International Ltd., and the Nez Perce Tribe.

A total of 403 white sturgeon were collected with set lines and by angling. Of this number, 384 were smaller than the legal size and subsequently released at the site of capture. Of the 19 legal-sized (42- to 60-inch) sturgeon collected, 1 was released accidentally, and 3 were released because the target quota for the reach in which they were caught had been met. A total of 15 legal-sized white sturgeon were retained for chemical analysis. In addition, one sub-legal-sized sturgeon was retained as a practice health assessment and dissection specimen.

Although it was not originally planned in the FSP, USEPA approved additional efforts to collect more sturgeon by supplementing the set lines with an angling effort. Twenty-two additional sturgeon were caught by angling on February 20 and 21, and March 5 and 6, 2007. However, no legal-sized (42- to 60-inch) sturgeon were captured during angling, and all sub-legal-sized sturgeon were subsequently released.

2.1.4.1.6 Fish and Invertebrate Tissue with Collocated Surface Sediment

The Round 3B fish and invertebrate tissue and collocated surface sediment field sampling activities were conducted between RM 1 and 12.2 from August 7 through December 6, 2007. The sample collection and processing methods used during the Round 3B field sampling effort followed the Round 3B Fish and Invertebrate Tissue and Collocated Surface Sediment FSP (Integral 2007k). The methods build upon previous experience collecting biota at the Site as described in the Round 1 FSP (SEA, Windward, Anchor, and Kennedy/Jenks 2002b), the Round 1 Laboratory QAPP (SEA 2002d), the Round 2 Benthic Invertebrate FSP (Windward and Integral 2005b) and Technical Memorandum (Windward and Integral 2005a), the Round 2 QAPP (Integral and Windward 2004) and QAPP Addenda 5 and 9 (Integral 2005q, 2007n), and the project HSPs (SEA 2002f; Integral 2004d, 2007p; Windward 2007f). All sampling and analysis methods detailed in this FSR were consistent with the methods used in previous FSPs and QAPPs for fish and invertebrate tissue and collocated sediment.

A reconnaissance survey was conducted by USEPA and LWG on August 7, 2007, to verify target sample locations and identify appropriate habitat for target species. Approval to proceed with the sampling was provided by USEPA in a letter dated August 17, 2007 (USEPA 2007). Sampling locations shown in Maps 2.1-5, 2.1-8, and 2.1-9 reflect the sampling locations resulting from the field reconnaissance survey.

The Round 3B fish and invertebrate tissue and collocated surface sediment sampling event commenced on August 27, 2007 and was completed by December 6, 2007. The sampling dates for the various sample collection efforts are summarized below:

- August 27–September 28, 2007—Collection of all target fish and crayfish species.
- October 4–5, 2007—Acquisition of GPS coordinates for actual sculpin and crayfish sampling stations.
- October 15–18, 2007—Collection of collocated sediment samples at sculpin and crayfish stations.
- November 12–16, 2007—Collection of clam tissue.
- November 19–22, 2007—Collection of collocated sediment samples at clam stations, with an additional day of sampling on December 6, 2007.

Three fish species (sculpin, smallmouth bass, and carp), one crayfish species, and one clam species were collected for tissue analyses. In addition, collocated surface sediment was collected at crayfish, sculpin, and clam stations. Four sampling

techniques were used during Round 3B to collect fish: backpack electrofishing, set lines (i.e., trot lines), angling, and crayfish traps. Clams were collected using a benthic sledge.

A total of 414 fish, 816 invertebrates, and 20 collocated sediment samples were collected over 32 field sampling days. Table F-1 in Appendix F of the FSR (Integral and Windward 2008) provides the records for each fish and invertebrate caught during the Round 3B sampling effort. The species collection effort included 230 sculpin, 80 crayfish, 136 smallmouth bass, 48 carp, and 736 clams. Twenty collocated sediment composites were collected at sculpin, crayfish, and clam sampling locations (Maps 2.1-5, 2.1-7, and 2.1-9).

Fishing and tissue collection efforts required a substantial amount of resources and personnel. Integral staff coordinated the overall effort, which was carried out primarily by personnel from Ellis Ecological Services as the fishing permit holder. Ellis Ecological Services was assisted by Windward Environmental LLC, SWCA Environmental Consultants, Kennedy/Jenks Consultants, Marine Endeavors LLC, Marine Sampling Systems, Mullins Guide Services, Benthic LLC, and the Oregon Bass Panfish Club.

All people directly involved with the fishing effort were authorized to collect fish under the NOAA Fisheries 4(d) scientific taking permit (OR2007-4082 partial and OR2007-4082M1 partial) and Section 10 scientific taking permit granted to EES by the ODFW.

Members of the regulatory agencies and trustees were present at various times to observe and oversee all aspects of field and field laboratory operations for fish, invertebrate, and collocated sediment collection and sample processing.

2.1.4.1.7 Sediment (Willamette Cove)

The objective of the Willamette Cove sediment sampling program was to locate the NAPL-impacted sediments reported by Oregon DEQ (2007) during an August 28, 2007 site walk and collect a representative surface sediment sample in accordance with the Round 2A surface sediment sampling protocol (Integral, Anchor, and Windward 2004) for the chemical analyses outlined in the data report (Integral 2008c). Except where noted in the data report (Integral 2008d), all surface sediment field activities, including sample collection, sample handling and processing, and data management, followed guidelines specified in the Round 2 QAPP (Integral and Windward 2004), the Round 2 QAPP Addendum 9 (Integral 2007p) and the Round 2 HSP (Integral 2004d).

On September 21, 2007, three test pits were excavated to locate NAPL-impacted sediments. A representative sample from the composited surface (0–30 cm) sediment was collected from one location for chemical analyses. The surface sediment sample LW3-GWC1 was collected according to the standard LWG field sampling protocol as outlined in the Round 2A FSP (Integral, Anchor, and Windward 2004). The location of

the Willamette Cove sediment sample is shown in Map 2.1-15; coordinates and field logs are presented in Appendix B of the data report (Integral 2008d).

2.1.4.1.8 Sediment and Sediment Toxicity Bioassay Testing

The RI/FS objectives that the Round 3B sediment sampling efforts supported included the following:

- Collect synoptic sediment chemistry and toxicity data to fill data gaps required to complete characterization of risks to the benthic community
- Collect surface sediment chemistry data from the upriver reach of the lower Willamette River to support the determination of final background sediment concentrations
- Collect surface sediment chemistry data from Multnomah Channel to evaluate the potential for contaminant migration from the study area to Multnomah Channel
- Refine the lateral and vertical extent of sediment contamination by filling data gaps within the study area to complete the RI and to support the FS
- Collect subsurface sediment chemistry data within the study area to complete characterization of subsurface sediment in areas where subsurface sediments posing potentially unacceptable risk may be exposed by future extreme high-flow flood events.

Surface and subsurface sediment samples were collected during Round 3B from November 13 to January 17, 2008, in three separate reaches: 1) within the Willamette River from RM 2 to 12.2; 2) the upper reach of the Multnomah Channel; and 3) within the Willamette River from RM 15.3 to 26. Surface sediment grabs were collected at 188 stations and subsurface cores were collected at 88 stations within these reaches. All locations sampled during Round 3B are shown on Maps 2.1-15 and 2.1-17.

Surface sediment samples were collected from the 188 stations during Round 3B, including field replicates and split samples, resulting in 204 surface sediment samples submitted for chemical analyses, and 60 sediment samples collected for bioassay testing. A total of 94 subsurface sediment cores, which includes field replicates, were collected from 88 stations during Round 3B. Including the field replicates and homogenate split samples, a total of 244 subsurface sediment samples were submitted for chemical and/or physical analyses. Including 6 field replicates, 56 cores were collected from the study area and Multnomah Channel for chemistry analyses, 23 cores were collected in the study area for erosion study analyses, 5 cores were collected in the study area for both chemistry and erosion study analyses, and 10 cores were collected in the study area for geotechnical analyses.

Round 3B sample collection and processing procedures followed guidelines specified in the Round 3B Sediment FSP (Integral, Windward, and Anchor 2007a,b), the Round 2 QAPP (Integral and Windward 2004), and QAPP Addendum 10 (Integral and

Windward 2007b). Deviations from the FSP and QAPP are discussed in the sediment and bioassay FSR (Integral 2008f) and summarized in the data report (Integral 2008e).

2.1.4.1.9 Sediment Traps

The suspended sediment component of the sampling program involved using sediment traps to collect the sediment settling from the surface water column. The primary purpose of Round 3 sediment trap sampling was to gather data for the evaluation of FS alternatives. In addition, this sediment trap work contributed to filling data gaps related to the nature and extent of potential sources and supported the preparation of the BERA.

The specific objectives of the Round 3 sediment trap sampling program were to collect sediment trap mass and chemical concentration data to further characterize the nature and extent of waterborne sediment contamination that enters the study area from upstream sources, is associated with regional sources within the study area, and exits the downstream end of the study area. The data will support the FS in terms of providing better understanding of potential inputs from regional sources, potential contributions from within and outside the study area, and the potential for recontamination and/or natural recovery of bedded sediments within the context of FS alternatives. The sediment trap sampling program was not designed to support estimation of chemical mass loading within or throughout the system.

Sediment traps were established in 16 locations in the lower Willamette River for Round 3 suspended sediment collection. To investigate the settling sediment load, pairs of sediment traps were deployed and maintained on both sides of the river approximately at RM 2, RM 6, just upstream of RM 11, and approximately at RM 16. Individual sediment traps were deployed and maintained at seven other locations throughout the study area and at one location in Multnomah Channel. The number and locations of sediment traps and the frequency of recovery and redeployment were designed to capture anticipated spatial and temporal variability of suspended sediment mass and to investigate the potential accumulation of suspended sediment chemical constituents in suspected depositional areas. The target and actual station locations are shown in Map 2.1-24.

The traps were deployed between October 30, 2006 and November 2, 2006, and were recovered quarterly for approximately 1 year. During the quarterly recovery, the accumulated sediments were collected for analysis in accordance with the FSP (Anchor 2006b), the Round 2 QAPP (Integral and Windward 2004) and Round 2 QAPP Addendum for Surface Water Sampling (Integral 2004e). The HSP (Integral 2004d) prepared and approved for the Round 2 sampling program was used as guidance for all aspects of Round 3 sediment trap sampling.

Samples were analyzed for conventional parameters (grain size, total solids, TOC, and specific gravity), metals, SVOCs, VOCs, total petroleum hydrocarbons (TPH), pesticides, PCB Aroclors, polychlorinated dibenzo-p-dioxin/furans (PCDD/Fs), and PCB congeners.

During the third quarter sampling, there was insufficient volume collected for the full analysis of five samples (ST3005, ST3006, ST3009, ST3011, and ST3013). Also, during the fourth quarter sampling, the volume of sediment collected from three locations (ST003, ST006, and ST009) was insufficient to conduct analysis of all COIs. Therefore, an analyte prioritization list for these samples was generated. This new prioritization scheme was approved by USEPA. The data analysis and prioritization scheme is discussed further in the data report (Anchor and Integral 2008a)

2.1.4.1.10 Upstream/Downstream Surface and Subsurface Sediment Samples

Surface and subsurface sediment samples were collected during Round 3A from January 30 to February 8, 2007, in two separate locations within the lower Willamette River: upstream reach from RM 9.5 to 12, and downstream reach from RM 0.9 to 1.9 (Maps 2.1-15 and 2.1-17). Samples were collected from 30 locations within these two reaches. A total of 30 surface sediment samples and 24 subsurface cores were collected from 30 stations during the Round 3A sediment sampling field event conducted from January 30 to February 8, 2007. Including field replicates and homogenate split samples, a total of 136 sediment samples were submitted for chemical and/or physical analyses, and 111 samples were submitted for radioisotope analyses.

The primary objectives of the upstream and downstream sampling program were as follows:

- Estimate contaminant loading to the study area from upstream during both typical hydrologic conditions and high-flow events
- Develop estimates of naturally occurring background concentrations and anthropogenic concentrations (consistent with USEPA policy) in surface water and sediment in the lower Willamette River upstream of the study area
- Assess the extent of potential downstream contamination from the study area in the lower Willamette River below RM 2 and in the upstream portion of Multnomah Channel.

The Round 3A upstream sediment program consisted of surface (0–30 cm) and subsurface sediment sampling and analysis in the reach from approximately RM 9.5 to 12. One set of cores was collected in known long-term depositional areas and analyzed for both radioisotope and contaminant chemistry to support the characterization of contaminant loading to the upper study area from upstream over time. Another set of cores was collected at two areas USEPA identified as potential upstream sources of contamination and processed for contaminant chemistry only.

The Round 3A downstream program consisted of surface (0–30 cm) and subsurface sediment sampling and analyses in the Willamette River from approximately RM 0.9 to 1.9 and a precision multibeam bathymetric survey in the Multnomah Channel from the Willamette River to the Sauvie Island Bridge.

The Round 3A upstream and downstream sediment samples were processed using protocols established in Round 2A and 2B. Except where noted, all Round 3A surface and subsurface sediment field activities, including vessel positioning, sample collection, sample handling and processing, and data management, followed guidelines specified in the Round 3A FSP for Upstream and Downstream Sediment Sampling (Integral 2006q), the Round 2 QAPP (Integral and Windward 2004), and the Round 2 HSP (Integral 2004d).

Round 3A sediment samples were analyzed according to methods described in the Round 2 QAPP (Integral and Windward 2004), with modifications described in the Portland Harbor RI/FS Round 2 QAPP Corrective Action Plan: SVOC Analysis of Sediment Core Samples (Integral 2004g), and Portland Harbor RI/FS Round 2A SCSR (Integral 2005s). Laboratory deviations were reported in the Round 3A Upstream & Downstream Sediment Data Report (Integral 2007g).

2.1.4.1.11 Natural Attenuation (Radioisotope Subsurface Sediment Cores)

During the January 30 to February 8, 2007 upstream and downstream sediment sampling event, subsurface sediment was collected for radioisotope analyses at three locations (RC01, RC02, and RC483) in the upper study area. The radioisotope chemistry core locations are shown in Map 2.1-19. Core logs for the radioisotope cores are provided in Appendix C of the Upstream and Downstream Data Report (Integral 2007g). A total of 111 samples (35 samples from core RC01, 38 samples from core RC02, and 38 samples from core RC483) were submitted for 7Be, 226Ra, 137Cs, and 210Pb radioisotope analyses.

The radioisotope cores were subsectioned into 2-cm intervals throughout the entire depth of each core, with a subset of these segments submitted for radioisotope analysis per the Round 3A FSP (Integral 2006q). Deviations from the analytical methods specified in the FSP, project QAPP, and laboratory QAPP (Appendix E; Integral 2006n) for radioisotope analysis are summarized in Section 3.4 of the data report (Integral 2007d).

2.1.4.1.12 Sediment Chemical Mobility Testing

Sediment chemical mobility testing activities were conducted from August 18 through September 5, 2008. Sediment cores were collected at 55 locations from August 18 to August 29, 2008, within RM 2 to 11 (Maps 2.1-17b-o). Surface water was collected from September 2 to September 5, 2008, within 11 initial areas of potential concern (AOPCs).

The sediment chemical mobility testing sediment and surface water field sampling activities were intended to support the FS by evaluating the chemical mobility of contaminated sediment that may potentially be remediated. Sediment chemical mobility testing sampling efforts included sediment, surface water, elutriate, and leachate chemistry focused within RM 2 to 11 of the lower Willamette River. The sampling effort included collection of sediments that will be subjected to three types of

elutriate or leachate production protocols: modified elutriate test, sequential batch leachate test, and toxicity characteristic leaching procedure tests. The modified elutriate and sequential batch leachate tests are described in the Corps Upland Testing Manual (USACE 2003) and the toxicity characteristic leaching procedure is described in federal regulations (40 CFR §261.24). These three test protocols are intended to provide information for the FS about leachate or elutriate production and chemical concentrations during various stages of sediment removal and disposal. The sequential batch leachate test can also be used to understand potential chemical mobility for some capping scenarios. To support these tests, analysis of subsurface bulk sediment chemistry and surface water chemistry were conducted to understand the chemical levels present in the materials used in the tests.

Sample collection and processing procedures followed guidelines specified in the Sediment Chemical Mobility Testing FSP (Anchor 2008b), the Round 2 FSP (Integral, Anchor, and Windward 2004), the Round 2A Surface Water FSP (Integral 2004b), the Round 2 QAPP (Integral and Windward 2004), QAPP Addendum 10 (Integral and Windward 2007b), the Sediment Chemical Mobility Testing QAPP Addendum 11 (Integral 2008g), and the project HSPs (Integral 2004d, 2007q). Deviations from the FSP and QAPP are discussed in the FSR and data report (Anchor and Integral 2008d; Integral 2009).

2.1.4.1.13 Side-scan Sonar

The side-scan sonar survey was conducted in accordance with the Round 3B Side-scan Sonar FSP (Anchor 2008c). The survey was timed to occur during the spring freshet, when the water level in the river is highest, to maximize bank-to-bank side-scan sonar coverage. The survey was performed from May 30 through June 4, 2008. The side-scan sonar survey area extended from RM 1, at approximately the small slough that enters the Willamette River immediately downstream from the Columbia Grain Terminal, to RM 12.2, at approximately 1,100 ft upstream of the Steel Bridge. The survey area included an approximately 2,500-ft-long segment of the Multnomah Channel and full coverage of the ship basins at the Schnitzer Terminal and Portland Shipyard. The survey did not include Slips 1 and 3 of Terminal 4 at the Port of Portland.

The first objective for the side-scan sonar survey was to determine the approximate distribution of pilings, dolphins, submerged structures and debris in the river channel and along both banks of the river to support decision-making processes related to the FS. An initial round of sonar data processing identified 1,369 targets. The side-scan sonar survey identified a total of 7,445 discrete targets in the approximately 12.2 miles of the lower Willamette River surveyed. The vast majority of targets identified are pilings and dolphins associated with docks and pier faces. Other targets include logs, miscellaneous debris, and surficial features including depressions, gravel, and anchor drag scours. It is likely that additional features and targets are present in the river below layers of silt or sand that would not be identified by the side-scan sonar survey.

Approximately two-thirds of the targets identified were clearly man-made objects (piers, pilings, dolphins, and structures) emplaced in the river for navigational, operational, or engineering purposes. Approximately 25 percent of the remaining material was classified as either debris, debris-NMH (no measurable height), or unclassified (debris). Debris was commonly found along the margins of dock structures and approximately a boat width away from them, a pattern that is consistent with vessel activity patterns.

The second objective of the side-scan sonar survey was to produce a mosaic of the side-scan sonar imagery to map the occurrence of surface sediment types (i.e., sands, fines, etc.) as they occur throughout the survey area. The interpreted sonar images are presented in the Side-scan Sonar data report (Anchor QEA 2009a). The interpretations were based on sonar backscatter intensity and sediment morphology. Interpretation of the side-scan sonar data by the survey analyst suggests that the bulk of the river is medium-grained sand. Areas of increased sonar backscatter were interpreted as coarse-grained sand. Areas of reduced sonar backscatter were interpreted as fine-grained sand and silt. Sand waves are noted in the channel center in the upper reaches of the survey area and are most notable in areas that have not been extensively dredged. It was not the intent of this survey to compare sediment morphology on the sonar image to any previously collected sediment grain size data.

2.1.5 Other Investigation Summaries

Nearly 700 documents have been compiled into the Portland Harbor RI/FS project library. These documents include analytical data, ecological studies, facility investigations, regional studies, and other non-specific documents about the Portland Harbor area. Specific historical and recent studies and data sets were selected for inclusion in this RI report, based on their representativeness of current site conditions. Information obtained from these other sources includes the following:

- Regional setting information from geologic maps, government and scientific literature regarding structural geology and hydrogeology, information on regional datums and meteorology, and historical and recent bathymetric studies conducted by NOAA
- Regional development and current human use area information from aerial photographs, zoning and fire insurance maps, City of Portland Bureau of Planning documents, and the City of Portland Willamette River Atlas
- Extensive information on lower Willamette River upland site characteristics and contaminant pathways that guided RI sampling programs and supported CSM development—including historical development and land uses, industrial operations, and COIs—provided by Oregon DEQ's Environmental Cleanup Site Information (ECSI) database, individual upland site investigation reports, and government publications

- Extensive information on non-municipal and municipal outfalls and upland drainage systems that contributed to the CSM, provided by the City of Portland, Oregon DEQ's Joint Source Control Investigations, the Columbia Regional Association of Governments (CRAG) studies, and individual upland site reports
- Dredging and capping histories from individual site reports and USACE permits
- Site habitat information and riverbank type designations supporting the BHHRA and BERA, provided by ODFW documents, the City of Portland Natural Resources Inventory Update (City of Portland 2008a), and the scientific literature
- Site fish and wildlife resident populations, behavior, and consumption information that support the BHHRA and BERA (e.g., Agency for Toxic Substances and Disease Registry [ATSDR] documents; Columbia River Inter-Tribal Fish Commission [CRITFC] documents; Oregon Department of Health Services [ODHS] et al. 2003)
- Upland discharge information supporting fate and transport loading estimates, provided by government planning documents, Oregon DEQ, and National Pollutant Discharge Elimination System (NPDES) discharge permit information
- Willamette River stage and flow data from the USGS Morrison Bridge station (#14211720) used to support fieldwork planning and calculate CSM loading estimates
- Chemical use and toxicity information to support the BHHRA, BERA, and CSM from government documents (e.g., ATSDR toxicological profiles, etc.) and the scientific literature (e.g., Batt 2004; Friberg et al. 1986)
- Studies on contaminant hazards posed to fish and wildlife (e.g., Eisler 1986, 1987, 1988, 1993, 1998)
- Contaminant fate and transport process information provided by other site investigations (e.g., Steuer 1995) and the scientific literature (e.g., Erickson 1997).

The above list and examples given are not meant to be inclusive of all the information sources utilized in this RI. A complete list of these investigations is summarized in Table 2.0-2 and presented in Maps 2.1-15 and 2.1-17. Appendix A1 provides additional information on the data collected by other parties.

2.2 DATA QUALITY ASSESSMENT

The data quality assessment process is a comparison of the implemented sampling approach and resulting analytical data against the sampling and data quality requirements specified by the data quality objectives. Results of the data quality assessment are used to determine whether data are of adequate quality and quantity to support the decision-making process. The data quality assessment performed for this study includes evaluation of the quality of the analytical data generated for each of the

field sampling efforts and evaluation of the adequacy of the data set in meeting the intended data uses.

2.2.1 Data Quality Objectives

The data quality objectives process is a strategic planning approach based on the scientific method to prepare for a data collection activity (USEPA 2000a). It provides a systematic procedure for defining the criteria that a data collection design should satisfy. This includes when to collect samples, where to collect samples, the tolerable level of decision error for the study, and how many samples to collect, balancing risk and cost in an acceptable manner.

A significant amount of historical information, both quantitative and qualitative, exists for the study area. The data quality objectives process was used early in the RI/FS process to identify specific data needs relative to the design of RI/FS field investigations and development of potential remedies. Data needs that ensued from the data quality objectives process formed the basis of the RI/FS sampling program. Table 2.2-1 presents an overview of data collection activities needed to fill data gaps for the preliminary remedial action objectives and RI/FS site characterization objectives. These data gaps were used to develop the FSPs for the Portland Harbor study area. Since data collection is an iterative process, additional data gaps were identified throughout the data collection process and used to develop additional FSPs.

2.2.2 Laboratory Data Quality/Data Validation

To provide a high level of quality for the analytical data collected during this study, samples were submitted to commercial laboratories for analysis in accordance with USEPA-approved QAPPs.

USEPA has not established definitive guidelines specifying the level of data validation required for Superfund investigations. However, USEPA Order 5360.1 and Office of Solid Waste and Emergency Response (OSWER) Directive 9355.9-01 (USEPA 1993a) requires that environmental measurements be of known quality, verifiable, and defensible. The Office of the Inspector General concluded in an audit of Region 9 Superfund sites (USEPA 1995) that data used for cleanup decision-making should be validated using USEPA functional guidelines (USEPA 1999, 2002a). According to these guidelines, two different levels of data validation are generally recognized for chemistry data. A summary data validation, referred to as QA1, represents a lower level of effort compared with a full validation, referred to as QA2. The elements of summary and full data validations for environmental chemistry data are presented in Table 2.3-1 (USEPA 1999, 2002a).

All RI data were validated by Integral Consulting Inc.'s (Integral) senior chemists and spot checked by a USEPA Quality Assurance Specialist. Following data validation, the data set was further reviewed for proper application of data qualifiers. Data identified during validation as being unacceptable for project uses were not carried forward in the RI.

Data of acceptable quality may still be associated with uncertainty in the RI. For example, a chemical not detected in a sample may actually be present, but its concentration below the reporting limit is unknown. This uncertainty applies to all cases in which chemicals are reported as not detected; the magnitude of this uncertainty increases with increasing reporting limits. None of the sampling events evaluated for inclusion in the RI were excluded in their entirety because of elevated reporting limits. The uncertainties associated with data quality and that are relevant to conclusions of the risk assessments are discussed in both the BHHRA (Appendix F) and the BERA (Appendix G).

Methods for performing data quality reviews for data generated by the LWG are described in the project-specific QAPP. In addition, a detailed review of the quality of each non-LWG chemical and biological data set was performed prior to entering those data sets into the project database. Methods for reviewing non-LWG data are described in the Programmatic Work Plan (Section 4 and Appendix F; see Integral, Windward, Kennedy/Jenks, Anchor, and GSI 2004).

Two overall data quality categories were established in the Programmatic Work Plan, as follows:

- **Category 1.** Category 1 data are of known quality and are considered acceptable for use in decision making for the Site. There is sufficient information on these data sets to confidently verify that the data, along with associated data qualifiers, accurately represent chemical concentrations present at the time of sampling.
- **Category 2.** Category 2 data are of generally unknown or suspect quality. The quality assurance and quality control (QA/QC) information shows that data quality is poor or suspect, or essential QA/QC data (e.g., surrogate recoveries, matrix spike/matrix spike duplicates) are either incomplete or lacking.

Sample counts of Category 1 and Category 2 data are summarized in Table 2.3-2. Project decisions will be based on analyses using Category 1 data. Category 1 data that have had a USEPA-approved level of data validation are designated as “Category 1 QA2” data sets. All data generated by the LWG hold the Category 1 QA2 designation. Some data generated by other parties are also designated Category 1 QA2. Non-LWG Category 1 data that received an abbreviated level of review are termed “Category 1 QA1.” Only Category 1, QA2 data are used in the BHHRA, the BERA, and the determination of background chemical concentrations (Section 7). Both Category 1, QA1 and QA2 data are used to describe the in-river distribution of contamination (Section 5) and to evaluate contaminant loading, fate, and transport (Section 6). Category 2 data were generally used for project scoping. For example, Category 2 tissue data were used to help identify COIs, and Category 2 sediment data were used in the initial assessment of trends in contaminant concentrations, which was useful for developing sampling programs. No Category 2 data for environmental media other than sediment are included in the RI data set provided in Appendix A3.

2.2.2.1 Chemical Data Review Criteria

Chemical data quality was assessed by evaluating the following factors:

- Traceability
- Comparability
- Sample integrity
- Potential measurement bias
- Accuracy
- Precision.

All of these factors were known or supported by existing QA/QC information (analytical methods, chain-of-custody, sample holding time, method blanks, matrix spike/matrix spike duplicates, laboratory control samples, replicates, surrogates) for Category 1 data. If supporting documentation for each factor was not available or was not reinforced by the availability of other high-quality QA/QC information, data were assigned a Category 2 designation. If the acceptance criteria for any of the above factors were not satisfied for either the entire data set or a specific analyte group, data for that data set or group were generally qualified and were determined to have limited usefulness. The chemical data were reviewed by analyte group (e.g., metals, SVOCs). As a result, a data set may contain all Category 1 data, all Category 2 data, or both Category 1 and Category 2.

2.2.2.2 Biological Data Review Criteria

Bioassay data quality was evaluated based on validation guidelines and performance criteria from the Puget Sound Estuary Program (PTI 1989). Bioassay validation guidelines include checks of completeness, holding conditions, standard reporting methods, and QA/QC results for negative control, reference sediment, positive control (reference toxicant), and measured water quality parameters according to standard testing methods and established performance criteria.

2.2.2.3 Sediment Stability and Temporal Integrity

The RI data set only includes data that were collected after the winter of 1996/1997 and that meet the other usability criteria described above; the earliest data included in the database were collected in May 1997. The assumption is that while near-surface changes in chemical concentrations due to sediment scour or accretion certainly have occurred in places, no natural large-scale erosion events or re-exposure of buried deep sediments has occurred since that time.

2.2.3 Data Usability

The data usability evaluation is a comparison of the implemented sampling approach and resulting analytical data against the sampling and data quality requirements specified in each field sampling and analysis plan. The purpose of each data collection

effort is to investigate impacted areas or areas potentially impacted to determine if observed contaminant concentrations are greater than applicable screening levels. If concentrations are less than screening levels, the area is considered not impacted. The purpose of the RI study is to evaluate available information and determine which areas, or media (e.g., soil, sediment, groundwater, surface water), are impacted by contaminant releases. For areas or media that are considered impacted, the information is carried through and evaluated further in the risk assessments and FS.

The sampling plans were designed to provide data to decide if areas are impacted within the study area. Since data can only estimate what the true condition of an area is, decisions that are based on measurement data could be in error. The data collected for this study were conducted judgmentally; therefore, the degree of certainty associated with these data sets cannot be evaluated.

The following sections describe the composition of the data sets for each RI data type. Additional information on the data set selection criteria for each data type in the RI, BHHRA, and BERA is provided in Appendix A3.

2.2.3.1 Sediment

Sediment chemistry data in the RI data set include LWG data collected from Rounds 1, 2, and 3 and data collected by other parties. The data documents are referenced in Tables 2.0-1 and 2.0-2. Only Category 1 QA2 surface sediment data that were not subsequently dredged or capped were used in the BHHRA and BERA.

The LWG data set is composed of samples collected from shorebird foraging beaches and human use beaches (surface transect composites), riverbed sediment samples (surface and subsurface), samples from biota sampling locations (collocated surface sediment), sediment toxicity samples (surface sediment), samples from TZW sampling locations (collocated surface sediment), and physical sediment characteristic samples (surface and subsurface). Data collected by other parties consist primarily of surface and subsurface riverbed samples. The majority of LWG surface and subsurface riverbed sediment samples were collected during Rounds 2 and 3 (some collocated surface sediment was collected in Round 1 from benthic invertebrate stations in the study area). Surface and subsurface sediment data were collected from the study area (RM 1.9–11.8), Multnomah Channel, downstream (RM 0–1.9), downtown Portland (RM 11.8–15.3), and upriver (RM 15.3–28.4). Surface and subsurface sediment sampling locations for all three LWG rounds, as well as studies conducted by other parties, are shown in Maps 2.1-15 and 2.1-17, respectively. LWG samples are identified by task/survey IDs “LWG01” (Round 1, surface samples only), “LWG02” (Round 2, surface and subsurface samples), and LWG03 (Round 3, surface and subsurface samples). Non-LWG sample survey IDs are cross-referenced to investigation summaries presented in Table 2.0-2 and Appendix A1. Numbers of samples and analyses performed on each sample are summarized in Table 2.3-3.

2.2.3.2 In-river Sediment Traps

The RI data set includes in-river sediment trap data collected by the LWG during Round 3. Data collected by the Port of Portland at Terminal 4 were excluded from the RI data set. Sediment trap data were not used in the BHHRA or BERA.

The LWG traps were deployed and maintained for 1 year at 12 locations within the study area, one location just downstream of the study area at RM 1.8, two upstream locations near RM 16, and at one location in Multnomah Channel (Map 2.1-24). The number of sediment traps and the frequency of recovery and redeployment were designed to capture anticipated spatial and temporal variability of suspended sediment mass and to investigate the potential contributions of chemicals via waterborne sediment for various regions of the study area. The LWG sediment trap sampling program was not designed to support estimation of chemical mass loading within or throughout the system. Table 2.3-4 lists the sample counts and analyses performed on each sample.

2.2.3.3 Bank Sediment and Soil

The RI data set includes bank (also referred to as the riparian zone; see USEPA 2005a) sediment and soil data largely collected by other parties as part of bank and upland investigations. Figure 2.2-1 depicts the shoreline boundary graphically. As discussed in Appendix A3, surface sediment/soil data of any quality collected below the mean high water line between +13 ft NAVD88 and +20ft NAVD88 are included in the RI data set. Bank sediment and soil data were not used in the BHHRA or BERA.

2.2.3.4 Surface Water

The RI data set includes data collected by both the LWG and other parties (Tables 2.0-1 and 2.0-2). The characterization of surface water in the following sections of the RI report includes the LWG-collected data, TSS data collected by the City of Portland, and TSS and TOC data collected by NW Natural at the Gasco site. In addition, naphthalene data from samples collected off the Siltronic Corporation facility are included in the RI data set. All other surface water data collected by other parties were excluded from the presentation of surface water data. Only LWG data were included in the BHHRA and BERA.

Surface water chemistry and conventional data in the RI data set include samples collected during three surface water sampling events that took place during Round 2A and four events during Round 3A. Sampling stations included both river-wide transects and single-point sampling stations at specific locations. River-wide transect sampling was designed to estimate integrated water concentration through a cross section of the river, or fraction of a cross section, at a point in time. Single-point samples were stationary samples or sample pairs located adjacent to amphibian habitats to support the BERA, in generally quiescent areas adjacent to beaches that are used by swimmers to support the BHHRA, and near known or suspected sources.

Round 2A data were collected at three transect stations (RM 4, 6.3, and 11) and at 20 single-point stations. Round 3A surface water samples were collected at six transect stations (RM 2, 2.9 [Multnomah Channel], 4, 6.3, 11, and 16) and 12 single-point stations. Offshore of Gasco (RM 6), single-point surface water samples were collected from 20 locations from three depths: near surface, mid-depth, and near-bottom for each of three tidal periods for a total of 180 samples. Near-bottom water samples were also collected at three locations at slack points in the tidal cycle, for a total of 12 samples (Anchor 2006c). At Siltronic, surface water was collected from 17 near-bottom locations collocated with groundwater sampling locations. Five surface water samples were also collected upstream and downstream of the site (MFA 2005a). Map 2.1-18 shows the surface water sampling locations, and Table 2.3-5 lists the sample counts and analyses performed on each sample.

2.2.3.5 Stormwater

The RI data set includes data and stormwater grab, sediment trap, and catch basin solids sample data collected by the LWG and other parties (Tables 2.0-1 and 2.0-2). Only the data collected by the LWG were used to generate estimated stormwater loads to the study area for the purposes of fate and transport modeling and recontamination analysis (see Section 6). Other stormwater data were provided by Oregon DEQ in early 2008 for sites collecting data under the JSCS program; these data are presented in Section 4.4, but were not used to develop stormwater loading calculations. Although stormwater permit data collected under the NPDES program was reviewed, no stormwater discharge permit data are included in the RI data set because chemical monitoring requirements for these permits are typically limited to a few chemicals that are hazardous substances. Of the non-LWG data, Category 1 data collected since June 1, 2004, are presented in Section 4 of the RI report for reference purposes only, but are not used in estimating stormwater loads. Stormwater data were not used in the BHHRA or BERA. Sampling locations for both the LWG and non-LWG data are shown on Map 2.1-23, and sample counts and analyses performed on each sample are summarized in Table 2.3-6.

2.2.3.6 Groundwater, Seeps, and Transition Zone Water

The transition zone is defined as the interval where both groundwater and surface water comprise some percentage of the water occupying pore space in the sediments (USEPA 2008a). The RI data set includes all TZW chemistry data collected by the LWG during Round 2, as well as groundwater, seep, and TZW data collected by other parties. TZW data were evaluated in the BHHRA and BERA. TZW data were collected by the LWG at nine sites located within the study area (Maps 2.1-20a-c), selected in agreement with USEPA as sites with a confirmed or reasonable likelihood for discharge of upland groundwater COIs to Portland Harbor. Additional stratigraphic characterization of a riverbed area offshore of the Gunderson site (RM 9) was conducted during Round 3, but it was determined that sampling of TZW at this site would not be necessary because the stratigraphic data did not provide physical evidence of a potentially complete flow pathway.

Seeps are defined as locations where water discharges from the ground either above or below the river surface (GSI 2003a). Seep data collected from Outfall 22B were also evaluated in the BHHRA.

Additional upland and baseline groundwater data collected by other parties were not included in the Portland Harbor RI data set, but were evaluated in Section 4 and are described in detail in Appendix C2.

Table 2.3-7 lists the numbers of samples and analyses performed on each sample.

2.2.3.7 Biota

The RI data set includes LWG-collected biota tissue data and adult Chinook salmon, adult lamprey, and adult sturgeon fish tissue data from the ODHS/USEPA/ ATSDR Fish Contaminant Study (ODHS et al. 2003). Biota tissue types included in the BHHRA or BERA are provided in Appendix F and Appendix G, respectively. No other data collected and evaluated by other parties were of acceptable quality for the BHHRA evaluation.

Fish and invertebrate tissue chemistry data were collected from the study area by the LWG and other parties to estimate exposure concentrations (as tissue residues or diet) for appropriate species or groups of ecological receptors (i.e., benthic invertebrates and fish). Biota tissue data were also collected upriver of the study area. Sampling locations for field-collected biota during all three sampling rounds are shown on Maps 2.1-5 through 2.1-11. Sampling locations specific to small-home-range species of fish and invertebrates are shown on Maps 2.1-5 and 2.1-6; large home-range fish species are shown on Maps 2.1-7 through 2.1-11. Table 2.3-8 summarizes the biota samples and analyses. Tables 2.3-9a-b list the LWG and non-LWG sample counts, respectively, and analyses performed on each sample. Table 2.3-10 provides the number of fish and invertebrates in each sample composite.

2.2.3.8 Bioassay

In Rounds 2 and 3, 293 surface sediment samples from the study area and upriver were submitted to a bioassay testing laboratory for toxicity testing. Two whole-sediment toxicity testing protocols were employed; the 10-day *Chironomus tentans* and the 28-day *Hyalella azteca* sediment toxicity tests measuring survival and growth. Bioassay reference stations were also collected upriver of the study area. Sediment bioassay sampling locations are shown on Map 2.1-5. These bioassay data are included in the BERA data set only (Appendix G).

Bioassays were also performed using commercially supplied clams (*Corbicula fluminea*) and laboratory-cultured worms (*Lumbriculus variegatus*) exposed to surface sediments collected at the same locations where field clams and worms were collected within the study area (Map 2.1-21). Results of the LWG's laboratory bioaccumulation bioassays were also included in the RI data set.

2.2.3.9 Invertebrates

Invertebrate tissue in the RI data set includes LWG field-collected tissue samples for crayfish (*Pacifasticus leniusculus*), clam (*Corbicula fluminea*), mussels (tentatively identified as *Margaritifera falcata* and *Anodonta nuttalliana*), and epibenthic invertebrates and zooplankton collected with multiplate samplers. Invertebrate sampling locations for these small-home-range species are shown on Map 2.1-5. For clams, mussels, and crayfish, the map locations are shown as centroids of the specific sampling areas for each species (i.e., crayfish sampled in an area of 100-ft shoreline contour by 100-ft extension into the river channel, and clams and mussels sampled in variable benthic sledge tow areas). Table 2.3-8 provides the total number and type of invertebrate tissue data and the analyses performed on each sample. Invertebrate samples were analyzed for the same suite of chemicals as fish. Collocated surface sediment samples were also collected at clam and crayfish tissue sampling locations (or as close as possible) and analyzed for a similar suite of chemicals (Map 2.1-5).

2.2.3.10 Fish

The following fish species were selected as ecological receptors for the various feeding guilds in the lower Willamette River:

- **Omnivorous and herbivorous fish**—Largescale sucker (*Catostomus macrocheilus*), carp (*Cyprinus carpio carpio*), and pre-breeding white sturgeon (*Acipenser transmontanus*)
- **Invertivorous fish**—Sculpin (*Cottus asper*, *C. perplexus*, and C. spp.), peamouth (*Mylocheilus caurinus*), and juvenile Chinook salmon (*Oncorhynchus tshawytscha*)
- **Piscivorous fish**—Smallmouth bass (*Micropterus dolomieui*) and northern pikeminnow (*Ptychocheilus oregonensis*)
- **Detritivorous fish**—Larval stages of (ammocoetes and macropthalmia) Pacific lamprey (*Lampetra* sp.).

Fish tissue data collected by the LWG are included in the RI, BHHRA, and BERA data sets. In addition, data for adult Chinook salmon, adult sturgeon, and adult lamprey collected by other parties were included in the RI and BHHRA data sets. Table 2.3-10 provides the number of fish and invertebrates in each sample composite.

Fish species composites were based on individual fish collected over various reaches of the river. Sculpin were composited from areas similar to where crayfish were collected. The map locations are shown as centroids of the sampled area of 100-ft shoreline contour by 100-ft extension into the river channel (Map 2.1-5). Largescale sucker, peamouth, and northern pikeminnow were composited over 1-mile stretches (Map 2.1-6); smallmouth bass were composited over 1-mile reaches for Round 1 and composited from either side of the river over 1-mile reaches for Round 3 (Maps 2.1-7a-d); and black crappie, brown bullhead, and carp were composited over 3-mile reaches (Maps 2.1-8 and 2.1-9a-c).

Juvenile sturgeon samples were not composited. Map 2.1-10 shows sturgeon and juvenile Chinook salmon samples collected within discrete set line areas (for sturgeon) or beach seine areas (for juvenile Chinook). Three juvenile sturgeon were collected and individually analyzed for each of five reaches that ranged from 1 to 2 miles long. The 15 points on Map 2.1-10 show the individual locations of all sturgeon collected (three at each reach).

Pacific lamprey ammocoetes and micropthalmia were collected wherever suitable habitat was encountered (Map 2.1-11). For lamprey ammocoetes and macropthalmia samples, composites were made up of samples collected at several different areas within the study area and the map locations are shown as each successful sampling site of the sampling areas for each composite. Three ammocoetes collected during Round 1 were not analyzed. Note that collected lamprey ammocoetes and micropthalmia specimens were not positively identified to species because as larvae they are difficult to distinguish from other lampreys.

Whole-body and fillet tissue types were composited separately for carp, black crappie, smallmouth bass, and brown bullhead. During Round 1, fillets were collected from different fish than were used for whole-body samples, including black crappie, brown bullhead, carp, and smallmouth bass. During Round 3B, however, fillet and whole body data were obtained using the same fish. Fillets were removed from Round 3B carp and smallmouth bass, and fillets and bodies without fillets (i.e., remaining bodies) were composited and analyzed separately. Methods for calculating whole-body concentration for smallmouth bass and carp are provided in Appendix A4.

Stomach contents were also examined, and prey species were enumerated for juvenile Chinook salmon and juvenile sturgeon; stomach contents were analyzed for the same select chemicals relative to fish dietary risks. Collocated surface sediment samples were also collected at sculpin tissue sampling locations (or as close as possible) and analyzed for a similar suite of chemicals (Map 2.1-5).

2.3 REMOVAL ACTIONS COMPLETED

As part of the Superfund process, USEPA determines if “early action” cleanup (also called “removal action”) is warranted for parts of the site that may be a threat to humans or the environment before the long-term cleanup for the site is completed. For Portland Harbor, these early action areas presently include Port of Portland Terminal 4, NW Natural, and BP/ARCO. Early action objectives for these sites include reducing ecological and human health risks associated with sediment contamination to acceptable levels and limiting the possibility of recontamination of sediments within the project area.

Other properties are either in early stages of planning for sediment cleanup or cleanup efforts are focused on upland areas. Planning continues for a non-time-critical removal action (NTCRA) to address contaminated sediments at Arkema, a former pesticide manufacturing facility at RM 7.3W. Upland source control, cleanup, and

redevelopment have occurred at the Triangle Park site (RM 7.4E) under a bona fide prospective purchaser agreement with USEPA. Planning is also underway for a NTCRA to remove potentially erodible contaminated soils at the U.S. Moorings site (RM 6.2W), which has been used to berth and maintain USACE dredges and vessels.

2.3.1 Port of Portland Terminal 4, Phase 1

Terminal 4, owned and operated by the Port of Portland at RM 4.3E, was designated as an early action area based on the presence of pesticides, PCBs, metals, and PAHs above acceptable levels in sediment offshore of the site. The Port of Portland is conducting a NTCRA under a separate AOC for Removal Action, executed by the Port of Portland and USEPA in October 2003.

The NTCRA will be conducted in two phases. Phase I was completed in 2009 and consisted of dredging and offsite disposal of contaminated sediment adjacent to Berth 411 and Pier 5 in Slip 3 and north of Berth 414, dredging and offsite disposal of contaminated sediment adjacent to Berth 410 within Slip 3, construction of a nearshore cap at the head of Slip 3, and stabilization and capping of the Wheeler Bay shoreline. Phase II is pending and will consist of dredging, capping, and monitored natural recovery in areas not completely addressed by Phase I, and constructing a confined disposal facility in Slip 1.

2.3.2 NW Natural Phase 1

An early action cleanup was completed by NW Natural for the areas offshore of the Gasco/Siltronic facility (RM 6.5W) in 2005. Gasco is a former manufactured gas plant that deposited wastes containing PAHs, benzene, cyanide, and other hazardous substances into upland tar ponds. These ponds overflowed into the Willamette River on occasion, forming an erodible tar deposit that was visible at low river stages. Considered by USEPA to be a hot spot of contamination in the river, the goal of the early action was to reduce risk from known areas of uncontrolled contamination. Approximately 15,000 cubic yards of contaminated tar was dredged from the river and disposed of at an approved hazardous waste landfill. The area was then capped with organoclay materials.

2.3.3 BP/ARCO

An early action removal was performed with oversight by DEQ at the BP/ARCO facility (RM 4.9W) in 2008, in conjunction with improvements to the facility's seawall. The primary contaminants found at the site were diesel fuel and gasoline in groundwater, which was migrating into the Willamette River. The early actions included 1) installation of an enhanced hydraulic control system in 2005 to more effectively contain petroleum hydrocarbons, 2) installation of a new sheet pile wall in 2007 to stabilize the facility and prevent groundwater migration of contaminants to the river, and 3) the removal in 2008 of a concrete revetment riverward of the new sheet pile wall, along with 13,293 cubic yards of underlying and nearshore contaminated

sediment. The sediment was disposed of at an approved hazardous waste facility and clean fill was placed in the excavated area.

3.0 ENVIRONMENTAL SETTING

This section describes the current and historical physical characteristics and human uses of the Portland Harbor Superfund Site (Site). Physical characteristics of the Site include meteorology, regional geology and hydrogeology, surface water hydrology, the physical system (which includes bathymetry, sediment characteristics, and hydrodynamics and sediment transport), habitat, and surface features. Human characteristics of the Site that are discussed here include historical and current land and river use, the municipal sewer system, and human access and use. In addition to providing context to the RI sampling and analysis, the factors presented in this section are considered in the refinement of the study area-wide CSM, which is presented in Section 10.

Section 3.1 focuses primarily on the physical setting within the study area (RM 1.9 to 11.8). However, the physical features of the Willamette River from Willamette Falls (RM 26) to the Columbia River (RM 0), as well as the upstream portion of Multnomah Channel, are discussed as needed to place the study area's physical characteristics into a regional context.

The Willamette River basin has a drainage area of 11,500 square miles and is bordered by foothills and mountains of the Cascade and Coast ranges up to 10,000 ft high to the south, east, and west (Trimble 1963). The main channel of the Willamette forms in the southern portion of the valley near Eugene, at the convergence of the Middle and Coast forks. It flows through the broad and fertile Willamette Valley region and at Oregon City flows over the Willamette Falls and passes through Portland before joining the Columbia River (Map 3.1-1).

The Willamette flows predominantly from the south to the north and has a total length of about 309 miles. It is the 19th largest river in the contiguous United States in terms of discharge. The portion of the river from Willamette Falls to the Columbia River is considered the lower Willamette River (see Map 1.0-1). Multnomah Channel is a distributary channel of the lower Willamette River that begins at RM 3.1 and flows northwest approximately 21 miles to its confluence with the Columbia River.

The upstream reaches of the Willamette River above Willamette Falls constitute a meandering and, in some cases, braided river channel. Upstream flooding is largely controlled by 13 major tributary reservoirs (Uhrich and Wentz 1999). In the lower Willamette River, especially in the vicinity of Portland Harbor, the channel banks have been stabilized in several areas by the placement of riprap, and construction of seawalls, bulkheads, etc. These measures have created a much more stable channel in the lower Willamette River.

The portion of the river where the federal navigation channel is maintained at –40 ft CRD (see Section 3.1.4.1) defines Portland Harbor and extends upstream from the Columbia River (RM 0) to the Broadway Bridge (RM 11.7; Map 1.0-1). From 1973

through 2007, average annual mean flow in the Willamette River was approximately 33,800 cfs at the Morrison Bridge (near RM 12.8) in Portland.[1]

3.1 PHYSICAL ENVIRONMENT

3.1.1 Meteorology

Located about 65 miles inland from the Pacific Ocean, the city of Portland and Portland Harbor are situated near the confluence of the Willamette and Columbia rivers. This area lies approximately 20 ft above sea level and is about midway between the Coast Range to the west and the Cascades Range to the east. The climate of Portland is usually described as temperate or oceanic, with mild, damp winters and relatively dry, warm summers. The Coast Range provides limited protection from Pacific Ocean storms while the steep slope of the Cascades Range impedes moisture-laden westerly winds, resulting in moderate rainfall in the area, especially during the winter months (NOAA 2010).

Precipitation falls primarily as rain, with nearly 90 percent occurring between mid-October and mid-May. Rainfall varies across the metropolitan area, with the West Hills (located to the west of the study area) receiving nearly 60 inches of rain per year while the Portland International Airport (located to the east of the study area) only receives about 36 inches. Forest Park, which is located in the West Hills, drains to the study area. Measurable snow accumulations are rarely more than 2 inches, occurring most frequently at elevations over 500 ft (including the West Hills) or along Portland's eastern boundary near the Columbia River Gorge at Troutdale (NOAA 2010). The city has experienced some major snow and ice storms caused by cold air outflow from the gorge. A storm in 1893 resulted in approximately 60 inches of snow accumulation (NOAA 2010).

Winds are from the north and west during the late spring and summer dry season and from the east and south during the fall and winter rainy season. Annual monthly wind speeds average 8.0 mph at the Portland airport (NOAA 2011). Average temperatures range from a low of 45°F (7°C) in the winter months to a high of the middle 90s (~35°C) in the late summer (NOAA 2000). The lowest temperature ever recorded in Portland was −3°F (−19°C), which occurred on February 2, 1950. The highest temperature ever recorded was 107°F (42°C), on July 30, 1965 and again on August 8 and 10, 1981 (NOAA 2011).

3.1.2 Geology

3.1.2.1 Geologic Setting

The study area is located along the southwestern edge of a large geologic structure known as the Portland Basin. The Portland Basin is a bowl-like structure that is 40 miles long and 20 miles wide and bounded by folded and faulted uplands. These

[1] Data obtained from the USGS Water Resources web site (http://waterdata.usgs.gov/or/nwis/sw).

northwest-trending structural zones are interpreted as dextral wrench faults that delineate the Portland pull-apart basin (Beeson et al. 1985; Yelen and Patton 1991). The Tualatin Mountains (Portland West Hills) form a ridge that runs parallel to the Willamette River to the west, from the Multnomah Channel to the City of Portland. The mountains define the western edge of the Portland Basin; groundwater and creeks and channels along the east face of the mountains flow downward to the Willamette River.

The basin has been filled with up to 1,400 ft of alluvial and glacio-fluvial flood deposits since the middle Miocene (approximately 12 million years ago). These sediments overlie older (Eocene and Miocene) rocks including the Columbia River Basalt Group (CRBG), Waverly Heights basalt, and older marine sediments. The older rocks are exposed where uplifting has occurred (e.g., RM 7 west side in the Doane Lake area) on the margins of the basin, including adjacent to the study area.

Because the study area is located at the edge of the basin, both the older rocks and overlying sediments are present near the surface and play a significant role in defining interactions between groundwater and the river. The geologic units found in the vicinity of the study area are illustrated in Figure 3.1-1 and briefly described below, from youngest to oldest (Beeson et al. 1991; Swanson et al. 1993):

3.1.2.1.1 Recent Anthropomorphic Fill

Anthropomorphic fill blankets much of the lowland area next to the river and is predominantly dredged river sediment, including fine sand and silty sand. Hydraulic dredge fill was used to fill portions of the flood plain, such as Doane Lake, Guild's Lake, Kittridge Lake, Mocks Bottom, Rivergate, and a number of sloughs and low-lying areas. The fill also was used to connect Swan Island to the east shore of the Willamette River and to elevate or extend the bank along significant lengths of both sides of the riverfront by filling behind artificial and natural silt and clay flood levee dike structures. Rocks, gravel, sand, and silt also were used to fill low-lying upland and bank areas. The thickness of this unit ranges from 0 to 20 or more feet. The permeability of this unit, where composed of clean dredge fill sand, is higher than the natural fine-grained alluvium. The presence of silt fill or a silty matrix in the sand fill generally reduces the permeability of the unit significantly.

3.1.2.1.2 Fine-grained Pleistocene Flood Deposits and Recent Alluvium (Undifferentiated)

This unit includes fine-grained facies of the Pleistocene Flood Deposits, as well as recent alluvium deposited by the present Willamette River. This unit generally consists of silt, clay, silty sand, and fine-to-medium sand that borders and underlies the present floodplain of the river (Beeson et al. 1991). The lower portions of this unit and where it forms the large bluffs bordering the east side of the river likely consist of the fine-grained facies of the flood deposits, whereas the upper portions near the river are likely more recent alluvium. The upper fine-grained portion of the unit has likely been reworked and deposited by the present Willamette River. The sands of this unit may be

indistinguishable from overlying dredge fill in some places (Landau 2002a). The thickness of this unit ranges from 20 to over 100 ft. The permeability of the clay, silt, and silty sand of this unit is generally relatively low, whereas the portions of the unit consisting of clean sands may have a relatively higher permeability. This unit forms part of the Unconsolidated Sedimentary Aquifer regional hydrostratigraphic unit proposed by Swanson et al. (1993).

3.1.2.1.3 Coarse-grained Pleistocene Flood Deposits (Gravels)

This unit includes fluvial deposits from the Pleistocene Missoula floods. The deposits fill deep channels that were incised into the Troutdale Formation and CRBG during the floods. The unit consists of uncemented sand, gravel, and cobbles with boulders in places. This unit is generally between 10 and 200 ft thick in the vicinity of the study area and underlies fine-grained flood deposits and recent alluvium under much of the study area. The Willamette River subsequently incised the flood deposits in places. The rise in sea level from the end of the Pleistocene to the present resulted in the filling of the incised channel by finer-grained flood and recent alluvial facies to form the current floodplain channel of the river.

3.1.2.1.4 Upper Troutdale Formation

The upper Troutdale Formation in the vicinity of the lower Willamette River includes cemented and uncemented alluvial sand, gravel, and cobbles deposited by the ancestral Willamette and Columbia rivers. The Troutdale Formation comprises the Troutdale Gravel Aquifer hydrostratigraphic unit. This unit is present in some places on the west side of the study area to thicknesses of 100 ft and is present along the entire length of the east side of the study area at thicknesses of up to 200 ft (Swanson et al. 1993).

3.1.2.1.5 Lower Troutdale Formation/Sandy River Mudstone

The Sandy River Mudstone (SRM) is a fine-grained equivalent of the lower Troutdale Formation (channel facies) that overlies the CRBG in the center of the basin and at the margins of the basin away from the axis of the Columbia River. The lower Troutdale Formation/SRM is present in places under the lower Willamette River (Swanson et al. 1993) and borders the Portland Hills, but is not considered a significant hydrogeologic unit within the study area. The lower Troutdale Formation/SRM consists mostly of silt and clay with lenses of sand and gravel and tends toward fine-grained (low permeability) textures at the basin margins (Swanson et al. 1993).

3.1.2.1.6 Columbia River Basalt Group

The CRBG consists of a thick sequence of Miocene basalt flows dating from between 17 and 6 million years ago (mya), but the CRBG flows that underlie much of the Portland Basin entered the area between 16.5 mya and 12 mya. Basalt flows of the CRBG were folded and faulted during the uplift of the Tualatin Mountains, concurrent with eruption and emplacement of younger flows present in the Portland Basin (Beeson et al. 1991). The CRBG is present at the surface or at relatively shallow depths along the west side of the study area and may be in direct contact with the river in places. The top of the unit drops off below ground surface (bgs) over a relatively short distance and

is 400 or more feet bgs on the east side of the study area. The thickness of the CRBG in the vicinity of the study area is estimated to be approximately 600 ft (Beeson et al. 1991).

3.1.2.2 Tectonic Setting

Portland Harbor's tectonic setting is an important element of the regional geology. The regional sources of seismicity affecting the Portland Metropolitan area are associated with three separate fault mechanisms. These include "mega-thrust" subduction earthquakes (moment magnitude [Mw] 8 to 9) and relatively deeper, Benioff-zone, intraplate events (Mw 6.5 to 7.3) both associated with the Cascadia Subduction Zone (CSZ), as well as the relatively shallow crustal zone earthquakes (Mw 5.0 to 7.0). Geotechnical analyses for seismic hazards associated with liquefaction and earthquake-induced slope deformation require that the specific earthquake sources be recognized so that effects of ground motion attenuation, duration, and frequency content of these hazards can be assessed. Descriptions of these potential earthquake sources are presented as follows.

3.1.2.2.1 Cascadia Subduction Zone

The CSZ extends from Northern California to British Columbia and the seismogenic portion of the CSZ is largely located offshore at the latitude of Portland. Within this zone, the oceanic Juan De Fuca Plate is being subducted beneath the continental North American Plate to the east. The interface between the two plates is dipping to the east, and, therefore, becomes deeper toward Portland. At the easternmost portion of the interface zone that is thought to be capable of generating strong ground motions, the interface between these two plates is located at a depth of approximately 20 to 25 km. Quantifying the seismicity and hazard posed by the CSZ is subject to several uncertainties, including the size of the maximum credible earthquake as described by the moment magnitude of the event, the rate of seismicity associated with the CSZ, and the nature of the ground motions associated with CSZ earthquakes. Geologic evidence of previous CSZ earthquakes has been observed within coastal marshes along the Oregon coast and in offshore landslide deposits (turbidites). These paleoseismic data have been used to infer the size of prehistoric earthquakes as well as their rate of recurrence. These geologic investigations indicate that large (Mw > 8) subduction zone earthquakes along Cascadia occur at intervals on the order of 300 to 500 years, well within the period of interest for this project. The most recent mega-thrust earthquake is estimated to have occurred approximately 300 years ago.

Based on the most current Probabilistic Seismic Hazard Analyses performed by the USGS National Seismic Hazard Mapping Program (Petersen et al. 2011), the closest distance from the Site to the portion of the CSZ that is thought to be capable of generating significant ground motions is approximately 95 to 100 km. This fault location is consistent with that specified by agencies such as the Oregon Department of Transportation (ODOT), USACE, and U.S. Bureau of Reclamation, and accepted by regulatory agencies such as the Federal Energy Regulatory Commission.

3.1.2.2.2 Benioff Zone

The Benioff zone encompasses the portion of the subducting Juan De Fuca Plate located at a depth of approximately 30 to 50 km below western Oregon. Very low levels of seismicity have been observed within the intraplate zone in Oregon. However, much higher levels of seismicity within this zone have been recorded in Washington and California. Several reasons for this seismic quiescence were suggested by Geomatrix (1995) and these include changes in the direction of subduction between Oregon and British Columbia as well as the effects of volcanic activity along the Cascade Range. Historical activity associated with the intraplate zone includes the 1949 Olympia Mw 7.1, 1965 Puget Sound Mw 6.5, and 2001 Nisqually Mw 6.8 earthquakes. The regional Probabilistic Seismic Hazard Analysis prepared for the USGS (Petersen et al. 2011) indicates that the Benioff zone earthquakes significantly contribute to the seismic hazard at the return period associated with the contingency level event (i.e., 475 years).

3.1.2.2.3 North American Plate

The third source of seismicity that can result in significant ground shaking within the greater Portland area is near-surface, crustal earthquakes occurring within the North American Plate. The historical seismicity of moderate-sized crustal earthquakes in western Oregon is higher than the seismicity associated with the CSZ and the intraplate zone. The 1993 Scotts Mills (Mw 5.6) and Klamath Falls (Mw 6.0) earthquakes are examples of relatively shallow (approximately 15 km) crustal earthquakes. The characterization of the local crustal earthquake sources includes known faults thought to be active in the Portland region, and consideration of possible seismicity that may occur in the region along unmapped sources. The crustal earthquakes that occur along currently unmapped faults in the region have been referred to in seismic hazard investigations as “randomly occurring” earthquakes, “aerial sources,” or “gridded seismicity.”

3.1.3 Hydrogeology

The current understanding of the generalized hydrogeology of the study area is presented in this section. The detailed hydrogeology of the upland areas on both sides of the river varies by location. This generalized discussion is intended to describe the important basic hydrogeologic units and their properties and groundwater flow within the study area and is not representative of any one particular location. An upland groundwater data review that summarizes hydrogeologic information and groundwater quality data from specific upland sites in the vicinity of the study area has been completed by the LWG (GSI 2003b).

3.1.3.1 Hydrogeologic Units

The geologic units described above can be grouped into study area-wide hydrogeologic units on the basis of having generally similar hydrogeologic characteristics. Important hydrogeologic characteristics include the position of the water table relative to each hydrogeologic unit, the physical relationship between each hydrogeologic unit and the

river, and physical characteristics of each hydrogeologic unit, such as permeability, heterogeneity, and anisotropy.

These hydrogeological units are described from uppermost to lowermost in the following sections and presented in Figure 3.1-2.

3.1.3.1.1 Fill, Fine-grained Facies of Flood Deposits, and Recent Alluvium

The fill, fine-grained facies of flood deposits, and recent alluvium (FFA) unit is composed of the fill, the combined fine-grained facies of the Pleistocene flood deposits, and the recent alluvium geologic units described by Beeson et al. (1991) and in Section 3.1.2. These geologic units were grouped together on the basis of each unit's shared textures and intrinsic heterogeneity, proximity to the river and to each other, and importance with regard to the occurrence of upland groundwater and interactions with the river.

This unit, which encompasses a broad range of soil textures and hydraulic characteristics, blankets much of the lowland area next to the river and includes much of the material abutting the river. The unit also consists of the fine sand and silty sand dredge fill overlying recent and Pleistocene silt and clay overbank sediments, which are interbedded with lenses and layers of fine to coarse sand. As discussed in Section 3.1.2.1.1, the dredge fill was placed behind low-permeability, artificial and natural flood levee dike structures in some locations. The thickness of this unit can be up to 150 ft, but it typically ranges between 30 and 100 ft.

The FFA hydrogeologic unit is the primary unit of importance in defining the interactions between upland groundwater and the river because of the following characteristics of the unit:

- The unit forms most of the river channel within the study area as well as the surrounding upland areas and, therefore, controls groundwater interactions with the river
- Most contaminated groundwater plumes present in the upland areas occur within strata of this unit.

The distribution of textures and thus groundwater flow properties of the unit vary both vertically and horizontally by location along the study area. Silt, clay, and silty sand are present adjacent to the river at a majority of locations where the unit is observed near low river stage levels. Boring logs at sites north of RM 4 on the east side of the river indicate that a greater portion of the unit north of RM 4 and at depths below low river stage levels consists of sand layers. This is generally true for most of the shallower areas within historical Portland Harbor flood plain. Comparison of hydraulic conductivity values for different textures within the FFA unit listed below illustrates the importance of the channel sand lenses and layers in focusing groundwater fluxes to the river at any particular location where present within this unit:

- Silt/clay: 0.005 to 2 ft per day (0.0000018 to 0.0007 cm/s)

- Silty sand: 0.1 to 2 ft per day (0.000035 to 0.0007 cm/s)
- Sand: 0.5 to 30 ft per day (0.00018 to 0.011 cm/s).

The typical measured hydraulic conductivities in the silt/clay facies of the FFA indicate that groundwater fluxes from these sediments within the study area are generally low. Identification of seeps present in silt/clay during the seep reconnaissance survey (GSI 2003a) is consistent with this conclusion. Conversely, groundwater fluxes from the uplands to the river within the FFA are expected to be greater in those areas where more permeable sand zones are present, such as on the east side of the river.

3.1.3.1.2 Coarse-grained Flood Deposits and Upper Troutdale Formation

The coarse-grained flood deposits and Upper Troutdale Formation (CGF) unit combines the unconsolidated coarse-facies flood deposits, including sands, gravels and cobbles, with the underlying uncemented and cemented gravels and cobbles of the upper Troutdale Formation. The flood gravels that compose the upper portion of this unit typically occupy scour channel surfaces on older units (e.g., the CRBG). Anthropomorphic fill, silt, clay, and sand of the flood deposits, and alluvium mostly cover the CGF, except in places on the highland bluffs on the east side of the river where the unit may be exposed.

The CGF unit is adjacent to and underlies much of the study area to thicknesses exceeding 200 ft. The overall thickness of the unit is more typically in the range of 100 ft. However, the unit is missing in places, including on the west side of the river towards the south end of the study area and directly under the river at RM 7. The top of the CGF unit is present at elevations of 0 ft to over –100 ft mean sea level (MSL). The unit is present at relatively shallow depths adjacent to the west side of the river in the vicinity of the Doane Lake area and may be in contact with river sediments. The hydraulic conductivity of this unit measured in the vicinity of the Doane Lake area ranges from 3 ft per day (0.0011 cm/s) to greater than 40 ft per day (0.014 cm/s) (AMEC 2001).

Because this unit has a relatively higher hydraulic conductivity than the overlying FFA unit, groundwater may flow more readily through this unit to deeper units where downward gradients are present and where the unit is present adjacent to the river, allowing deeper groundwater to more readily discharge to the river. Higher fluxes to the river within the CGF unit may increase downward gradients and thus increase groundwater and contaminant plume movement in the FFA unit. The effect of the CGF unit on groundwater flow in the FFA is a factor in the selection of characterization methods. Locations where the CGF unit may exert a stronger influence on deeper groundwater flow to the river, and thus vertical gradients in the FFA, include the Doane Lake area (RM 6–7W), the southern edge of the study area (RM 11), and on the east side of the river in the vicinity of the International Terminal (RM 4E).

3.1.3.1.3 Lower Troutdale Formation/Sandy River Mudstone

This hydrogeologic unit is present in some places under the west side of the study area and is present under the entire length of the east side of the study area. The unit is predominantly silt and clay where explored in the vicinity of the study area, and thus the permeability of the unit is low. Where present, the unit overlies the CRBG below depths of –100 to –150 ft MSL and tends to pinch out on the west side and towards the southern end of the study area where the CRBG is present at shallower depths. The unit typically is separated from the river by at least 100 to 200 ft of alluvium and deposits of the upper Troutdale Formation. Based on the hydrogeologic characteristics of this unit and the depth relative to the river, it is not considered to contribute significantly to surface water/groundwater interactions within the study area.

3.1.3.1.4 Columbia River Basalt Group

The CRBG consists of a concordant sequence of basalt lava flows. Groundwater flow in the CRBG is focused along the higher permeability interflow zones and in some areas of fracture-enhanced permeability (e.g., faults). Hydraulic conductivities measured in individual basalt interflow zones in the vicinity of the study area range from 1.5 to 10.9 ft per day (0.00053 to 0.0038 cm/s) (AMEC 2001). Hydraulic conductivities measured in CRBG basalt flow interiors at Hanford, Washington, range from 1×10^{-4} to 1×10^{-7} ft per day (3.5×10^{-8} to 2.5×10^{-13} cm/s) (Strait and Mercer 1986), illustrating that the basalt interflow zones (flow top and bottom collectively) are the primary groundwater flow pathways in the CRBG.

The CRBG is present at relatively shallow depths along portions of the west side of the study area and may be in direct contact with the river in places. The top of the unit is irregular on the west side of the study area with channels from scouring by flood events and the ancestral Willamette River. The top of the unit on the west side of the study area is between elevation 0 ft and –50 ft MSL north of RM 9, except for an ancestral channel in the vicinity of Doane Lake (Figure 3.1-1). The top of the CRBG slopes down to an elevation of –250 ft MSL or more across the river on the east side of the study area. The relief of the unit across the study area appears to be due to structural downwarping towards the center of the basin, and may be accentuated by normal faulting postulated along both sides of the study area (Beeson et al. 1991; Beeson 2003, pers. comm.). The overall significance of the CRBG with regard to groundwater/surface water interactions within the study area is not well characterized; however, the CRBG is considered to be most relevant to groundwater interactions with the river on the west side of the river downstream of about RM 9 because of its proximity to the river.

3.1.3.2 Groundwater Flow

The general groundwater flow systems of interest recognized along the study area are a shallow (shallow FFA), an intermediate (deep FFA), and a deep (CGF and CRBG) system. A deeper, regional flow system also is present, which includes the CRBG, where it is deep below the river (on the east side of the river), and lower Troutdale Formation/SRM. This deeper, regional flow system is not considered to be important in

understanding the interactions between upland groundwater and the river that are relevant to this RI. The deeper, regional flow system may be relevant to contaminated groundwater or product from upland sources that may be posing a threat to such a system.

At a local level, these divisions between flow systems are likely indistinct in places along the study area. Additionally, some investigations have identified further flow system refinements or divisions based on the local hydrogeology. However, the general flow systems described above appear to apply for the majority of the study area and provide a general model from which variations can be evaluated on a local scale. Figure 3.1-3 presents the generalized conceptual picture of groundwater flow through these flow systems. This figure supports the following discussions of groundwater flow systems.

The Willamette River is the focus of discharge for the three flow systems of interest to the RI, including where the CRBG is present near the surface on the west side of the river. The shallow flow system is the primary focus of most upland groundwater investigations, and is the focus of this RI because most of the upland groundwater affected by contaminants of interest is present within this system, and this system discharges to the shallow and nearshore areas where exposure to human and ecological receptors is most likely. The potential for impact to the deeper system is relatively low, except where there may be a large source of dense, nonaqueous-phase liquid (DNAPL) that has the potential to migrate to the FFA and/or upper portion of the basalt. Impact to sediments from the shallow and intermediate flow systems are the focus of this RI, except at locations where the CGF and CRBG appear to be impacted by chemical constituents and are connected to the river.

3.1.3.2.1 Shallow Flow System

The shallow, unconfined, groundwater flow system along the margins of the study area consists mostly of fill and alluvial silt and clay deposits and some medium- to coarse-grained channel sand of the shallow FFA that blankets the lowlands next to the river, as shown in the generalized conceptual image on Figure 3.1-3. At many locations, the shallow flow system is hosted within the lower portion of fine dredge-fill sand and underlying silty sand and silt. The shallow system is recharged by direct precipitation and infiltration, infiltration from the hills on the west side of the study area, and exchange with several surface water bodies along the study area (e.g., Doane Lake). Groundwater in this system is unconfined. Groundwater level data in the upland areas indicate that there is a downward gradient toward deeper units from the shallow system. Groundwater levels and fluxes in the shallow system are affected by seasonal river stage changes, as well as by diurnal tidal influences. The degree of tidal influence decreases with increasing distance from the river and shallower groundwater depths. Groundwater gradients within the shallow system are generally steep immediately adjacent to the river and flatten out away from the river bank. The shallow flow system discharges to the river either above the river surface as surface seeps, or below the river surface as subsurface discharge, generally in nearshore areas. Because of tidal and

seasonal river stage fluctuations, a given groundwater discharge may express above or below the river surface at different times.

The permeability of the FFA materials is variable within the shallow flow system, but generally is relatively low. The presence of low-permeability features, such as silt and clay dikes constructed to retain hydraulically emplaced dredge fill, cutoff walls, and retaining walls, may act to impede groundwater flow locally in the shallow system, resulting in higher groundwater levels and steep shallow groundwater gradients near the shore. The presence of preferential pathways (human-made and natural) in the shallow FFA can be a significant, albeit localized, influence on the discharge of groundwater to the river.

Light, nonaqueous-phase liquid spills are present only within the shallow flow system. Dissolved chemicals associated with upland releases are present in the shallow flow system. Dissolved plumes may be affected by vertical hydraulic gradients, which may cause vertical migration of the dissolved constituents. The shallow system also appears to influence the effect of DNAPL releases by retaining a portion of the released volume through spreading and retention in or along less permeable sediments. These stratigraphic controls can limit the depth of downward migration of DNAPL.

3.1.3.2.2 Intermediate Flow System

The intermediate flow system occurs within thicker sequences of the fine-grained alluvial sediments of the FFA. Groundwater in the intermediate system generally discharges to the Willamette River below the river surface to deeper portions of the river (Figure 3.1-3), with discharge focused at the locations where more permeable strata (typically sand) may intersect the river. Horizontal hydraulic gradients within the intermediate flow system tend to be flatter near the river than observed in the shallow system, and thus high river stages and tidal changes may exert a greater influence on fluxes from the intermediate system to the river by further flattening or perhaps reversing the gradient locally.

The intermediate flow system is particularly relevant for groundwater transport of chemicals to the river where DNAPL is present or where chemical densities, preferential pathways, or downward gradients could potentially allow dissolved chemical constituents to penetrate into the deeper units. The intermediate flow system is the most likely mechanism that would allow for groundwater discharge into the sediments present in the deeper portions of the Willamette River. However, most groundwater chemical plumes identified in the upland areas of the study area do not occur within the intermediate flow system.

3.1.3.2.3 Deep Flow System

The deep flow system occurs within the CGF and basalt interflow zones of the CRBG, where the CRBG is present near the surface on the west side of the river. Downstream of about RM 9 on the west side of the river, residual basalt gravels immediately overlying the CBRG have been identified as important hydrogeologic features and

potential conduits for groundwater contaminant transport. Groundwater in the deep system discharges to the Willamette River only in deeper portions of the river, with discharges focused at the locations where the gravels and/or basalt interflow zones are near or intersect the river sediments (Figure 3.1-3).

The CRBG does not play a role in the deep flow system on the east side of the river, because it occurs at substantially greater depth due to structural downwarping and associated normal faulting. The flow system becomes strongly affected by the Columbia River on the east side of the study area with increasing distance from the Willamette River. Deep groundwater flow from the base of Tualatin Hills toward the east side of the river occurs in the CGF, which is generally highly transmissive; however, gradients may be relatively low. Seasonal gradient reversals are known to occur during periods of high river stages. Where near the river, the connection, and thus response, to river stage changes is expected to be great.

The deep flow system is not anticipated to play a significant role in groundwater contaminant transport from the upland areas to the river within the study area because the majority of contaminants in groundwater are not present within this system.

3.1.3.3 Groundwater Processes

Generally, groundwater flow adjacent to the study area is toward the river. The Tualatin Mountains (Portland West Hills) form a ridge that runs parallel to the Willamette River to the west, from the Multnomah Channel to the City of Portland. The mountains define the western edge of the Portland Basin; groundwater and creeks and channels along the east face of the mountains flow downward to the Willamette River. On the east side of the river, starting upstream of RM 4, a broad terrace divides the floodplains of the Willamette and Columbia rivers. Deep groundwater flows are influenced by the Columbia on the east side of the river, with effects increasing as distance from the Willamette River increases. Groundwater gradients are relatively flat in some areas along the east side of the river, due to both underlying geology and the influence of the Columbia River.

In the absence of preferential pathways, groundwater flow to the sediments and river will be diffuse along the length of the interface of each flow system with the river. However, permeability contrasts of several orders of magnitude can be expected in the FFA where alluvial processes create lenses and channels of sand within or surrounding finer-grained materials. The result of these permeability contrasts is that groundwater discharge will tend to be heavily influenced by the location and geometry of higher and lower permeability layers (e.g., sands or silts/clays) in relation to the river.

The groundwater flow regime zones bordering the river show seasonal patterns related to seasonal river stage and precipitation variations. The gradient and the resultant flux from these groundwater flow zones vary with seasonal river stage changes. Diurnal tidal stage changes also result in temporary gradient and thus flow changes, particularly where the degree of connection between the river and adjacent aquifer is greater.

Discharge of these groundwater flow systems through the river sediments to surface water is controlled by 1) the permeability contrast between the sediments and underlying aquifer, and 2) the difference between the hydraulic head in groundwater at the aquifer/sediment interface and the river stage, which determines hydraulic gradient. Full gradient reversals between the river and the adjacent groundwater flow systems are likely localized near the bank under most conditions because of the relatively high groundwater levels within the adjacent upland areas and resultant steep hydraulic gradients along the riverbank. However, very high river stages may produce larger temporary hydraulic gradient reversals that propagate further into the adjacent groundwater flow zones.

3.1.3.4 Groundwater Flux Rates

Estimates of groundwater seepage rates from adjacent upland areas to the study area are available from several sources, as summarized below. They include direct measurements of groundwater seepage rates at selected locations within Portland Harbor, calculations of groundwater flux rates at upland sites that border the lower Willamette River, and estimates based on published regional groundwater modeling. All estimates are based on limited data and are subject to varying degrees of uncertainty. Additionally, groundwater flux rates are expected to be highly variable both spatially and temporally, due to localized and differing hydrogeologic conditions in the uplands that border the river, seasonal patterns in precipitation and groundwater recharge, and diurnal and seasonal variations in river stage.

3.1.3.4.1 Seepage Meter Flux Measurements

Direct measurements of groundwater seepage rates to the river were taken during the LWG Round 2 investigation and during the offshore investigation performed by NW Natural at RM 6.2 (Anchor et al. 2007). Locations of these measurements are discussed in Section 2.1.3.1.8 and Appendix C2 of this RI report. Measurements were taken in nearshore areas as well as farther offshore, including several locations within the navigational channel. The seepage meters were installed on the west side of the river only, offshore from 9 upland sites in a total length covering about 8,800 ft of shoreline, representing about 6 percent of the total shoreline within Portland Harbor. In all, 77 ultrasonic seepage meter measurements were taken (70 LWG measurements and 7 non-LWG measurements), primarily during the summer and early fall months when groundwater flux toward the river is presumed to be relatively high due to low river stage, although this presumption has not been verified. Groundwater investigations at NW Natural (Anchor 2008d) indicate the highest gradients toward the river occurred in late March when the river stage drops, but groundwater levels in the uplands are still high due to recent precipitation and groundwater recharge.

These seepage meter measurements offshore of the nine study sites were taken in areas where contaminated groundwater plumes were suspected to be discharging to the river. Seepage meter deployment areas offshore of these sites and summary results for each area are presented in Maps 3.1-2-1a-i. At each measurement location, seepage measurements were collected at 15-minute intervals over deployment periods lasting at

least 24 hours to capture diurnal variations in flux. The 15-minute seepage data were then time-integrated over one or more consecutive 24-hour periods to obtain estimates of daily average seepage rates. The 15-minute measured discharges ranged up to a maximum of 74 cm/day, and the lowest were about −30 cm/day. Daily average values ranged from a maximum of 14 cm/day to a minimum of −19 cm/day, with median values of about 4 cm/day in sand, and about 0.5 cm/day in sand/silt and silt (Figure 3.1-4). Measured groundwater flux rates showed substantial variability between measurement sites; in general, higher seepage rates were observed in sandy areas, and the lower values were observed in less conductive silt zones, as expected. A general decrease in measured seepage rates with increasing water depth was also evident, as illustrated in Figure 3.1-4.

The majority of measurements indicated net groundwater discharge to the river, consistent with the lower Willamette River's function as a sink for shallow groundwater discharge. Negative seepage values are interpreted to represent only very localized hydraulic interactions between the water column and channel bed, and do not indicate that surface water is significantly penetrating into upland groundwater flow zones bordering the river.

3.1.3.4.2 Upland Groundwater Flux Rate Calculations

Appendix E of this RI report and a technical memorandum (*Upland Groundwater Flux Rates: Supporting Information and Calculations*; Integral 2015) present a discussion of the approach used to estimate groundwater discharge to the study area based on hydrogeologic data compiled for the RI for upland sites bordering the river and the application of Darcy's Law. Resulting values range from 0.1 to 3.8 cm/day, with a narrower range of 0.1 to 0.3 cm/day when certain values considered to be unrepresentative of regional conditions were excluded. This narrower range of unit groundwater fluxes is used in calculations of contaminant fluxes from subsurface and surface sediments driven by groundwater advection and equilibrium partitioning between sediments and the transition zone. These calculations are described in Section 6 and Appendix E of this RI report. Section 6 also includes a discussion of the limitations and uncertainties associated with the groundwater unit flux values used in support of the advective contaminant flux estimates.

3.1.3.4.3 Modeled Groundwater Flux Estimates

A groundwater modeling study of the Portland Basin was performed by the USGS (Morgan and McFarland 1996; see Figure 14, p. 36). Over much of the study area, the reported discharge values are 1 cfs or less per model cell, with locally higher values in the range of 1 to 10 cfs per model cell. Taking the dimensions of each model cell into account (3,000 ft by 3,000 ft per side [Morgan and McFarland 1996; see p. 10]), these model estimates are equivalent to unit groundwater seepage rates of up to 0.3 cm/day into the lower Willamette River over much of the study area, with locally higher rates in the range of 0.3 to 3 cm/day.

Overall, the unit flux measurements obtained from seepage meters, particularly from sandy areas, are generally somewhat higher than the regional discharge estimates from modeling and Darcy's Law calculations. This difference may be attributable to selective placement of seepage meters in nearshore zones of likely or suspected groundwater discharge, where unit fluxes are likely to be higher than in finer-grained material and in deeper, mid-channel locations.

3.1.3.5 Groundwater/Surface Water Transition Zone

The groundwater/surface water transition zone (Transition Zone) is the interval where both groundwater and surface water comprise some percentage of the water occupying pore space in the sediments (Figure 3.1-5). The physical and biochemical properties of water within the Transition Zone reflect the effects of mixing between groundwater and surface water that occurs within the sediments. The transition zone is significant to the RI because it is the location where important chemical (both natural and anthropogenic) and biological transformation processes occur that affect the properties of chemicals that may be present in TZW and sediment, and it encompasses the sediment biologically active zone where benthic infaunal ecological receptors may reside.

The zone of mixing between groundwater and surface water that defines the size of the Transition Zone exhibits temporal and spatial variability due to changes in gradients between the surface water and groundwater. The depth and degree of mixing also varies as a function of the magnitude and duration of diurnal and seasonal river stage changes, hydraulic properties of the sediment bed and aquifer materials, and spatial intersections of the river channel with the shallow, intermediate, and deep groundwater flow systems. Although temporary reversals in nearshore groundwater hydraulic gradients and flow direction occur in response to temporal changes in river stage, the net overall flux of groundwater is into the river, driven by the riverward groundwater hydraulic gradients within the adjacent upland flow system. The higher than average river stages associated with seasonal influences may drive more surface water into the sediment bed and the adjacent groundwater flow zones than reversals caused by shorter-term diurnal stage changes, but will not likely result in a significant overall increase in the degree of mixing of surface water with groundwater. Groundwater is expected to discharge at higher rates and, therefore, may comprise a greater percentage of the TZW in the shallower nearshore areas than in the deeper water locations where the deeper flow systems discharge to the river.

3.1.4 Surface Water Hydrology

River stage and currents in the lower Willamette River and Portland Harbor are influenced by hydrologic conditions in both the Willamette and Columbia rivers, and are further affected by the operations of federal and non-federal dams along these two rivers. River stage refers to the height of the river measured relative to a specific elevation or "datum." A variety of vertical datums are used in the Portland Harbor region, and these are discussed below.

3.1.4.1 Regional Datums

Current or historical bathymetric and topographic data may be referenced to a variety of vertical datums in Portland Harbor. The bathymetric data collected as a part of this RI/FS are presented relative to NAVD88. This vertical datum is the national standard geodetic reference for heights and was selected for this project because it is a level datum and is easy to use with GPS. NAVD88 is a fixed datum derived from local MSL observations at Father Point/Rimouski, Quebec, Canada. NAVD88 replaced the National Geodetic Vertical Datum of 1929 through the Pacific Northwest Supplemental Adjustment of 1947 (NGVD29/47) as the national standard geodetic reference for heights.

NGVD29/47 is a fixed datum adopted and adjusted in 1947 as a national standard geodetic reference for heights prior to June 24, 1993, and is now considered superseded by NAVD88. NGVD29 is sometimes referred to as Sea Level Datum of 1929 or as MSL on some early issues of USGS topographic quads. NGVD29 was originally derived from observations at 26 long-term tide stations in the U.S. and Canada. Data referencing MSL as the vertical datum in the Portland Harbor are technically based on NGVD29/47.

CRD is used as the nautical chart datum for the lower Willamette River. CRD is a reference plane established by the USACE in 1912 by observing low water elevations at various points along the Columbia and Willamette rivers (USACE 1966). Consequently, CRD is not a fixed/level datum but slopes upward as one moves upstream. CRD is used upstream of RM 24 on the Columbia to the Bonneville Dam and on the Willamette River to Willamette Falls. Mariners can obtain the depth on a chart and apply tide or river-level gauge readings, relative to CRD, to compute actual water depth at the time of sailing. Low water values are used for navigation charting to provide conservative depth values in the event accurate tide data are not available to the mariner.

These three datums, NAVD88, NGVD29/47, and CRD, are the major datums used on maps and charts of Portland Harbor. The relationships or conversion factors between them are shown in Table 3.1-1 for the lower Willamette River to about RM 16 (Ross Island). In the lower Willamette, elevations reported relative to CRD are approximately 5 ft less than NAVD88 elevations (e.g., the –15 ft NAVD88 contour on LWG bathymetry maps equates to a –20 ft CRD elevation).

Water level (river stage) data measured by the Morrison Bridge gauge (RM 12.8) are recorded as the Portland River Datum (PRD) and are 1.55 ft above NGVD29/47 (USACE 1991). CRD is 1.85 ft above NGVD29/47 at the Morrison Bridge. On December 27, 2001, DEA confirmed the relationship between this gauge and CRD by running a differential leveling circuit from a nearby control monument used in the control network for the Willamette multibeam surveys. This survey confirmed that the Morrison Street staff gauge reports water levels 0.30 ft above CRD, as defined by the USACE (1991).

The river stages discussed in this section are the directly measured Morrison Bridge gauge levels and are therefore reported as PRD elevations in feet. To convert from PRD to CRD, subtract 0.3 ft from the reported river level. The datum relationships discussed for Portland Harbor above are illustrated in Figure 3.1-6.

3.1.4.2 Regional Hydrology

The Columbia River drains a large segment of the northwestern United States and parts of western Canada. The Columbia basin is so large that isolated events such as localized rainstorms may have little or no effect on river flow. In its natural state, high flows on the Columbia River are most influenced by snow melt, which takes place during the spring months. This results in high water typically occurring in late May or early June, followed by receding water levels until the rains begin in late fall.

Lowest water on the Columbia River typically occurs in October or early November, reflecting a lack of precipitation and snowmelt in the basin during the summer months. With the onset of winter rains and snow, runoff will vary during the winter months, until the spring snowmelt leads to the high water period.

The Willamette River is a major tributary of the Columbia River and flows into the river at Columbia River Mile 103. Over the water years 1973 through 2007—a 35-year period of record—the Willamette River average daily mean discharge was 33,000 cfs, while that of the Columbia River above the confluence of the Willamette was 177,000 cfs.[2]

The lowest water levels in the Willamette, as in the Columbia, typically occur between September and early November prior to the initiation of the winter rains. Unlike the Columbia River, however, Willamette River flows generally increase in response to regional storms due to the comparatively small size of the basin. Record winter floods (e.g., 1964 and 1996) occurred when periods of heavy snowfall at lower elevations were followed by warming periods and heavy rains, resulting in rapid increases in runoff.

Figure 3.1-7 shows a plot of the mean daily river stage data (reported in feet, PRD) measured by the USGS gauge #14211720 on the Morrison Bridge in Portland near RM 12.8 from October 1972 through March 2008. The seasonal water level trends described above are evident in this plot. Low water typically occurs during the regional dry season from August to November. Winter (November to March) river stage is relatively high but variable due to short-term changes in precipitation levels in the Willamette basin. Finally, a distinct and persistent period of relative high water occurs from late May through June when the Willamette River flow into the Columbia is slowed during the spring freshet by the high-water stage in the Columbia River.

[2] The average daily mean values noted are based on data from the USGS gauge #14211720 (Willamette River at Portland, OR) and from USGS gauge #14105700 (Columbia River at The Dalles, OR), which is located downstream of the confluence of the Willamette but is the closest USGS gauge for which data are available for water years 1973–2007. These data are available at: http://waterdata.usgs.gov/nwis/sw.

3.1.4.3 Willamette River Hydrology

River stage and currents in the lower Willamette River and Portland Harbor are influenced by hydrologic conditions in both the Willamette and Columbia rivers, and are further affected by the operations of federal and non-federal dams along these two rivers. River stage refers to the height of the river measured relative to a specific elevation or "datum" which is discussed in Section 3.1.4.1.

Recent investigations of the hydrodynamics of the lower Willamette River, study area, and Multnomah Channel are summarized in this section. Both empirical information (flow measurements) and HST modeling (WEST and Tetra Tech 2009) have been conducted as part of this RI to support the understanding of the physical system and hydrodynamics. The primary objective of these efforts for the RI was to gain a sufficient understanding of the physical system to support the RI site characterization, the BHHRA, the BERA, and site-wide fate and transport modeling.

3.1.4.3.1 Stages and Discharges

Lowest water in the Willamette, as in the Columbia, typically occurs between September and early November prior to the initiation of the winter rains. With the onset of the rains, flows in the Willamette will generally increase, sometimes in rapid (several days) response to regional storms. The record winter floods (e.g., 1964 and 1996) occurred when a period of heavy snowfall at lower elevations was followed by a period of warming and heavy rains. The combination of the snowmelt and rain leads to exceptionally high runoff that occurs rapidly due to the small size of the basin as compared, for example, with the Columbia River basin.

The effect of the multipurpose dams on the Columbia River and its tributaries has been to generally reduce the spring high water flows through ponding of the excess water to the extent permitted by the capacity of the reservoirs at each of the dams. Starting in late summer, this stored water is released, which increases flows above the low flows that would otherwise occur. By winter, these reservoirs have been drawn down and the reservoir capacity is used to take the peak off of winter flows and to optimize the generation of electricity.

There are 13 federal reservoirs on the Willamette River and its tributaries, having a combined storage capacity of over 1.6 million acre-feet. These reservoirs reduce the river flow during the winter snow and rain events by storing water. With each major storm, water is stored and then released at the end of the storm to smooth out the flow of the river. During persistent rainy periods and/or during exceptionally large precipitation events, the storage capacity may be exceeded, and additional flow entering the system leads to flooding, as occurred in 1964 and 1996. During these flood events, water flow in the river can be up to 50 times greater than the flow during low-water periods. Late in the winter, after the probability of a major flooding event has passed, the reservoirs are filled to capacity. These reservoirs are used for low flows and to provide storage capacity in preparation for the flood season.

Water levels and currents in the lower Willamette River can be influenced by the Columbia River in several ways. The most apparent influence occurs during spring when high flows from the Columbia River increase the hydraulic head at the confluence of the two rivers and cause the Willamette River flow to be detained (Figure 3.1-7). When this occurs, currents in the Willamette are much reduced due to the elevated river stage in the Columbia River. As the Columbia River drops, the Willamette water level will also drop and flows will increase to more typical conditions.

A less obvious influence can occur in the winter when the Willamette River is in flood. The flows on the Columbia River can be held back by its dam system, which has the effect of lowering the backwater effect of the Columbia and thus dropping the levels in Portland Harbor below their typical condition. This mechanism was used in the 1996 flood to reduce the flood levels of the lower Willamette River, including Portland Harbor.

Tidal action also compounds the hydrology and interplay of the two rivers, and affects the Willamette River upstream as far as Portland Harbor and beyond. Tides along the North American West Coast are mixed semidiurnal (two unequal high tides and two unequal low tides daily), with an average tidal range of approximately 8 ft in the Pacific Ocean. The high tide can influence Willamette River levels by up to 3 ft in Portland Harbor when the river is at a low stage. These tidal fluctuations can result in short-term flow reversals (i.e., upstream flow) in Portland Harbor during times of extremely low river stage combined with a large variation in tide levels, which can occur in late summer to early fall. This effect was measured in May 2003 as part of the bathymetry survey effort using an acoustic Doppler current meter (DEA 2003c). As river stage rises, the tidal effect is gradually dampened and disappears at river levels around 10 ft CRD.

USGS Gauge Data

Figure 3.1-7 shows a plot of the mean daily river stage data (reported in feet PRD) from October 1, 1972 through March 31, 2008 at the Morrison Bridge in Portland near RM 12.8 (USGS gauge #14211720).[3] Mean historical daily discharge (cfs) calculations from this gauge are shown in Figure 3.1-8, and Figure 3.1-9 presents the annual average discharges by water year[4] over the period of record. Flow data from October 1972 to September 1994 were computed by the USGS using an acoustic velocity meter (Lee 2002, pers. comm.). Most data after September 1994 are USGS estimates based on measurements from regional stations (Miller 2006, pers. comm.).

[3] Data obtained from Regulation and Water Quality Section Web site (http://www.nwd-wc.usace.army.mil/perl/dataquery.pl?k=id:PRTO+record://PRTO/HG//1DAY/MEAN/) and the USGS National Water Information System Web site (http://waterdata.usgs.gov/or/nwis/uv?14211720). Where USGS data are available, they replaced USACE data for compiling the graphs shown in this section. The USACE site notes that these "data have not been verified and may contain bad and/or missing data and are only provisional and subject to revision and significant change." The data are used here only to illustrate long-term relative trends in the Willamette River stage at Portland. No data are available for 1991 and 1992.

[4] A water year extends from October 1 to September 30 (e.g., October 1, 1972 to September 30, 1973 comprises the 1973 water year).

The seasonal cycle of water levels on the Willamette River is illustrated in Figure 3.1-7. Annual low water levels typically occur during the regional dry season from August to November. Winter (November to March) river stage is relatively high but variable due to short-term changes in precipitation levels in the Willamette basin. Finally, a distinct and persistent period of relatively high water levels occurs from late May through June when Willamette River flow into the Columbia is slowed by high-water stage/flow in the Columbia River during the spring freshet in the much larger Columbia River Basin, as described above.

The two highest peaks in the daily mean discharge record occurred in the winters of 1996 and 1997, when peak flows reached 420,000 cfs on February 9, 1996 and 293,000 cfs on January 2, 1997 (Figure 3.1-8). For the water years 1973 through 2007—a 35-year period of record—the mean annual daily discharge was between 20,000 and 30,000 cfs during 14 years of this period (Figure 3.1-9). Annual mean daily flows were above 30,000 cfs during 19 years, with 7 of those years above 40,000 cfs, and 3 years in excess of 50,000 cfs. Only two water years (1977 and 2001) had average daily flows between 10,000 and 20,000 cfs. Figure 3.1-10 presents the frequency (number of days per year) distribution of daily mean discharge values from the October 1, 1972 through March 31, 2008 data set. Flow on the Willamette River is most often between 10,000 and 30,000 cfs. Approximately 75 percent of the time flows are less than about 40,000 cfs, and exceed 90,000 cfs less than 10 percent of the time.

Figures 3.1-11a–h show river stage data through each of the RI sample-collection years (i.e., 2001–March 31, 2008). For comparison, the graphs also include a plot of average annual river stage values based on the entire period of record (October 1972–March 2008), and plots of the values within one and two standard deviations from the average (representing approximately 68 percent and 95 percent of the recorded values, respectively). The lower Willamette River flood stage (18.3 ft PRD [18 ft CRD]) was not reached during the RI sampling period.

The lower Willamette River discharge rates during the RI years followed a typical seasonal pattern and, as with river stage levels, were generally within the range of typical discharges on record. Figures 3.1-12a–h present plots of river discharge data through each of the RI years (2001–March 31, 2008), with plots of the average daily discharge (October 1, 1972–March 31, 2008) and values within one and two standard deviations from the average shown for comparison. Early 2001 and early 2005 were relatively low-flow winter/spring periods and early and late 2006 had relatively high flows compared with the long-term averages.

ADCP Surveys

Flows were also measured by the LWG at multiple locations in the lower Willamette River using an ADCP during three of the four time-series bathymetric surveys which were conducted to measure riverbed elevation changes over time (see Section 3.1.6.2). The ADCP data provided snapshot observations of flows in the study area across a range of flow and tidal conditions (DEA 2002b, 2003c, 2004b). The empirical flow

data also supported the development and calibration of a hydrodynamic model developed for this RI/FS (WEST and Integral 2005). The model output shows that currents generally flow downstream during four of the six flow-tide combinations. Reverse or upstream flows occur when river flow is low and the tide is in flood.

In general, flow in many of the relatively shallow nearshore embayments and slips is characterized by eddies and/or inshore flow, except on ebbing tides during low-flow periods, when downstream or offshore flow directions are dominant. As expected, higher current speeds occur in the deeper portions of the river channel, and lower speeds occur in the shallow nearshore areas, regardless of flow direction. Flow in Multnomah Channel is downstream under all flow/tide combinations modeled.

During high flows on the Willamette and comparable flows on the Columbia (Figures 3.1-13a–h), flow is consistently downstream on the lower Willamette River, and the model predicts that there is an apparent eddy effect (reduced circular flows) where the Willamette River flows into the Columbia River.

The flow data collected during the ADCP surveys in April 2002, May 2003, and January 2004 suggested that lower Willamette River discharge through Multnomah Channel could be significant, ranging from 25 to 50 percent of the discharge volume of the Willamette during the "snap-shot" ADCP measurement periods. The percentage of Willamette River flow through Multnomah Channel is a function of the relative flow regimes in the Willamette and Columbia rivers, as well as tidal stage.

Multnomah Channel Flows

To investigate Multnomah Channel flows on a more continuous temporal basis, the CE-QUAL-W2 hydrodynamic model of the Columbia River/Willamette River System developed by Portland State University was used to model daily average flows in the system over a nearly 4-year period from January 1999 through December 2002 (Integral 2006q). Figure 3.1-14 shows the flows (daily average cubic meters per second) for the Willamette and Columbia rivers and the modeled flows for the Multnomah Channel over the 1,400+-day (approximately 4-year) model run. The figure also shows the fraction of the total Willamette River flow through Multnomah Channel (black line). "Fraction" values greater than 1 indicate that flow down Multnomah Channel exceeds the Willamette River flow upstream of Multnomah Channel (i.e., at these times, Multnomah Channel flows are a mixture of Willamette River water and inflow from the Columbia River).

The modeling effort identified three distinct river flow combinations and evaluated the proportion of discharge carried by Multnomah Channel:

- **Low flows in both the Columbia River and Willamette River**—When flows are relatively low in both the Willamette and Columbia rivers, about 50 to 60 percent of the Willamette flow goes down Multnomah Channel.

- **Low flow in the Columbia River and high flow in the Willamette River—** When relatively high flows in the Willamette River are concurrent with relatively low flows in the Columbia River, the proportion of Willamette River flow carried by Multnomah Channel decreases to about 25 to 30 percent of the total Willamette River flow.
- **High flow in the Columbia River and low flow in the Willamette River—** When Columbia River flows are high and Willamette River flows are low, the increased river stage at the Columbia/Willamette confluence forces much of the Willamette River flow down Multnomah Channel. At certain low-flow Willamette periods (summer/early fall), all of the Willamette River flow, in terms of daily average volumes, plus some flow from the Columbia River, goes down Multnomah Channel. This last condition occurs about 25 percent of the time over the period modeled (January 1999 to December 2002).

No clear periods of concurrent high flows in both the Willamette River and Multnomah Channel were identified within the nearly 4-year model simulation period. Averaged over the study period, flows in Multnomah Channel represent about 60 percent of the Willamette River flow upstream of Multnomah Channel. It should be kept in mind that some of the Multnomah Channel flow is Columbia River water, but the relative volumes of Willamette River versus Columbia River water flowing down Multnomah Channel cannot be determined from these modeling results.

3.1.4.3.2 Velocities and Currents

Velocity data for the lower Willamette River consists mainly of data collected over the years by the USGS. From July 1962 to January 1965, the USGS measured velocities at the Broadway Bridge near RM 11.7 and the Ross Island Bridge near RM 14. Stream flow conditions varied from low tidal-affected flows to near maximum flood of record during December 1964. Measured cross-sectional mean velocities ranged from a maximum of 8 ft/s downstream during the December 1964 flood to a low upstream velocity of nearly 1 ft/s during a tidal cycle on October 15-16, 1963 (Dempster and Lutz 1968).

From October 1972 to September 1994, the USGS maintained an acoustic velocity meter with water stage and velocity index recorder at the Morrison Bridge gauge near RM 12.8. During that time period, rating curves were periodically updated with velocity measurements at the gauge location over a range of flow conditions. On January 14, 2000, the USGS collected isolated transects of instantaneous velocity data using a vessel-mounted ADCP (Wood 2013 per. comm.). Transects were collected at RM 12.8, a relatively narrow stretch of the river, and near RM 4.1, a broader stretch of the river (Barrett 2002; Wood 2002). Mean velocity and discharge at RM 12.8[5] were 2.65 ft/s and 111,500 cfs respectively, and 1.41 ft/s and 118,300 cfs at RM 4.1[6].

[5] Data collection was from 13:08 hrs. to 13:42 hrs.
[6] Data collection was from 15:25 hrs. to 16:30 hrs.

Flows were measured by the LWG at multiple locations in the lower Willamette River using an ADCP during three of the four time-series bathymetric surveys which were conducted to measure riverbed elevation changes over time (see Section 3.1.6.2 for discussion on bathymetric surveys). The ADCP data provided snapshot observations of flows in the study area across a range of flow and tidal conditions (DEA 2002b, 2003c, 2004b). The first survey was conducted on April 19, 2002 along 16 transects from RM 1 to 11 during a high-water event. The second survey occurred on May 13, 2003. ADCP profiles were collected in the vicinity of the Multnomah Channel (RM 3) to understand the flows to the Multnomah Channel. On January 31, 2004, a third ADCP survey was conducted during a relatively high-flow event along the same 17 transects sampled in the previous two studies. Detailed ADCP survey and data processing methods are described in the ADCP Survey Reports (DEA 2002b, 2003c, 2004b).

April 2002 Survey

ADCP data were collected by DEA for the LWG during a high-water event on April 19, 2002 (DEA 2002b). The transects were located at RM 1, 2, 2.5, 3.1 (Multnomah Channel), 4, 4.6 (into Terminal 4 Slip 3), 5.8 (St. Johns Bridge), 6.3 (off Gasco), 6.8 (into Willamette Cove), 7.8 (off Willbridge Terminal), 8 (from Coast Guard Station, across shipyard to west bank), Swan Island Lagoon (2 short transects—one across mouth, one at upper end), 9.6, 10, and 11. The river stage at the time of the data collection was approximately 11.6 ft CRD (11.9 ft PRD) at the Morrison Street Bridge (Figure 3.1-11b; DEA 2002b).

Water velocities obtained from the ADCP survey ranged from an upstream velocity of nearly 1 ft/s (upstream flow in back eddy) to a downstream velocity of 2 ft/s. Flows across the transects were computed at approximately 70,000 cfs above Multnomah Channel and approximately 35,000 cfs below Multnomah Channel. The Willamette flow on April 19, 2002 was roughly double the average Willamette discharge rate of about 32,000 cfs. Table 3.1-2 summarizes ADCP transect time, location, and approximate total flow.

Figure 3.1-15a presents ADCP data at Transect 11 at RM 8, just downstream of Swan Island and the Portland Shipyard. These two transects were selected because they illustrate some flow regimes that are atypical of the general flow patterns seen during this survey. Both the vector plot (Figure 3.1-15a) and velocity profile (Figure 3.1-15b) reveal a sharp drop in velocity behind Swan Island and a small back eddy into Swan Island Lagoon. The velocity profile in Figure 3.1-15b also illustrates some vertical structure with increased flows in the upper water column in mid-channel.

Figure 3.1-16a presents the measured ADCP data at Transect 14 at RM 9.6 across the deep dredged hole off of Swan Island. An increase in the water column average velocities can be seen in Figure 3.1-16b. A back eddy can be observed in both the vector plot and the velocity profile. The velocity profile also shows strong near-bottom velocities in the hole with increased velocity toward the water surface.

May 2003 Survey

On May 13, 2003, multiple ADCP profiles were collected along the three transects in the lower Willamette River in the vicinity of the Multnomah Channel (RM 3), and a fourth transect was located within Multnomah Channel. ADCP profiles were repeated 5 to 6 times along each transect over a 14-hour period to capture ADCP data over a complete tidal cycle. The complete results of this effort have been documented by DEA (2003c).

Table 3.1-3 shows the discharges (Q, ft^3/s) observed along the four transects of the May 2003 survey during each ADCP pass. Positive values equal net downstream discharge in the lower Willamette River and Multnomah Channel. Note that discharge, Q, does not equate directly to flow velocities because the cross-sectional area of the river varies from place-to-place. Net discharge was downstream along all transects over the entire tidal cycle with two exceptions: during the maximum flood tide (Pass 5), net discharge was upstream at Transect 3 (downstream of Multnomah Channel) and at Transect 4 (at the Multnomah Channel head). Water velocities along the transects were relatively steady during Passes 1 to 3, the ebb tide. Velocities averaged from 0.25 to 0.5 ft/s in the lower Willamette River channel. Velocities were slightly higher (0.5 to 1.0 ft/s) in Multnomah Channel. Near low tide, Pass 4, water velocities in the lower Willamette River slowed and began to reverse direction, first along the eastern bank and propagating westward. By Pass 5, the flood tide, the water flow was completely upstream at Transect 3, and reversed direction along the eastern half of the lower Willamette River at Transect 4, and along a narrow portion of the eastern bank at Transect 5. By Pass 6, the high tide, flow velocities, both in direction and magnitude, were comparable those seen during the morning ebb tide.

January 2004 Survey

A third ADCP survey was conducted on January 31, 2004 to provide data on current velocities during a high-flow event. The results of this effort have been documented in the survey results report (DEA 2004b). Seventeen transects between RM 0 and 11 were profiled over a 9-hour period during a 130,000 cfs flood event (DEA 2004b). Selected transects near the head of Multnomah Channel (3, 4, 5, and 17) were run once in the morning on a rising tide, and again in the afternoon on a falling tide (DEA 2004b). The discharge (Q) data from these transects are included in Table 3.1-3. Measured discharges just upstream of Multnomah Channel, Transect 5, peaked at about 130,000 cfs during this high-flow event; this is 3 to 4 times greater than the peak discharges measured in May 2003. Based on the measured discharges in Multnomah Channel, approximately 25 percent of the Willamette flow was exiting the system down the channel during the high-flow event. During the lower flow period in May 2003, over 50 percent of the Willamette flow was discharging down Multnomah Channel during the ebbing tide.

Plots of the winter 2004 transect data are shown in Figures 3.1-17a–t. The data indicate that flow is predominantly downstream throughout the survey, with current speeds up to a maximum of 3.5 ft/sec observed at RM 11.0 (Transect 16; Figure 3.1-17t). Lower

maximum velocities on the order of approximately 2.5 ft/s are observed in the downstream transects, particularly downstream of Multnomah Channel (Figures 3.1-17a-d). Areas of relatively sluggish flow or eddies are apparent on the margins of certain transects that enter relatively shallow or protected areas (Transects 3, 6, 9, 10), and across the entrance to Swan Island Lagoon (Figures 3.1-17c, d, k, n, and o). River level readings from the Morrison Street gauge at RM 12.8 at the time of the survey display a tidal signal, indicating that the tidal influence on river levels was not overridden by the high-flow event (DEA 2004b).

The empirical flow data detailed above supported the development and calibration of a hydrodynamic model developed for this RI (WEST and Integral 2005). The revised Phase 2 HST model (WEST and Tetra Tech 2009) was used here to develop vector plots of current velocities throughout the study area during both mid-ebb and mid-flood tides for both high- and low-river-flow periods (Figures 3.1-18a through 3.1-21c). Vector plots were also generated that show current velocities during maximum flood tide coupled with low river flow (Figures 3.1-22a–h) for the entire lower Willamette River (to assess the maximum extent of upstream flow reversals) and during high flows in both the Willamette and Columbia rivers (Figures 3.1-13a–h). Lower Columbia and Willamette flow and stage data are included in footnotes on the vector plots.

The model output shows that currents generally flow downstream during four of the six flow-tide combinations. Reverse or upstream flows occur when river flow is low and the tide is in flood.

In general, flow in many of the relatively shallow nearshore embayments and slips is characterized by eddies and/or inshore flow, except on ebbing tides during low-flow periods, when downstream or offshore flow directions are dominant. As expected, higher current speeds occur in the deeper portions of the river channel, and lower speeds occur in the shallow nearshore areas, regardless of flow direction. Flow in Multnomah Channel is downstream under all flow/tide combinations modeled.

Based on this hydrodynamic model output, at the maximum flood tide during the low-flow period, reversed flows extend upstream to approximately RM 15, where upstream flow velocities are minimal, approximately 0.2 ft per second in the channel (Figures 3.1-22a–h), and are very low upstream of RM 15 to about RM 18.

During high flows on the Willamette and comparable flows on the Columbia (Figures 3.1-13a–h), flow is consistently downstream on the lower Willamette River, and the model predicts that there is an apparent eddy effect (reduced circular flows) where the Willamette River flows into the Columbia River.

The ADCP data were all collected during periods of high flow in the Willamette River (DEA 2002b, 2003c, 2004b). Data collection occurred during the day, typically within the 12-hour window between 6:00 a.m. and 6:00 p.m. Consequently, the ADCP data along the study reach are more variable with respect to tides than the HST model output, which encompasses the entire reach under a given tide stage. Additionally, the

ADCP results are not readily comparable to the low-flow model scenarios. That said, the following general observations between the ADCP current data and the HST model (assuming high Willamette River flow) can be made:

- The ADCP results and the HST model both indicate that under high-flow conditions, the Willamette River has an overall net downstream flow direction. Further, the May 2003 ADCP data (which were collected from repeat measures along several transects over the course of a day to capture different tide stages) agree with the model that flow direction reversals do occur in nearshore areas, regardless of tide level and can also occur in the main river channel during flood tide.
- Both the ADCP results and the HST model show higher flow velocities in the deeper, open water areas of the channel relative to nearshore, shallower areas. The model predicts main channel velocities of approximately 50 cm/s (or about 1.6 ft/s), with higher velocities occurring upstream relative to downstream. The ADCP results exhibit a similar pattern: main channel velocities typically ranged from 39 to 61 cm/s (1.3 to 2 ft/s), with the upper reaches having velocities as high as 76 to 91 cm/s (2.5 to 3 ft/s) during very high-flow events, as evidenced from the April 2004 ADCP event.

3.1.5 Soils

3.1.5.1 Regional Soils

The regional soils in the vicinity of the Site are composed of Sauvie-Rafton-Pilchuck soils (about 30 percent Sauvie soils, 10 percent Rafton soils, 10 percent Pilchuck, and 50 percent soils of minor extent and Urban land) that consist of silt loams, silty clay loams, and sands (NRCS 1983). They formed in recent alluvium. These soils are generally underlain by coarse or moderately course alluvium below a depth of 60 inches. Slopes range from nearly level to moderately steep (0 to 15 percent) soils on bottom lands, and elevation ranges from 10 to 20 ft (NRCS 1983).

The Sauvie soils have a surface layer of very dark grayish brown silt loam and a subsoil of dark grayish brown, mottled silty clay loam. The substratum is dark grayish brown, mottled silt loam over fine sandy loam to a depth of 60 inches or more (NRCS 1983).

The Rafton soils have a surface layer of dark grayish brown, mottled silt loam and a subsoil of grayish brown and brown mottled silt loam. The substratum is dark grayish brown silt loam over black silt loam to a depth of 60 inches or more. These soils are subject to frequent flooding from December to July and in places are subject to ponding in July (NRCS 1983).

The Pilchuck soils have a surface layer of very dark grayish brown sand. The substratum is dark grayish brown sand to a depth of 60 inches or more (NRCS 1983). Sandy material dredged from the river channel is in some areas of Pilchuck soils.

Of minor extent in this area are the somewhat excessively drained Burlington fine sandy loam, the poorly drained Faloma silt loam, the very poorly drained Moag silty clay loam, and the somewhat excessively drained Sifton gravelly loam soils (NRCS 1983). The Burlington is on long narrow terraces, generally above an elevation of 20 ft. The Faloma soil has a sandy substratum. The Moag soil is in convex areas. The Sifton soil is on terraces, generally above an elevation of 20 ft. Other soils found in this area include Urban land, Riverwash, and water areas (NRCS 1983).

3.1.5.2 River Sediments

Several types of investigations have been conducted as part of the RI to characterize the physical nature of bedded sediments and their potential for movement within and through the lower Willamette River due to natural or anthropogenic forces. Additionally, a numerical HST model was developed (Integral and WEST 2006; WEST 2004, 2005; WEST and Integral 2005, 2006; WEST and Tetra Tech 2009) and used to predict physical characteristics where they were not measured and the potential impact of extreme (flood) events on Site sediments, particularly the potential for buried contaminated sediments to be re-exposed.

The sections that follow provide an overview of the major physical system Site information, including sediment characteristics and a description of the major sediment transport regimes based on this body of empirical and modeling information.

3.1.5.2.1 Physical Characteristics

The physical properties of sediments yield significant information regarding the physical dynamics of the river system. Physical sediment data (e.g., grain size, specific gravity, total solids) and TOC have been collected as part of all sediment sampling for the RI and are also available from other sampling efforts conducted in the lower Willamette River (see Table 2.0-1). TOC in river sediments comes from decaying natural organic matter and from synthetic sources (e.g., detergents, pesticides, fertilizers, herbicides, industrial chemicals, and chlorinated organics) and is usually associated with fine-grained or silty sediments.

The interval from 0 to 30 cm bml was used to define surface sediments within the lower Willamette River. This surface sediment interval definition was based on the empirical bathymetric change data, which indicate that most changes to the riverbed (e.g., erosion and deposition) occur within this interval under typical conditions within the study area. Below 30 cm, LWG-collected subsurface core samples were processed such that major discontinuities in sediment texture (e.g., sand/silt) were used to define subsurface sample breaks (see Integral, Anchor, and Windward 2004).

The grain-size data measured in surface sediment samples in the RI database were used to generate contour maps of surface sediment grain size (as percent fines[7]; i.e., coarse

[7] Fines are defined as sediments less than 63 microns in diameter that would pass through a through a No. 230 U.S. Standard sieve mesh. Based on the Wentworth Size Class, this includes coarse silt, medium silt, fine silt, very fine silt, and clay. This combined silt and clay fraction is also referred to as mud on the Wentworth scale.

silt [63 µ] and finer) and TOC (percent) in the study area (Maps 3.1-3 and 3.1-4). In the absence of anthropogenic activities that affect sediment textures, the physical characteristics of surface-bedded sediment are general indicators of the energy regime of the riverbed at that location. Typically, fine-grained sediments (silts, clays) dominate in relatively low-energy environments where current velocities are low enough to allow fine particles to settle out of the water column and remain deposited, whereas coarse sediments (sands, gravels) are indicative of higher-energy environments where fines are kept in suspension in the water column and/or winnowed out of previously deposited material and transported away during transitory high-energy events (e.g., floods or anthropogenic disturbances, such as prop wash, wave action, dredging, etc.).

The sediment samples compiled for the RI from the confluence with the Columbia River to Willamette Falls at RM 26 exhibit a large variety of sediment types ranging from sandy gravels to mud (i.e., silts and clays combined). The majority of the sediments over this 26-mile reach are sands or muddy sands, with more course grained sediments found in the relatively high energy areas upstream of the study area (i.e., RM 11 to 26). The general characteristics of the upriver and downtown reaches compared with the study area are summarized below. These descriptions are based on an initial survey of surface sediment textures described in GeoSea Consulting (2001). Further details on the regional sediment transport regimes are presented in Section 3.1.5.2.6.).

Upriver Reach

In the upriver reach from RM 15.3 to 26, the river is confined in Tertiary basalt, which outcrops on much of its bottom. The Clackamas River brings some sand into the river, and there are pockets of reworked sand and some finer-grained sediments along the margins and in backwaters. Much of the bottom is hard ground in this area. Where sediment is found, it is predominately sand or gravelly sand, but there are pockets of muddy sand near banks and in some sheltered locations. Coarse sandy sediment occurs downstream of Oswego Creek, which drains Lake Oswego and may account for the accretion of sediments in this area.

Downtown Reach

A mix of sediments characterizes the downtown reach from RM 11.8 to 15.3, but they consist mostly of either sand or muddy sand. Silts and clays (mud) are found along the western margins of the lagoon inside Ross Island, where historical aggregate mining took place. Some hard ground is also found in this reach, but in more isolated and smaller areas than in the upriver reach. Between Elk Rock Island and the vicinity of the Marquam Fixed Bridge, the river generally widens and flows through Pleistocene sediments, with the result that sediments contain somewhat more mud than in the upriver reach. The sediments from inside the lagoon in Ross Island are generally much finer grained than the sediments in the adjacent channel. Fine sediment entering the lagoon likely settles inside the lagoon, although there is constant human activity taking place.

RI Study Area Reach

The river widens as it enters the RI study area reach. At the upstream end of the study rea (RM 11.8), Map 3.1-3 shows that sandy surface deposits (i.e., 0–20 percent fines [silts and clays or mud]) are predominant from upstream of the study area downstream to RM 11, especially along the western half of the river. The river gradually widens from RM 10 to 11, and this area is a mosaic of predominately sandy sediments (21–40 percent fines) and mixed muddy sand and sandy mud (41–60 percent fines) textures. Deeper holes and nearshore areas and embayments are dominated by muds (61–100 percent fines).

The river widens markedly from RM 7 to 10, and surface sediments are dominated by fines, with the exception of some nearshore bank areas and some discontinuous areas along the western edge of the navigation channel. The finest texture sediments (81–100 percent fines) are widespread from RM 7 to 9, including locations within Willbridge Terminal, in the downstream lee of Swan Island (Portland Shipyard), and in Swan Island Lagoon.

From about RM 5 to 7, the river and navigation channel narrows again, and this reach is dominated by sands with relatively small subareas (e.g., within Willamette Cove and western nearshore around RM 6) that are dominated by fines characteristic of lower energy environments. Much of the remainder of the study area and beyond, to about RM 1.5, is dominated by fines, with a texture of 61–80 percent fines dominant upstream of Multnomah Channel (RM 3–5) and 81–100 percent fines widespread downstream of Multnomah Channel (RM 1.5–3). Conversely, the relatively shallow and narrow Multnomah Channel is dominated by sands, as is a portion of the study area upstream and immediately adjacent to the Multnomah Channel entrance extending to the east bank. This is the largest area in the lower Willamette River between RM 1.5 and 5 that is not dominated by fines.

As expected, the TOC content of the surface sediments (Map 3.1-4) generally mirrors the sediment grain-size distribution, with higher TOC content collocated with the finer-grained deposits. TOC levels generally range from 0.5 to approximately 3 percent, but a few isolated areas contain higher levels (6 to up to 27 percent); these are all downstream of RM 7 and include the head of Willamette Cove, an area west of the main channel from RM 6.2 to 6.4, a mid-channel area at RM 5.7, and a relatively large area east of the channel at RM 2.

Vertical gradients in grain size can be examined visually across the study area by comparing Map 3.1-3 (contoured surface sediment texture; i.e., upper 30 cm, 1 ft) with Map 3.1-5 (contoured sediment texture for the shallow subsurface horizon; i.e., subsurface intervals ranging between 1 and 5 ft on average). Overall, the surface and shallow subsurface sediment textures are consistent throughout the study area, suggesting that the current energy regimes in the system are relatively stable. There is, however, a subtle but perceptible widespread shift from finer-grained surface sediments to a slightly coarser-grained subsurface layer (e.g., from 81–100 percent fines to 61–

80 percent fines) across much of the site. This may reflect seasonal or inter-annual winnowing of the finer sediments from the sediment bed during higher flow periods and the subsequent long-term burial of the slightly coarser residual sediments. Finally, there are three areas that show distinctly coarser surface sediments overlying finer material; these include the head of Swan Island Lagoon, the McCormick and Baxter/Willamette Cove area, and the area outside the entrance to Multnomah Channel, extending into the channel itself. Anthropogenic placement of fill at the head of Swan Island Lagoon by 1975 and the sand cap cover placed in the river and beach at the McCormick and Baxter Creosoting Company (McCormick and Baxter) site in 2005 appear to explain this pattern in Swan Island Lagoon and around McCormick and Baxter/Willamette Cove, respectively. The vertical shift to finer material at depth immediately adjacent to and within the mouth of the Multnomah Channel is not as apparent, but the "relict" muds may reflect the less dynamic sedimentary environment that existed in this portion of the river prior to the Portland Harbor navigation channel dredging and other land use modifications in the region (e.g., bank treatments).

3.1.5.2.2 Riverbed Elevation Changes

Riverbed elevations changes are presented as changes in bathymetry measured at overlapping locations for two points in time. While several bathymetric surveys were conducted throughout the RI, the January 2002 and January 2009 surveys have been selected to represent the long-term changes in bathymetry. The January 2002 survey was conducted by the LWG (Section 2.1.1.1) and the January 2009 survey was conducted by NOAA. Section 3.1.6.2 discusses all the bathymetric surveys conducted in the lower Willamette River during the RI. Map 3.1-6 was created by overlaying the 1-m cells from each survey and subtracting the January 2009 data from the January 2002 data (the depth values are generally negative numbers, e.g., –15 ft NAVD88) to generate a direction and magnitude of change for each cell. The vertical resolution of the multibeam survey overlay was ±0.25 ft (approximately 7.6 cm), so cell comparisons that show positive or negative changes less than or equal to 0.25 ft represent no discernible change in riverbed elevation. Map 3.1-6 shows the net bathymetric change over the 7-year period between the first (January 2002) survey and the January 2009 survey in the lower Willamette River. This time frame includes a winter (late 2005-2006) where there was a prolonged period of relatively high flows approach 200,000 cfs.

Map 3.1-6 presents positive elevation changes (shallower in 2009 compared to 2002) indicate shoaling, and negative elevation changes (deeper in 2009 compared to 2002) indicate deepening. The no-change areas are shaded gray, while shoaling areas (positive change) are shown in yellow to orange shades, and areas that deepened (negative change) are shown in blue shades. The 2002–2009 bathymetric change data are also presented in terms of percentage of river mile area in Table 3.1-4 and in Figures 3.1-23a-m. Key observations of major overall bathymetric changes from 2002 to 2009 are listed below:

- Nearly three-quarters of the surveyed area (69 percent) shows elevation changes of less than 1 ft (30 cm) in either positive or negative directions.
- Overall, shoaling is the dominant change observed, with 26 percent of the riverbed surveyed showing net accretion exceeding 1 ft (30 cm), whereas net erosion exceeding 1 ft is noted in only 5 percent of the riverbed overall. However, this includes dredged areas, so the percentage of the riverbed eroding over this time frame due to natural forces is somewhat less than 5 percent.
- Wide areas of deposition occur in the channel and along channel margins in the broader sections of the river (RM 1.5 to 3 [eastern margin], RM 4 to 5, and RM 7 to 10). These areas are known to be long-term sediment accumulation areas based on historical dredging records.
- Signs of in-filling are apparent in formerly dredged borrow areas (e.g., RM 5.2, RM 9 to 10, and RM 10.5 to 11.8).
- Across all eastern nearshore zones, areas of no change accounted for between 7 percent (RM 2–3) and 43 percent (RM 6–7) of each river mile. Percentages of area shoaling ranged from 5 percent (between the end of the navigation channel and RM 11.8) to 90 percent (RM 2–3). Percentages of area deepening ranged from 4 percent (RM 2–3) to 68 percent (RM 10–11).
- In the western nearshore zones, areas of no change make up between 7 percent (RM 0–1) and 54 percent (RM 1–2) of each river mile area, while shoaling areas make up less than 1 percent (RM 0–1) to 85 percent (RM 10-11) and deepening areas make up between 7 percent (RM 10–11) and 92 percent (RM 0–1) of each river mile area.
- In some places, bedforms (e.g., between RM 5 and 6, and RM 11 and 12) can be seen in the navigation channel (alternating high and low spots).
- Throughout the navigation channel, areas of no change account for 12 percent (RM 2–3 and RM 9–10) to 52 percent (RM 6–7) of the river mile segments. Shoaling percentages range from 8 percent (RM 0–1) to 83 percent (RM 2–3), and deepening percentages range from 2 percent (RM 3–4) to 60 percent (RM 0–1).
- The reaches between RM 5 and 7 and RM 10 and 11.8, where the river is relatively narrow, show areas of small-scale net erosion, as does the western off-channel area from RM 0 to 3 (outside bend of the lower Willamette River as it turns toward the Columbia).
- Many deepening areas are closely associated with berthing areas, slips, and pier structures (e.g., Terminal 4 riverfront dock, Portland Shipyard, Willbridge Terminal), likely the result of anthropogenic factors, such as prop wash from ships and dredging. Since 1997 dredging has occurred at Port of Portland Terminals 2, 4, and 5; the Willbridge Terminal; the CLD Pacific Grain Irving Elevator; the Glacier NW dock; the former Goldendale Aluminum dock; the International Terminals; the BP West Coast Products Terminal 22; the Vigor

Industrial dock; the City Fire Bureau Station 6 dock; the Portland Cement Terminal; and the Ash Grove Cement Rivergate Lime Plant.

3.1.5.2.3 Erodibility

Sediment erosion rates and critical erosion shear stress values for lower Willamette River sediments were measured directly as part of the data collection effort conducted by the LWG in the spring of 2006 (Integral 2006e). This study involved the collection of 17 cores from locations throughout the study area selected to represent a range of bottom conditions in terms of sediment texture and local hydrodynamic conditions. These data are discussed here for their empirical value as a measure of riverbed erodibility of surface sediments throughout the study area in late March 2006.

The sediment cores were subjected to various flows using a Sedflume system to produce a range of shear stresses (a force applied parallel or tangentially to a surface; from 0.1 Newtons [N]/m^2 to 10 N/m^2) to the sediment surface. Resulting critical erosion flow velocities and erosion rates were measured at approximately 5-cm intervals to depths of approximately 25 cm. Physical properties of bulk density and grain-size distributions were also analyzed at approximately 5-cm intervals. Erosion rates per shear stress applied varied depending on sediment grain size, bulk density, and sediment depth. A summary of the number of applications per shear stress value and the range of observed erosion rates (in cm/s, depth of sediment eroded per unit time) on all Sedflume cores is presented in the Table 3.1-5.

Critical erosion velocity shear stress values[8] (Sea Engineering 2006) were calculated at approximately 5-cm intervals. Median grain size (d50) values for the sediment intervals ranged from 9.7 µm (medium silt) to 401 µm (medium sand), and critical shear stresses (T_{cr}) were calculated to range from 0.06 N/m^2 to 1.28 N/m^2. These data from the Sedflume cores, summarized by core depth interval, are tabulated in Table 3.1-6.

The Phase 1 hydrodynamic model (WEST and Integral 2005) was also used to predict bed shear stresses that would occur in the lower Willamette River under typical low-flow (e.g., 40,000 cfs) and relatively infrequent high-flow (e.g., 160,000 cfs) conditions.[9] Map 3.1-7 shows modeled bed shear under these low- and high-flow conditions. Under the low-flow conditions, bed shear values are predicted to remain below 0.4 N/m^2 throughout most of the channel and below 0.1 N/m^2 in the nearshore areas. Slightly higher shear stresses (up to 0.7 N/m^2) are predicted for the channel near RM 11 and for the head of Multnomah Channel. As a first-order approximation, these data indicate that significant sediment bed movement or resuspension due to natural

[8] Critical erosion velocity shear stress is defined in the Sedflume method (SEA Engineering 2006) as the shear stress at which erosion occurs at 10^{-4} cm/s.

[9] Mean daily flows of approximately 160,000 cfs or more were recorded on 119 days (0.9 percent) over the 30-year period of record and on 14 days (0.5 percent) over the RI water years 2001 through March 31, 2008. Mean daily flows of 40,000 cfs or less were recorded on 9,374 days (74 percent) over the period of record and on 2,031 days (77 percent) over the RI water years 2001 through March 31, 2008.

hydrodynamic forces does not occur under the typical flow conditions that take place over much of the year (i.e., less than 50,000 cfs) in the lower Willamette River.

Under the relatively rare high-flow conditions, the predicted bed shear values remain low in most nearshore areas, slips, and embayments but are much higher, as well as more variable, in the channel. The predicted bed shear values in the main channel range from 0.614 N/m^2 between RM 2 and 2.3 to the maximum value of 19.7 N/m^2, which occurs in the channel at approximately RM 10.3. The highest values (>5.0 N/m^2) occur in both the nearshore and channel areas in the more constricted reaches (e.g., between RM 10 and 11, and again between RM 5 and 7; Map 3.1-7). The predicted high-flow bed shear values in the channel approach or exceed the highest critical shear stress calculated from the Sedflume study (1.28 N/m^2) throughout much of the study area, indicating that sediment transport is likely to occur throughout much of the channel during this flow condition.

3.1.5.2.4 Suspended Sediment

Suspended sediment loads are an important component to understanding sediment transport in the lower Willamette River. Sediment in motion can be classified according to its transport mechanism as either bed load (particles that are rolling, sliding, or saltating along the bed) or suspended load (particles moving in the water column) (Biedenharn et al. 2006). The hydrodynamic conditions which generate bottom shear forces that are predicted to result in the resuspension of study area bedded sediments (and so increase suspended load) based on site-specific erosion measurements are described in Section 3.1.5.2.3.

Biedenharn et al (2006) note that an alternative approach of classifying sediment in a river system is based on the source of the sediment within the catchment. In this classification scheme, typically used in regional sediment management programs, the total sediment load in a system is made up of bed-material load, which is sediment in transport that is derived from and found in appreciable quantities in the channel bed, and wash load, which is sediment in transport that is derived from sources other than the bed.

Wash load is typically produced through land erosion and can be associated with precipitation/storm events (including CSO and other lateral stormwater inputs). Wash load is composed of grain sizes finer than those found in the bed material. Wash load readily remains in suspension, and is generally washed out of the river without being deposited.

Total Suspended Solids Data Sets

TSS data have been collected by the LWG both as part of the surface water data collection effort to understand distributions and patterns of chemical concentrations, and to support the hydrodynamic model and understand the relationship between river hydrodynamics and the suspended sediment (i.e., suspended load). Surface water samples were collected by the LWG and analyzed for TSS (reported in mg/L) during

Rounds 2A and 3A. The surface water data set also contains TSS data collected by NW Natural (see Appendix A1: WLCGSG07) and the City of Portland (see Appendix A1: WLC1200Z). The NW Natural data were collected as part of an independent investigation conducted in 2007 that included the collection of surface water samples, and the City of Portland data were collected as part of a long-term surface water monitoring program conducted at multiple points along the river. The TSS data sets are described in Tables 3.1-7 and 3.1-8. Figures 3.1-24a-h and 3.1-25a-h present the discharge hydrograph, precipitation, sampling events, and TSS results from the period of October 1, 2000 through April 2008. The TSS results shown in Figures 3.1-25a-h are broken out into upriver and study area sampling locations. (The City of Portland's RM 1.1 sampling location is also plotted in the study area data series on these figures.)

Relationships between Total Suspended Solids and River Discharge

The TSS data, associated daily mean discharge values on the day of sampling, and precipitation recorded on the day of sampling and the day prior to sampling, are presented in Table 3.1-9. A scatterplot of all the TSS results and their corresponding discharge values is shown in Figure 3.1-26. The data indicate that while TSS concentrations generally increase as discharge increases, there is significant scatter in the data, especially at the lower end of the discharge range. As discussed in Section 3.1.5.2.3, significant sediment bed movement or resuspension due to natural hydrodynamic forces does not occur under flows of less than 50,000 cfs in the lower Willamette River. At lower flow rates, a variety of natural and anthropogenic factors may influence TSS concentrations, including inputs of erodible material in response to storm events occurring locally or farther up the watershed, outfall discharges, etc. (i.e., wash load), as well as anthropogenic factors, such as bedded sediment resuspension due to prop wash.

The data were examined to evaluate the possible role of precipitation on the observed variability of TSS concentrations at lower flow rates. TSS results possibly influenced by precipitation events were identified based on rainfall amounts recorded on the day the TSS samples were collected and the day prior (Table 3.1-9). TSS samples associated with rainfall totals of 0.2 inch or more summed over those two days were flagged as potentially influenced by rainfall. Plots of these data sets against discharge, separated by location into upriver and study area (plus the City of Portland's RM 1.1 station), are shown in Figures 3.1-27 and 3.1-28.

Statistical tests were performed to compare the rainfall-influenced and non-rainfall-influenced TSS data sets; these were run separately for high (>50,000 cfs) and low (<50,000 cfs) discharge values. Because the TSS data are not normally distributed, nonparametric tests were used. The Mann-Whitney test (also known as the Wilcoxon rank-sum test) was used to compare the central tendencies (medians) of the two data sets, and the Kolmogorov-Smirnov test was used to compare the shapes and locations of their distributions. These tests determine the probability that the two data sets were derived from the same population. In all cases, a 95 percent confidence interval was used to determine statistical significance.

During periods of high discharge, the Mann-Whitney test results indicate that there is no statistically significant difference between the medians of the precipitation-influenced and non-precipitation-influenced data sets (p=0.2538). Similarly, the Kolmogorov-Smirnov test suggests that the distance between the empirical cumulative distribution functions is not statistically significant (p=0.1177). Conversely, during periods of low discharge, the distinction between precipitation-influenced and non-precipitation-influenced TSS values is significant. The Mann-Whitney and Kolmogorov-Smirnov tests both result in p-values that are <0.01. As such, we can conclude that the effect of precipitation on TSS values is statistically significant only when flow rates are low. The correlation between TSS and discharge in the combined upriver and study area data sets was evaluated using Kendall's tau (τ) coefficient. This non-parametric test accounts for ties and for censored data (i.e., non-detects). Tau is a normalized representation of the number of concordant pairs (TSS concentration and discharge increase or decrease together) to discordant pairs (TSS concentration decreases as discharge increases, or vice versa). A value of 1 would indicate that TSS and discharge always move in the same direction (increasing and decreasing together), a value of −1 would imply a perfect inverse relationship (one variable always decreases when the other increases), and a value of 0 would signify no relationship between the variables. This test was run on separately on high and low discharge data sets, and iterations were produced for all data, precipitation-influenced data only, and non-precipitation-influenced data only.

Under high discharge conditions (>50,000 cfs), τ for the data set is 0.52 (p<<0.01), indicating a significant positive correlation between TSS and discharge. This correlation at high flow rates is stronger for non-precipitation-influenced data (τ=0.61) than precipitation-influenced data (τ=0.44). The TSS data associated with lower flow rates (i.e., less than 50,000 cfs) show a much weaker positive correlation (τ=0.09) than the higher flow rate data. This low discharge correlation is slightly stronger when only the non-precipitation-influenced TSS data are considered (τ=0.13), but there is no statistically significant correlation when using only the precipitation-influenced data. This indicates that TSS and discharge are much more strongly correlated during periods of high discharge than during periods of low discharge. In both cases (high and low discharge), non-precipitation-influenced TSS data are much more strongly correlated with discharge than precipitation-influenced TSS data.

Overall, these evaluations indicate that a positive correlation exists between TSS concentrations and flow rate in the lower Willamette River except for instances of low discharge paired with heavy rainfall. The relationship is significantly stronger among the data collected at flow rates above 50,000 cfs, when natural resuspension of bed sediment is expected to occur. Below 50,000 cfs, TSS concentrations are only weakly correlated with flow. Additionally, TSS data associated with precipitation events are less correlated with river flow than non-precipitation-influenced TSS data, which suggests that runoff inputs may introduce additional variability into the TSS-discharge relationship. This result is echoed by the Mann-Whitney and Kolmogorov-Smirnov test results for low discharge scenarios, which show that TSS concentrations differ when

comparing precipitation-influenced and non-precipitation-influenced data. The role of precipitation in controlling TSS was not, however, significant during periods of high discharge, suggesting that the natural resuspension of bed sediment is a more dominant factor than runoff in driving TSS values.

Suspended Particle Grain Size

In situ suspended particle sizes were measured at HMV01 through HMV05 (RM 2, 6.3, 11, and 18) in early April 2006 using a LISST as part of the physical system data collection (Integral 2006n). Particle size was measured in 0.5-m increments through the water column. The median grain-size measurements with depth at each station are plotted in Figure 3.1-29, and a summary of the grain-size ranges measured is tabulated in Table 3.1-10. As indicated by the data, particles primarily in the silt and fine-to-medium sand size ranges were in suspension when river flows were less than 30,000 cfs. The coarsest median grain sizes were found upstream of the harbor at station HMV05 (RM 18) where the river is relatively narrow.

3.1.5.2.5 Hydrodynamic and Sediment Transport

A numerical HST modeling effort was conducted as part of the Portland Harbor RI to complement the empirical observations and gain a further understanding of physical system dynamics. A primary objective of this modeling for the RI was to predict the potential impact of extreme (flood) events on Site sediment stability, particularly the potential for buried contaminated sediments to be re-exposed. Other objectives include understanding the complex hydrodynamics (i.e., the movement of surface water) of the lower Willamette River system (e.g., see Section 3.1.3)

Development of the HST model began in 2003, and the model has been through several development phases with USEPA coordination and input. The RI HST modeling work is detailed in a series of documents (Integral 2006e; Integral and WEST 2006; WEST 2004, 2005; WEST and Integral 2005, 2006), and the final revised RI Phase 2 HST modeling report has been provided under separate cover (WEST and Tetra Tech 2009). Key aspects of the model, important developmental milestones, site-specific data collected to improve model performance, and major model sediment transport outputs are summarized in the sections that follow.

The HST model uses the Environmental Fluid Dynamics Code (EFDC). EFDC is a public domain, multifunctional, surface water modeling system, which can include hydrodynamic, sediment-transport, and eutrophication components. EFDC has been used for more than 80 modeling studies of rivers, lakes, estuaries, coastal regions, and wetlands in the United States and abroad.

The EFDC model's sediment-transport component is capable of simulating the transport of multiple size classes of cohesive and non-cohesive sediment (Tetra Tech 2002). A sediment processes function library allows the model user to choose from a wide range of currently accepted parameterizations for settling, deposition, resuspension, and bedload transport. The sediment bed is represented by multiple layers and includes a

number of armoring representations for noncohesive sediment and a mixed bed material finite-strain consolidation formulation for dynamic prediction of bed-layer thickness, void ratio, and pore water advection. The sediment-transport component can operate in a morphological mode, with full coupling between the hydrodynamic components, to represent dynamic evolution of bed topography. Water column/bed exchange processes include particulate deposition and resuspension, pore water entrainment, and pore water advection and diffusion.

Phase 1 Modeling

In accordance with the Modeling Approach Technical Memorandum (WEST 2004), Phase 1 of the RI modeling, including model setup, an analysis of model sensitivity, and initial model calibration and validation runs for both hydrodynamics and sediment transport were conducted (WEST and Integral 2005) and revised (WEST 2005). The Phase 1 revisions incorporated refinements identified in USEPA's review of the initial Phase 1 results, as well as site-specific sediment data collected in Round 2 of the Portland Harbor RI/FS in the latter half of 2004. The primary objective of the Phase 1 modeling was to determine if a two-dimensional (2-D) model would be adequate for the site, in terms of addressing model objectives. Due to the relatively small tidal influence in the lower Willamette River and the general lack of a significant density structure (i.e., density gradients with depth in the water column that significantly influence circulation; WEST 2004), Phase 1 concluded that a 2-D model was adequate. The secondary Phase 1 modeling objective was to gain an understanding of the site's physical processes and the impact of various model parameters on the model predictions. Based on the model sensitivity and performance analyses, additional potential site-specific data needs were identified.

Overall, the Phase 1 model effectively simulated the hydrodynamics. However, bed elevation changes were not well captured by the model at the target accuracy levels. As a result, a number of site-specific data needs related to improving the sediment transport performance of the model were identified and collected in 2006.

In general, these data needs were associated with the behavior of cohesive sediments in the system (e.g., settling velocities and erodibility).

Phase 2 Modeling

In Phase 2, the HST model was revised and recalibrated using the site-specific modeling data collected in 2006. The revised model computation domain extends from the confluence with the Columbia River (RM 0) to the confluence with the Clackamas River (RM 24.1), and the Multnomah Channel to its confluence with the Columbia River near St. Helens, Oregon (WEST and Integral 2006). The upstream boundary of the Phase 2 HST model was shifted to approximately 2.4 miles downstream of the Willamette Falls (RM 26.6), which was the upstream boundary in the Phase 1 model (WEST and Integral 2006).

The Phase 2 model focused on identifying a combination of the reference critical shear stress for deposition, reference resuspension rate, reference critical shear stress for resuspension, and reference void ratio to minimize the differences (both statistically and graphically) between the measured and simulated bed change over the calibration period.

Compared to the revised Phase 1 results, the Phase 2 model showed some improvement in the agreement between simulated and measured bed elevations by incorporating site-specific data. The model did a better job in the deeper portions of the river than the nearshore areas. This is expected as sediment transport in nearshore areas might also be affected by other factors (e.g., local flow features near structures and prop wash) that are not explicitly represented in the model. The revised Phase 2 calibration results are detailed in the Revised Phase 2 Recalibration Results for the Hydrodynamic Sedimentation Model (WEST and Tetra Tech 2009).

HST Model – Flood Simulation

In 2009, the LWG fully modified the sediment transport portion of the HST model. The primary HST model application for the RI is to examine the potential for contaminated subsurface sediment re-exposure due to a major flood event in the lower Willamette River.

The 2009 HST model was used to predict the bed elevation changes (i.e., the areas and magnitude of erosion and deposition in the study area) that would result from five different high-flow scenarios. A range of high-flow simulations were run because bed response can be a function of the long-term hydrographic conditions that exist leading up to the flood event. Figure 3.1-30 shows the simulated hydrograph for the flood event that produced the largest overall riverbed elevation changes (note that this hydrograph includes a simulation of the 1996 flood following 5 years of high flow). Map 3.1-8a shows the net bed elevation changes, both erosion and accretion, following the simulated high-flow event. For comparison, Map 3.1-8b shows the maximum erosion levels predicted for each model cell during this simulated high-flow event; this map is a mosaic of maximum erosion per cell at any point during the simulation, and so shows the maximum extent of erosion for each cell regardless of backfilling that might occur on the falling limb of the hydrograph. The flood event maximum erosion map (Map 3.1-8b) shows that 38 percent of model cells in the study area undergo erosion at any point during the simulated flood; most of these cells (85 percent) undergo erosion of 30 cm (1 ft) or less. Overall, 6 percent of study area cells undergo maximum erosion greater than 30 cm (up to 192 cm or ~6.4 ft) and, therefore, are predicted to exceed the 30-cm project-defined surface sediment layer during the modeled flood event. This erosion of deeper, "subsurface" sediments, indicated by the three darkest shades of blue cells is localized in three regions of the study area (Map 3.1-8b):

- The navigation channel from RM 10 to 11.8, particularly upstream of RM 10.7
- The navigation channel from about RM 5.2 to 6.8 and adjacent eastern nearshore zone cells between RM 6.1 and 6.7

- An isolated cell in the eastern nearshore at RM 3.1.

These more deeply eroded areas correspond to areas that are predominantly sandy in texture, which tend to be erosional under high flow conditions.

Beyond these areas, the HST flood simulation predicts that most areas of erosion will occur within the navigation channel. Much of the navigation channel will experience erosion on the order of 15 to 30 cm. Most nearshore or off-channel (e.g., Swan Island Lagoon) areas are not predicted to erode. Similarly, several portions of the navigation channel (i.e., RM 1.7 to 3.0), most of RM 4 to 5, and the western half of the channel from RM 7.3 to 9.2, also are not predicted to be erosional.

It should be noted that anthropogenic forces (e.g., boat wakes, prop wash, etc.) and wave action that typically occur in the nearshore areas and may disturb sediments are not accounted for in the RI HST model. Thus, the predictability of the model to determine the exposure of subsurface contamination is limited in these nearshore environments where anthropogenic forces dominate.

3.1.5.2.6 Sediment Transport Regimes

In the deeper, offshore areas of the harbor (i.e., the navigation channel and adjacent areas in the main stem of the lower Willamette River deeper than about –20 ft NAVD88, see Map 3.1-9), the movement of water and sediment appears to be controlled in large part by the physical shape of the river, both the cross-sectional area and anthropogenic alterations such as borrow pits, dredged areas, and structures (e.g., bridge footings). In the off-channel, nearshore areas, especially areas less than –20 ft (NAVD88) in depth, the sediment dynamics are complicated by local riverbank morphology, seasonal changes in water levels, bank treatments, and other anthropogenic factors such as prop wash. Map 3.1-10 shows several cross-sectional channel profiles from RM 1 to 13 and illustrates the variability of the river morphology throughout the study area. The cross-sectional profiles include both the 2002 (blue) and 2009 (red) bathymetry and show where deposition and erosion have occurred. Select sediment-profile images from the 2001 SPI survey are included on Map 3.1-10 to show how river bed surface textures and sediment shear strength (as indicated by the depth of the SPI camera prism penetration; SEA 2002b) vary in accordance with the river's cross-sectional area and depositional setting. Finally, the plan view 2002 to 2009 bathymetric change data (Map 3.1-6) is included as the background layer on Map 3.1-10 to provide the reader with a comparison of variation in cross sections with bathymetric elevation changes.

Map 3.1-11 shows predicted (HST model) bottom shear forces in the lower Willamette River from RM 24 (the upstream end of the 2009 HST model domain) to the Columbia River (RM 0) under a relatively high flow regime (160,000 cfs); this was the flow condition observed in the lower Willamette River in late January 2004 when the Columbia River stage was relatively low. The combination of high flows in the Willamette River coupled with a low Columbia River stage is expected to produce the greatest bottom shear forces in the lower Willamette River. With the exception of the area from approximately RM 15 to 17, Map 3.1-11 shows that narrower upriver areas

from RM 12 to 24 experience much higher near-bottom shear forces than occur within Portland Harbor (RM 12 to the Columbia River at RM 0).

Table 3.1-11 summarizes some of the key hydrodynamic and sediment transport characteristics of the lower Willamette River by major reaches with a focus on the distinct variations observed in subsections of the study area. The hydrodynamic character and sediment transport regimes of the lower Willamette River may be broadly described in terms of the 10 reaches discussed in the following subsections.

Upriver Reaches

There are two reaches upstream of the study area that are summarized in Table 3.1-11 and described below:

Upriver (RM 26 to 15.3)

The upriver segment includes the stretch of the river from Willamette Falls to the upstream end of Ross Island (approximately RM 26 to RM 15.3). Here the river is relatively narrow and flows through suburban areas under largely natural conditions, with the exception of the control structure (USACE Locks) at the Willamette Falls (approximately RM 26). Much of the river bottom consists of exposed basalt bedrock (GeoSea Consulting 2001). Bed shear stresses through this area are generally high (averaging 5.8 N/m^2), with the highest shear stresses occurring in the bend between RM 23 and 24 (>40 N/m^2; Map 3.1-11). Sustained current speeds in this reach appear to prevent all but the coarsest material from settling in the main stem of the river. Some low to moderate shear stresses occur in the smaller bifurcated channels, embayments, and sheltered nearshore areas. The most extensive relatively low-energy area occurs at the downstream end of this reach from approximately RM 15 to 17 and includes the river channel that runs behind (east of) Ross Island; predicted shear stresses here range from 0.4 to 4 N/m^2.

Downtown Reach (RM 15.3 to 11.8)

The downtown segment of the lower Willamette River extends from the upstream end of Ross Island (RM 15.3) to the upstream end of the study area at RM 11.8. Like the upriver reach, this is also a relatively high-energy segment of the river, where the main channel of the river is narrow (average cross-sectional area estimated at 34,000 ft^2) with steep channel margins that are largely constrained by upland bulkheads along both riverbanks. The deepest areas of the channel are found on the outer edges of bends in the river below Ross Island, and in the dominant bifurcation channel west of Ross Island. Relatively high bed shear stresses (averaging 3.4 N/m^2) occur in the main portions of the channel, while lower shear stresses occur in the channel east of Ross Island and in shallower nearshore areas associated with some bends in the river (Map 3.1-11).

The high-energy environment of the main channel is evidenced by the observed bedded sediment texture, which consists primarily of gravels and sands (SEA 2002a). Localized areas of exposed bedrock occur, particularly near bridges where scouring

appears related to footing structures (GeoSea Consulting 2001). Fine-grained deposits are observed in some nearshore areas sheltered from the main flow of the river (SEA 2002b). The SPI image from RM 12.4 (Map 3.1-10) illustrates the high energy setting of this area, showing an apparently small-scale transgressive, well-sorted, fine to medium, brown sand bedform overlying and advancing over a poorly sorted gray, silty, fine sand (SEA 2002b). The 2002 to 2009 bathymetric change data (Map 3.1-6) show limited sediment accretion throughout this reach, particularly downstream of RM 14, where areas showing no change and small-scale deepening (≤1 ft) are dominant (Integral 2004a).

RI Study Area

The study area extends from RM 1.9 to 11.8 and the lower Willamette River −40 ft CRD authorized federal navigation channel nearly overlaps it, extending upstream from the Columbia River to RM 11.7 (Broadway Bridge).

Map 3.1-12 juxtaposes on a single panel the contoured surface grain-size patterns, the measured bathymetric change from 2002 to 2009, and the HST-predicted net riverbed elevation changes following a major flood event for the study area. The overlap of certain elements of these features across the study area, as well as the physical and hydrodynamic conditions observed and measured within the study area, helps support the discussions provided below.

RM 11.8 to 10

The cross-sectional area of the river begins to increase in this segment as the river broadens in a downstream direction, but the hydrodynamic energy in this segment of the study area remains relatively high (Maps 3.1-10 and 3.1-11) and comparable to the upriver reaches (e.g., see high-flow bed shear values in Table 3.1-11). This is evidenced by the high potential bed shear stresses, particularly in the eastern portion of the main channel where the channel bank is steep (Map 3.1-9), and by the observed bed sediment texture, which is dominated by sand (Map 3.1-12). The lower bed shear stresses predicted to occur by the RI HST model outside the channel, along the eastern bank at RM 11.5 at the Goldendale Aluminum facility (Map 3.1-11), is supported by the historical dredging that has been required to maintain that facility's docking berth (CH2M Hill 2001a).

The off-channel, nearshore areas of this reach are narrow, and show a nearly equal proportion of small-scale deepening, shoaling, and no-change areas (Integral 2004a). The channel through this reach has generally undergone minor net deepening over the study period (on the order of 30 cm [1 ft], or less), though small areas have deepened more substantially. Deposition on the order of several feet has occurred in the deep areas of previously dredged holes (borrow pits) on the western side of the channel (Map 3.1-11). These are the farthest-upstream areas of net deposition greater than 1 ft in the lower Willamette River surveyed bathymetrically (i.e., from the Columbia River to the upper end of Ross Island) as part of the Portland Harbor RI/FS. Sand waves are

evident migrating along the western portion of the channel between RM 11 and 11.7 (Map 3.1-6).

The 2009 HST model flood scenario predicts areas of deep (>100 cm) erosion occurring in some central portions of the navigation channel between RM 10.7 and 11.6 in this reach (Map 3.1-8b), but deposition reduces the extent of net deepening, or even dominates, in other portions of the channel, and dominates in nearly all off-channel areas (Map 3.1-8a). However, the observed changes in bathymetry (Map 3.1-6) contradict the model's predictions, showing the limited applicability of the model to accurately predict erosion and deposition in this reach of the river.

RM 10 to 9.2

The river becomes predominantly depositional as it widens significantly around RM 10. The increase in cross-sectional area reduces flow velocities, as reflected by the lower predicted bed shear stresses (Table 3.1-11) from the 2009 HST model, particularly along the broad western flank of the channel (Map 3.1-6), and the widespread sediment accumulation predicted by the 2009 HST model in this area (Map 3.1-8a). The observed changes in bathymetry (Map 3.1-6) show that there is more widespread sediment accumulation than predicted by the model, especially on the west bank of the river and extending into the navigational channel. An extensive shoaling on the order of 60 to 150 cm (~2 to 5 ft) in extent is evident along the broad western flank of the channel here.

Observed bed sediment textures reflect the cross-channel energy differences, with coarser-grained deposits dominating the eastern portion of the riverbed and finer-grained deposits occurring along the western portion (Map 3.1-3). The SPI image taken at RM 9.3 (station STA66F; Map 3.1-10) shows the riverbed to be composed of a thin silt layer overlying well-sorted medium sand, evidence that this eastern nearshore location undergoes alternating periods of sediment transport, when the fines are winnowed from the sands, followed by quiescent periods that allow deposition of the silt (SEA 2002b).

The 2009 HST model predicts erosion to depths of approximately 30 cm in the navigation channel in this reach during the flood event (Map 3.1-8b), but net results show deposition dominating in the nearshore areas and reducing or eliminating the net erosion in some parts of the channel (Map 3.1-8a). However, the observed changes in bathymetry (Map 3.1-6) show that there is more deposition in the navigational channel and less deposition in the nearshore areas, especially on the east side of the river.

RM 9.2 to 6.9

This reach is the broadest segment of the study area with a relatively wide cross-sectional area (Map 3.1-10), estimated at an average of 68,000 ft^2, and moderate to low bottom shear stresses (Table 3.1-11). The reach is dominated by fine-grained surface sediments (Map 3.1-3). The depositional nature of the majority of this reach is seen in the areas of shoaling observed in the channel between RM 7.8 and 9.2 and along

the eastern (directly downstream of Swan Island) and western channel-edge areas downstream to RM 6.9 (Map 3.1-6). Maintenance dredging has been required historically along the western shoreline of this reach (see Section 3.2.3.1.13). The large off-channel areas in this reach (e.g., Swan Island Lagoon) are characterized by very low bed shear but little or no sediment deposition (Map 3.1-12). Isolated areas of deepening observed in Swan Island Lagoon and at Willbridge Terminal are likely the result of anthropogenic factors such as prop wash and dredging. Dredging of sediments along the Willbridge Terminal piers occurred between winter 2002 and winter 2009 (Map 3.1-6).

RM 6.9 to 5

The river again narrows in this reach to an average cross-sectional area of approximately 57,000 ft^2 (Map 3.1-10). This stretch of river is a relatively high-energy sediment transport zone with high-flow bed shear rates (4.2 N/m^2) that approach the values predicted upstream of RM 10. Predicted maximum bed shear stresses (Map 3.1-11 and Table 3.1-11) indicate that more erosion and less sedimentation is likely to occur.

The high-energy nature of this segment of the river results in predominantly sandy surface sediments (Map 3.1-3). Examples of this are illustrated in the SPI photos in Map 3.1-10. The riverbed surface in the SPI snapshot from RM 6.9 (STA 47C) is composed of fine to medium, brown sand; the tan silt lenses within the sand matrix are evidence of active sediment transport (SEA 2002b). The riverbed seen in the SPI snapshot at RM 5.5 (STA 36B) is composed of poorly to moderately sorted, fine to medium sand, and also appears to be undergoing sediment transport (SEA 2002b).

The 2002 to 2009 bathymetric change (Map 3.1-6) shows that the channel in this reach is a mosaic of no change, small areas of sediment accumulation (mostly associated with channel depressions), and some small-scale scour. Localized areas of exposed bedrock have been noted, particularly on the west side of the river near the St. Johns Bridge. Sand wave migration is evident along the central portion of the channel between RM 5 and 6. Outside the channel, the narrow eastern nearshore area and the nearshore western area from RM 6.5 to 6.9 is dominated by scour, whereas the narrow western nearshore zone shows sediment accumulation between RM 5 and 6.5.

The 2009 HST modeled flood scenario predicts relatively deep (61 to 152 cm [2 to 5 ft]) erosion occurring in portions of the thalweg (i.e., the deepest area of the channel) and, to a lesser extent (less than 61 cm), in adjacent channel margin areas (Map 3.1-8b). Some of the deeper portions of the navigation channel downstream of RM 5.5 and some off-channel areas predict net deposition following the high-energy event (Map 3.1-8a). This includes the outer portions of Willamette Cove and narrow swaths along the eastern and western nearshore areas from RM 5 to 5.5 and from RM 5.8 to 6.1.

RM 5 to 3

The river widens again below RM 5 to an average cross-sectional area of 65,000 ft^2 (Map 3.1-10). The bathymetry is dominated by a deep (up to –70 ft NAVD88) dredged area in the eastern half of the channel between RM 4 and 5, which gradually shoals to the typical -40 ft depth CRD downstream of the International Terminal Slip (RM 3.6E). The time-series bathymetry indicates that the majority of the riverbed in the main channel undergoes minor net shoaling (30 cm or less) with swaths of more significant sediment accumulation along east and west channel edges and nearshore areas, especially between RM 4 and 5 (Map 3.1-6). The isolated areas of scour that are evident in some nearshore areas are likely due to anthropogenic factors; some dredging is also evident at the Port's Terminal 4 slips located between RM 4 and 5 on the eastern shore of the river. The hydrodynamic model predicts low to moderate bed shear stresses, with relatively lower bed shear in the deeper upstream portion of this river segment and along the channel margins (Map 3.1-11 and Table 3.1-11).

Surface sediments are dominated by silts (60–80 percent fines) with some exceptions. The International Terminal Slip is mostly sand with very little fines (0–40 percent fines), most likely due to anthropogenic factors (e.g., prop wash) (Map 3.1-3). The mid-channel at RM 4 and a cross-channel swath at RM 3.2 leading into Multnomah Channel are also dominated by sandy surface sediments.

The 2009 HST modeled flood scenario predicts erosion on the order of 30 cm (1 ft) in portions of the navigation channel and in the channel margin and nearshore areas downstream of RM 3.4 (Map 3.1-8b). Up to 61 cm of erosion is predicted for an isolated cell in the eastern nearshore at RM 3.1. However, deposition during the flood event is predicted to reduce or eliminate the net erosion observed in many cells in this reach (Map 3.1-8a). Model results show net deposition exceeding 30 cm in much of the channel and nearshore area from RM 4 to 5, and to a lesser extent in the RM 3 to 4 segment, including small depositional zones along the western nearshore area just upstream of Multnomah Channel and just upstream of RM 3 in the eastern nearshore zone (this is a predicted nearshore shoal that continues to RM 1.5).

RM 3 to 1.9

A significant fraction (up to 50 percent) of the downstream lower Willamette River flow moves down the Multnomah Channel; the reduced discharge volume of the lower Willamette River downstream of Multnomah Channel results in markedly reduced bottom shear bed values (Maps 3.1-7 and 3.1-11). In addition, the main stem of the lower Willamette River continues to widen in this reach as it bends to the northeast, to an average cross-sectional area of approximately 68,000 ft^2 (Map 3.1-10). Maximum bed shear values are approximately half what they were just upriver from Multnomah Channel (Table 3.1-11) and are particularly low on the inside curve of the bend (Map 3.1-11). This is the lowest energy main channel reach in the study area. This is reflected in the observed surface sediment texture, which is predominantly fine-grained, and in the shoaling observed in the channel and east of the channel throughout this reach between 2002 and 2009. The area to the west of the channel boundary in this

reach shows little net change over this time period. The 2009 HST modeled flood scenario predicts very little erosion, with deposition dominating the area virtually from bank to bank (Maps 3.1-8a,b). This is inconsistent with the time-series bathymetry (Map 3.1-6), which shows that deposition is occurring at the inside bend of the river on the eastern shore and is in dynamic equilibrium (i.e., neither deposition nor erosional) at the outside bend of the river on the western shore.

Downstream Reaches

There are two reaches downstream of the study area that are briefly described below:

Downstream Reach (RM 1.9 to 0)

The remaining river segment downstream of the study area extends to the Willamette's confluence with the Columbia River. Bed-shear stresses are low to moderate (Table 3.1-11), increasing from about RM 1.6 downstream as the river narrows and becomes more dynamic as it reaches the Columbia River (Map 3.1-11). Net shoaling (greater than 60 cm [2 ft]) was observed along the eastern channel edge and east of the channel to around RM 1.5 (Map 3.1-6). This is a continuation of the pattern seen upstream of RM 1.9; this is the furthest downstream extent of significant sediment deposition in the lower Willamette River channel. Net deepening (60 cm or less) occurred from 2002 to 2009 in a narrow strip outside the channel along the western nearshore area, particularly in the final 1 mile of this reach, possibly representing natural channel migration along the outside bend of the river.

Surface sediments transition from silts to sands at approximately RM 1.5 and remain predominantly coarse-grained to the Columbia. The 2009 HST modeled flood scenario predicts erosion to occur throughout most of this area, generally up to 30 cm, but up to 61 and 152 cm in areas downstream of RM 1 (Map 3.1-8b). Some net deposition is predicted to occur in this reach in the center of the navigation channel just upstream of RM 1 and along the eastern shoreline (Map 3.1-8a). This is consistent with the observations from the time-series bathymetry.

Multnomah Channel (Lower Willamette River to the Sauvie Island Bridge)

Multnomah Channel between the lower Willamette River and Sauvie Island Bridge (~0.5 mile downstream) sees relatively high flows and bottom shear forces. The channel is much narrower (~one-third the width) than the main stem of the lower Willamette River, and the flow moving down the channel is constrained by dikes (Map 3.1-9). Sandy sediments dominate the channel and the area immediately adjacent to it in the lower Willamette River (Map 3.1-12). Time-series bathymetric change data is not available for the Multnomah Channel since the bathymetric studies were only conducted for the main channel of the lower Willamette River. The 2009 HST modeled flood scenario includes the entrance and uppermost portions of the Multnomah Channel and indicates little or no change in the riverbed elevations in this area.

3.1.6 Surface Features

3.1.6.1 Topography

Elevation in Portland Harbor varies from 0 to 300 ft (0 to 90 m), with buttes as high as 650 ft (200 m). Portland Harbor is a geological depression bordered to the east by the Tualatin Mountains (also known as the West Hills or Southwest Hills of Portland), which are a spur of the Northern Oregon Coast Range and include a portion of the Boring Lava Field (Allen 1975), and to the west by a 120-ft-high natural bluff that runs along the northeast border of the Site (see Map 3.1-1).

The West Hills date from the late Cenozoic era and range up to over 1,000 ft (300 m). Composed mainly of basalt, the mountains were formed by several flows of the Grande Ronde basalt flows that were part of the larger Columbia River basalts. Much of the northern portion is undeveloped land within the 5,000 acres (20 km^2) of Forest Park. The landscape, inside and outside the park, is predominantly forested. The slopes of the hills, rising relatively steeply at about 1.5H:1V to 3.5H:1V, are subject to periodic landslides; most slides are small and shallow.

Most of the lowlands on either side of the Willamette River within Portland Harbor are located on a terrace with elevations that range between 30 and 50 ft above sea level, mostly composed of fill material. The lowlands extend for approximately 0.5 to 1 mile from the river before reaching the confining features of the Tualatin Mountains to the east or the 120-ft-high natural bluff that runs along the northeast border of the Site.

3.1.6.2 Bathymetry

An initial bathymetry study was conducted by DEA between December 13, 2001 and January 14, 2002, during the winter period of relatively high water. The primary goal of the survey was to develop an accurate, baseline, riverbed elevation database for this portion of the lower Willamette River. A smaller survey was also conducted by the LWG in February 2007 that focused only in Multnomah Channel.

Three additional major multibeam bathymetric surveys were conducted by the LWG in July–September 2002, May 2003, and February 2004. Another multibeam survey of the lower Willamette River was conducted by NOAA in January 2009. Comparison of these time-series bathymetry survey results with the initial survey allows areas of riverbed that shoaled or scoured to be identified. A discussion of these comparisons is provided in Section 3.1.5.2.2.

The vertical accuracy of the water depth measurements in the bathymetric surveys was specified at less than or equal to 0.5 ft (NAVD88), and the horizontal accuracy was set at less than or equal to 1 m. The data were processed using a 1-m grid size to generate a digital terrain model, and the survey results were plotted in both three-dimensional (3-D) color-graded (i.e., “hillshade”) and contour formats. The most recent survey results (NOAA 2009) are presented in Map 3.1-9.

Map 3.1-9 shows that most of the study area is from –30 to –50 ft CRD (–25 to –45 ft NAVD88) and is dominated by the authorized federal navigation channel, which runs from RM 0 (Columbia River) to RM 11.7 (Broadway Bridge) and extends nearly bank-to-bank from RM 4 to 6 and again from RM 8 to 11.7. Elevations in the federal navigation channel are generally –40 to –50 ft CRD. Except along the western channel edge from RM 8 to 10 where extensive shoaling has occurred, these portions of the study area have very narrow and steeply sloped off-channel areas. Broader off-channel areas with shallow benches (–10 to –30 ft CRD) occur from RM 1 to 4 along the outside curve of the river, including across the head of Multnomah Channel, between RM 6 and 8, and at the head of Swan Island Lagoon. There are a number of off-channel areas, such as Swan Island Lagoon, Willbridge Terminal, Willamette Cove, Terminal 4, and International Slip, that vary widely in depth as a function of their history and current land use (e.g., actively dredged berths). Finally, there are several deep areas in the harbor that extend from –60 to –80 ft CRD. These are historical borrow areas that were dredged to create the adjacent uplands; the two most extensive ones are in the eastern portion of the channel from RM 4.3 to 5 and RM 9.2 to 10. Map 3.1-13 shows the long-term bathymetric changes that occurred in the lower Willamette River between 1888 and 2001. This map was produced by overlaying and subtracting the 2001 bathymetric survey data from 1888/1895 bathymetric data provided by the City of Portland[10] and illustrates the large-scale deepened, diverted, and filled areas.

3.1.6.3 Manmade Structures

3.1.6.3.1 Bridges

There are five bridge structures within the study area: the St. Johns Bridge (RM 5.8) is a suspension bridge that was constructed in 1931, the Burlington Northern Railroad Bridge (RM 6.8) is a swing bridge (i.e., bridge has a swing span, which pivots on its base to allow for the passage of taller ships) that was constructed in 1906, the Fremont Bridge (RM 11.2) is a steel tied arch design that was constructed in 1973, the Broadway Bridge (RM 11.5) is a truss with double-leaf rall-type bascule lift span design that was constructed in 1913, and the Steel Bridge (RM 12.2) is a double-deck swing-span bridge that was constructed first in 1880 (rail only) with an expansion in 1888 (auto addition) and completely replaced in 1912.

3.1.6.3.2 Piers, Marinas, Docks, and Floating Home Moorages

About 525 acres of the lower Willamette River are occupied by piers, marinas, docks, and floating home moorages. The following provides a general discussion of the location of these structures throughout the site. Maps 3.1-14a-f provide more specific location of these structures.

[10] Bathymetric data provided by the City of Portland was based on a GIS digital model developed using the United States Coast & Geodetic Survey 1888 Columbia River chart (Fales Landing to Portland) and USACE 1895 surveys of the Upper Willamette (Sheets 14 and 15).

Western Shoreline Structures

- RM 0 (confluence with Columbia River) to RM 3 (Multnomah Channel), Sauvie Island—There are some small personal use boat docks (5), abandoned pilings, and pile dikes.
- RM 3 to 3.2 (Portland General Electric [PGE] Harborton)—There are no in-water structures.
- RM 3.2 to 4.1—There are existing in-water structures include pilings, dolphins, and dock and loading facilities associated with supporting upland uses (barges, tank farms, plywood mill, wood chips).
- RM 4.1 to 4.8—There are no in-water structures.
- RM 4.8 to 11.2—Existing floating facilities include wharfs, pilings and piers for handling cargo, boat construction, tug and barge moorage, and launching facilities.
- RM 11.2 to 12.2—Existing in-water facilities and structures include pilings and piers over water at the McCormick Pier residential complex, Old Albers Mill office, Centennial Mills, and Fremont Place office complex. Floating structures include the McCormick Pier private marina.

Eastern Shore Structures

- RM 0 to 0.9 (Columbia Slough), Kelly Point Park—There are no in-water structures.
- RM 0.9 to 5.8—Existing in-water structures include wharfs, piers, bulkheads, and dolphins needed for ship and barge moorage.
- RM 5.8 to 6.8, Cathedral Park—In-water structures include a public boat ramp, fishing pier, and abandoned pilings.
- RM 6.8 to 7.8—There are many deteriorating in-water structures, including piling structures, docks, and miscellaneous man-made structures.
- RM 7.8 to 8.2—There are no in-water structures.
- RM 8.2 to 9.2, Swan Island Lagoon—The east side includes smaller dock structures and floating boathouse. There is a public boat ramp at the southern end of the lagoon (RM 9.2). The western shore is a continuous piling structure used for ship tie-up.
- RM 8.2 to 9.2, west side of Swan Island—There are three dry docks at the head of Swan Island (including the largest floating dry dock in the Pacific Rim—87,000 tons which was removed in 2001), and numerous ship repair berths.
- RM 9.2 to 10—There are no in-water structures.
- RM 10 to 12.2—In-water structures include bulk loading facility, abandoned pilings, concrete foundations, warehouse pilings, and bulkheads. There is also log raft storage in this area.

3.1.7 Habitat

The majority of the study area is industrialized, with modified shoreline and nearshore areas. Wharfs and piers extend out toward the channel, and bulkheads and riprap revetments armor portions of the riverbank. Active dredging has produced a uniform channel with little habitat diversity. However, some segments of the study area are more complex, with small embayments, shallow water areas, gently sloped beaches, localized small wood accumulations, and less shoreline development, providing some habitat for a suite of local fauna.

This section describes the general types and quality of aquatic habitat available to ecological species in the lower Willamette River. The habitats for each ecological receptor group are described in greater detail in the BERA (Appendix G).

3.1.7.1 Open-Water Habitat

The lower Willamette River is characterized by a developed navigation channel and shoreline. The river historically had large amounts of off-channel habitat in the form of floodplain lakes such as Ramsey, Doane, and Guild's lakes. After industrialization, only a few shallower backwater sites (e.g., Willamette Cove, Swan Island Lagoon, individual slips), as well as a tributary (Columbia Slough) and a secondary channel (Multnomah Channel) remain (Map 3.1-15). The deep open water provides foraging habitat for fish and wildlife that feed in the water column. Piers and other structures in the open water provide additional habitat for certain species such as smallmouth bass. Shallow-water habitats provide refuge for juvenile salmonids and other fishes, as well as greater foraging opportunities for birds and mammals. Friesen et al. (2004) found that juvenile salmon were present in every month sampled from May 2000 to July 2003. Juvenile salmon were captured more frequently during winter and spring than during other seasons. Coho and steelhead were generally present only during winter and spring.

Historically the lower Willamette River was dominated by shallow water habitat, with approximately 80 percent of the river with depths less than 20 ft CRD. Dredging and alteration of the river channel have reversed these ratios, and the river is now 20 percent shallow water and 80 percent deep (Map 3.1-16; City of Portland 2009a). Shallow-water habitats, such as those preferred by some foraging wildlife (e.g., otter and mink), are now largely limited to the narrow strip between the shoreline and the navigation channel, which generally is vulnerable to disturbance and anthropogenic alteration due to its proximity to shore. Remaining pockets of shallow water habitat include areas such as Willamette Cove, Swan Island Lagoon, International Terminals Slip, Wheeler Bay, Shaver, Balch Creek Cove, Triangle Park, the mouth and channel of Multnomah Channel, and the Sauvie Island shoreline.

There are three types of benthic habitats in the open water of the lower Willamette River:

- Unconsolidated sediments (sands and silts) in the deeper water (greater than approximately 20 ft CRD) of the navigation channel and lower channel slopes
- Unconsolidated sediments (sands and silts) in shallow water depths (less than 20 ft CRD) in gently sloping nearshore areas (e.g., beaches and benches) and on the upper channel slopes
- Developed shoreline (e.g., rock riprap, sheet pile, bulkheads, piers).

In addition, very limited areas of rock and rock outcrop are present in the lower Willamette River. The navigation channel habitat is subject to variable (daily [tidal], seasonal, and annual) hydrodynamic forces, the impacts of navigation, natural sediment deposition, bed load transport/erosion, and periodic navigational dredging. These forces vary spatially through the system, largely as a function of the channel cross-sectional area, resulting in the presence of both relatively stable and unstable sedimentary environments and patchy infaunal and epibenthic communities that are characteristic of the local physical regime. The physical sedimentary regimes are a function of the local riverbank morphologies, and sheltered areas away from anthropogenic disturbance should support well-developed infaunal invertebrate communities that are characteristic of large river systems. Conversely, exposed nearshore areas, particularly around berths, docks, and boat ramps, likely have limited benthic communities due to the greater physical disturbance in these areas. Tidal and seasonal water level variability and nearshore disturbances (e.g., boat wakes) have a much larger effect in shallow water than they do in deeper water. The hard surfaces of the developed shoreline provide habitat for an epibenthic community.

3.1.7.2 Bank and Riparian Habitat

The most common bank types occurring in the study area are riprap, sandy and rocky beach, unclassified fill, and seawall (Map 3.1-17).[11] In 2008, the City of Portland reported that vegetated riprap (25 percent), unclassified fill (21 percent), and beach (23 percent) were the dominant bank types in the North Reach (Broadway Bridge to the Columbia River; City of Portland 2008a). The riprap or rocky bank type is usually fairly steep with no or very narrow adjacent shallow water habitat present. These areas are usually exposed to heavy wave action and strong currents. The sandy bank type with little to no vegetation is characterized by gently sloped beaches (i.e., sand banks are rarely steep). However, this bank type is often adjacent to steep riprapped shorelines or developed uplands that are frequently exposed to heavy wave action and faster moving water. The rocky or sandy bank types with a mix of native and invasive vegetation are common within the study area. These bank types range from gently to steeply sloped beaches and, similar to the sandy bank type without vegetation, are often adjacent to steep uplands, although the uplands are either of sandy or rocky substrate. The rocky or sandy bank types are generally located in areas with less development and

[11] Classifications on Map 3.1-17 are based upon an ODFW 2000–2003 study (Vile and Friesen 2004) and are known to be outdated or incorrect in some locations.

a lack of bank hardening, such as in Swan Island Lagoon, the Multnomah Channel, Kelley Point Park, and Sauvie Island.

The type of riverbank present in the study area is expected to influence fish species occurrence and use of a given area. Riverbanks with large woody debris and riparian vegetation that provides cover and creates small shallow pools will likely be used by juvenile salmonids and other small fish species (Bjornn and Reiser 1991; Sedell and Froggatt 1984). Areas with limited wood accumulations include the beach adjacent to Freightliner Corp., Kelley Point Park, and Mar Com. Friesen et al. (2004) found that in the lower Willamette River, coho preferred beach habitat and rock outcrops and avoided riprap and artificial fill, and the abundance of all species was low at seawall sites.

The riprap and rocky substrate are the preferred habitats of sculpin and smallmouth bass (Farr and Ward 1993; SEA et al. 2003; Wydoski and Whitney 2003). Sculpin are predominately present in the shallow water habitats, and smallmouth bass are present in areas with moderate current. The shallow backwater pools and slow-moving areas of the river provide habitats for juvenile largescale suckers (yearling and subyearling) and peamouth (Wydoski and Whitney 2003). The peamouth remains nearshore during winter months and moves to deeper waters in the summer months. The shallow waters with abundant plants and woody debris available for cover are the preferred habitats for largemouth bass.

Numerous aquatic and shorebird species such as cormorants and spotted sandpipers use the habitats in the lower Willamette River. The upland environment near the lower Willamette River is primarily urban, with fragmented areas of riparian forest, wetlands, and associated upland forests (Map 3.1-18). Historical development and filling of channels and wetlands has left only small strips or isolated pockets of riparian wildlife habitat, with the exception of areas such as Harborton Wetlands, Oaks Bottom, Forest Park, and Powers Marine Park. Therefore, although isolated wildlife habitat areas along the lower Willamette River corridor exist, linkages to the larger landscape, such as Forest Park, are limited to a few areas. Forest Park, the largest of these upland habitat areas, is generally isolated from the lower Willamette River by the industrial corridor with the exception of a few small controlled watercourses. The barrier presented by the industrial corridor is unlikely to significantly inhibit the movement of birds between the river and the upland forest; however, it poses a significant barrier to the movement of other types of wildlife, such as reptiles, amphibians and small mammals, which, as a result, experience limited or no connectivity to the river.

Urban nesting sites, such as bridges and chimney roosts; bluff areas; grasslands at Powell Butte; native oak assemblages; bottomland hardwood forests; and wetlands have been identified in the vicinity of the study area (City of Portland 2008a).

Potential general wildlife habitat areas in the study area are shown on Map 3.1-19. These include the sites identified by the City of Portland (Adolfson et al. 2000) or based on field observations made during the shorebird habitat reconnaissance (Windward

2004, pers. comm.) or site bathymetry. In the City of Portland's inventory (Adolfson et al. 2000), 15 sites of habitat value for fish, reptiles, amphibians, and wildlife were identified. These habitat sites are known to be utilized by numerous aquatic birds and semi-aquatic mammals. Notable habitat sites in the study area include the South Rivergate corridor at the north end of the study area, the Harborton forest and wetlands, Willamette Cove, the railroad corridor, and the Swan Island beaches and lagoon on the southern end (Adolfson et al. 2000). Other habitat sites identified in the general area were Kelley Point, at the confluence of the Willamette and the Columbia rivers, and the Ross Island and Oaks Bottom Complex around RM 16.

The following provides some more notable habitat features throughout the site:

3.1.7.2.1 Western Shoreline Habitat Features

- RM 0 (confluence with Columbia River) to RM 3 (Multnomah Channel), Sauvie Island—Riverbank is an earthen levee with variable width beaches, some natural vegetation, and occasional riprap.
- RM 3 to 3.2 (PGE Harborton)—Shoreline is a combination of riprap and rubble overgrown with vegetation, making it natural appearing. Habitat is available for shorebirds, amphibians, and aquatic plants.
- RM 3.2 to 4.1—The shoreline character is a mixture of natural-appearing and man-made conditions including riprap, rubble, and piling structures.
- RM 4.1 to 4.8—Natural-appearing riverbank and shoreline covered with cottonwoods and brush with narrow beach area.
- RM 4.8 to 11.2—Shoreline conditions range from riprap and rubble to pier and pilings, although there are some isolated natural-appearing areas.
- RM 11.2 to 12.2—The shoreline consists of riprap along the entire segment.

3.1.7.2.2 Eastern Shore Habitat Features

- RM 0 to 0.9 (Columbia Slough), Kelly Point Park—Largely natural-appearing with large cottonwood trees, beach, and shoreline.
- RM 0.9 to 5.8—Shoreline condition varies, ranging from some vegetation and beach to bulkheads.
- RM 5.8 to 6.8, Cathedral Park—Natural-appearing riparian areas and beach.
- RM 6.8 to 7.8—A small area of natural-appearing shoreline vegetation adjacent to the railroad bridge. Articulated block on beach at McCormick and Baxter site with new plantings in riparian area. Remainder of shoreline is riprap or rubble. Small cove in front of Triangle Park property.
- RM 7.8 to 8.2—Natural-appearing with brush and cottonwoods. Steep riverbank with man-made alterations by the railroad.
- RM 8.2 to 9.2, Swan Island Lagoon—Shoreline character ranges from man-made piling structures to natural-appearing, though most is modified. Some

wildlife habitat area exists along east side of the lagoon. The extreme south end of the lagoon is currently undeveloped but has been filled to prohibit the Willamette River from flowing through the channel creating Swan Island Lagoon.

- RM 8.2 to 9.2—Entire shoreline is riprap.
- RM 9.2 to 10—Shoreline is riprap, but has sandy beach area.
- RM 10 to 12.2—Shoreline has been heavily modified with little natural vegetation, but some existing beach area. Between the Fremont Bridge and the Steel Bridge, the shoreline is heavily modified with riprap.

3.1.7.3 Critical Habitat

Section 7(a)(2) of the ESA requires that any action authorized, funded, or carried out by the federal government is not likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of designated critical habitat for any listed species—in this case, salmon and steelhead. "Critical habitat" is defined as 1) specific areas within the geographical area occupied by the species at the time of listing, if they contain physical or biological features essential to conservation of the species, and those features which may require special management considerations or protection; and 2) specific areas outside the geographical area occupied by the species if the agency determines that the area itself is essential for conservation of the species.

The lower Willamette River has been designated by the National Marine Fisheries Service as critical habitat for Lower Columbia River Chinook salmon, Lower Columbia River steelhead, Upper Willamette River Chinook salmon, and Upper Willamette River steelhead (70 Fed. Reg. 52630), and is proposed critical habitat for Lower Columbia River Coho salmon (78 Fed. Reg. 2726). All of these species are anadromous, hatching in fresh water streams outside of the study area, migrating to salt water, and returning to fresh water to spawn. The study area provides migration and rearing habitat and both adult and juvenile salmonids are common in the lower Willamette River during various times of the year. Adults are present during their upriver spring migrations, whereas, juvenile salmonids can be found in the lower Willamette River year-round.

The critical habitat designations identified above (70 Fed. Reg. 52630, 78 Fed. Reg. 2726) indicate that freshwater rearing sites and migration corridors, such as provided by the study area, are essential to the conservation of the listed salmonid species. The critical habitat designations indicate that features of rearing sites that support listed salmonids include "water quantity and floodplain connectivity to form and maintain physical habitat conditions and support juvenile growth and mobility; water quality and forage supporting juvenile development; and natural cover such as shade, submerged and overhanging large wood, log jams and beaver dams, aquatic vegetation, large rocks and boulders, side channels, and undercut banks." (70 Fed. Reg. 52630, 78 Fed. Reg. 2726). Features of freshwater migration corridors that support listed salmonids are that they are "free of obstruction and excessive predation with water quantity and quality conditions and natural cover such as submerged and

overhanging large wood, aquatic vegetation, large rocks and boulders, side channels, and undercut banks supporting juvenile and adult mobility and survival." (70 Fed. Reg. 52630, 78 Fed. Reg. 2726). Many of the critical habitat features discussed above are substantially degraded in the study area, and since the study area is essential for rearing and migration of ESA-listed salmonids, it may require substantial habitat improvement to promote the conservation and recovery of these species.

3.2 HUMAN USE

3.2.1 Demography

3.2.1.1 Multnomah County

The Portland Harbor study area is located in Multnomah County. As of the 2010 census (US Census Bureau 2010), there are 735,334 people residing the Multnomah County, most of whom reside within the City of Portland (see Section 3.2.1.2) and half (50.5 percent) are women. The population density is approximately 1,705 people per square mile with a per capita income of $29,544 (2011 dollars). Approximately 16.5 percent of the population is below poverty level.

There are 326,227 housing units with a median value of $281,900 and a 55.2 percent ownership rate. Each household comprises approximately 2.34 persons and a median household income of $50,726. The majority of the population (70 percent) is between the ages of 18 and 65, with 20 percent below the age of 18 and 10% above the age of 65.

The census reported the county as 81.2 percent White (597,091 people), 11.1 percent Hispanic or Latino (81,622), 6.7 percent Asian (49,267), 5.7 percent Black or African American (41,914), 1.5 percent Native American (11,030), and 0.6 percent Native Hawaiian or other Pacific Islander (4,412); 4.3 percent of the population reported belonging to two or more racial groups (31,619) and 14 percent were foreign born (102,946). Reportedly, 19.5 percent of the population (143,390) over the age of 5 speaks a language other than English at home.

The total number of firms[12] in Multnomah County in 2007 (2007 Economic Census) was 75,230. Of those, the census reports ownership as 86.8 percent White (65,300), 6.2 percent Asian (4,664), 3 percent Black (2,257), 3 percent Hispanic (2,257), 0.8 percent Native American (602), and 0.2 percent Native Hawaiian or other Pacific Islander (150). Women-owned firms comprised 31.6 percent (23,773) of the total firms.

[12] A firm may operate one place of business or more, such as a chain of restaurants, or have no fixed business location, such as the firm represented by a self-employed carpenter or salesperson. A firm contrasts with an establishment, which is a single physical location at which business is conducted. Most other data from the Economic Census are reported on an establishment basis rather than a firm basis.

The 2007 Economic Census data on the manufacturing sector[13] of Multnomah County reports manufacturers' shipments at $10.5 million, merchant wholesaler sales at $22 million, retail sales at $9.9 million, and accommodation and food service sales at $2 million.

3.2.1.2 City of Portland

The city of Portland is located in Multnomah County at the upper bound of the Portland Harbor study area. Portland is the largest city in the state of Oregon and the 29th largest city in the U.S. As of the 2010 census, there are 583,776 people residing in the city of Portland (US Census Bureau 2010) and half (50.5 percent) are women. The population density is approximately 4,375.2 people per square mile. There are 265,439 housing units with a median value of $292,800 and a 54.2 percent ownership rate. Each household comprises approximately 2.27 persons.

The median income for a household in the city is $40,146, and the median income for a family is $50,271. The per capita income for the city is $22,643. The census reported 13.1 percent of the population and 8.5 percent of families are below the poverty line.

The census reported the city as 76.1 percent White (444,254 people), 9.4 percent Hispanic or Latino (54,875), 7.1 percent Asian (41,448), 6.3 percent Black or African American (36,778), 1.0 percent Native American (5,838), 0.5 percent Native Hawaiian or Pacific Islander (2,919), 4.7 percent belonging to two or more racial groups (24,437), and 5.0 percent from other races (28,987).

The age distribution was 21.1 percent under the age of 18 (123,177 people), 10.3 percent from 18 to 24 (60,129), 34.7 percent from 25 to 44 (202,570), 22.4 percent from 45 to 64 (130,766), and 11.6 percent who are 65 years of age or older (67,718). The median age is 35 years.

The total number of firms in the City of Portland in 2007 (2007 Economic Census) was 76,485. Of those, the census reports ownership as 86.2 percent White (65,930), 6.7 percent Asian (5,124), 3.1 percent Black (2,371), 3 percent Hispanic (2,294), 0.8 percent Native American (612), and 0.2 percent Native Hawaiian or other Pacific Islander (153). Women-owned firms comprised 31.9 percent (24,399) of the total firms.

The 2007 Economic Census data on the manufacturing sector of the City of Portland reports manufacturers' shipments at $8.4 million, merchant wholesaler sales at $20.6 million, retail sales at $8.2 million, and accommodation and food service sales at $1.8 million.

[13] Establishments engaged in the mechanical, physical, or chemical transformation of materials, substances, or components into new products.

3.2.2 Land Use

Land uses within the lower Willamette River watershed in the vicinity of Portland and its suburbs are urban/industrial, residential, and rural/agricultural. Many of the state's heaviest industrial users are present in the lower Willamette watershed. Land uses in the basin upstream of Portland include timber production, grazing, irrigated and dryland agriculture, and urban areas.

The east side of the lower Willamette River is relatively flat with little elevation change; consequently, the east side has been almost completely developed. The steeper slopes in the West Hills on the west side of the river developed more slowly. With a few exceptions, such as the Oaks Bottom complex, most of the natural riparian areas and wetlands on both sides of the river were filled over the past 150 years. The west side also has significantly more parks and open space, primarily because of Forest Park.

Portland Harbor and the lower Willamette River have served as a major industrial water corridor for more than a century. Industrial use of the study area and adjacent areas has been extensive. The majority of the study area is currently zoned for industrial land use and is designated as an "Industrial Sanctuary" on the Portland Comprehensive Plan Map (City of Portland 2006b). The Portland industrial sanctuary policy is designed to encourage the growth of industrial activities in the city by preserving industrial land. In addition to industrial use zoning designation, the City of Portland citywide zoning map (January 2009) displays several other zoning designations for smaller portions of the study area, including open space (e.g., Cathedral Park and Willamette Cove); general employment (mixed use allowed though primarily an industrial use focus); and multi-dwelling residential (e.g., University of Portland). The zoning codes apply to lands along the river and not to the actual river itself.

As shown in Map 3.2-1b-c, the Guild's Lake Industrial Sanctuary Plan (GLISP), which covers one portion of the study area zoned for industrial use, is intended to preserve and enhance industrial land in the Guild's Lake area, generally bounded by Vaughn Street on the south, the St. Johns Bridge on the north, Highway 30 on the west, and the Willamette River on the east (City of Portland 2001a). Over many decades, public and private investments in infrastructure, such as marine, rail, and highway facilities, as well as investments in industrial physical plants, have occurred within this area. The stated purpose of the GLISP is to maintain and protect this area for heavy and general industrial uses. The plan's objectives were adopted as part of Portland's Comprehensive Plan to ensure preservation of this land use over the next 20 years.

3.2.2.1 Historical Development of the Lower Willamette River

This section summarizes the major historical land use, fill placement, and shoreline and overwater operations. Historical aerial photographs were reviewed to evaluate general trends in land use along the Willamette River waterfront. Mosaic images created by the Port of Portland from scanned historical aerial photographs of the river and waterfront were also reviewed, as were more recent aerial photographs (Maps 3.2-2a–f). The oldest historical aerial photographs available for this harbor-wide review were taken in

1936. Based on the pace of land development observed during the preliminary review of all of the aerial photo mosaics, six of the photo mosaics (1936, 1948, 1961, 1974, 2000, and 2007) were selected for broader-scale depiction of changes in land usage (Maps 3.2-3 through 3.2-8). For most years selected, aerial photo images were available for the entire river waterfront from the Columbia River to Ross Island.

Fill placement is shown on Maps 3.1-14a–f. Detailed information on the fill placement activities can be found in Table 3.2-1. Information used to construct this table was obtained from the aerial photographs, information collected by the LWG during the RI, and the City of Portland. The descriptions of subsurface soils in site investigation reports suggest that much of the fill placed in these areas consists of Willamette River sediment/sand/gravel dredged offshore of the respective facilities or in the immediate vicinity. Other sources of fill include dredged material from Multnomah Channel and the Columbia River. Anthropogenic sources of fill include concrete, brick, boiler ash, pencil pitch, Liberty ship bows, metal, asphalt, soil/slag material and construction debris. The source of the fill, if known, is identified in Table 3.2-1.

Overwater structures, such as wharfs, piers, floating docks, and pilings, were built largely to accommodate or support shipping traffic and remain common. These structures along the shoreline are clearly visible in the aerial photographs provided in Maps 3.2-9a–t.

Industrial and commercial development along the river began in the mid- to late-1800s in scattered areas such as downtown Portland, St. Johns, Linnton, and Macadam. Portland Harbor remained largely undeveloped through the late-1800s, but as urban development in the downtown area at the beginning of the 20th century pushed industrial development downriver, businesses began to relocate to the current industrial area of the harbor. The west side of the river was settled and developed first.

The most notable changes for the major reaches in the study area are described in the following subsections. These reach breaks are defined based on changes in the lower Willamette River's physical characteristics. General land use changes for the east and west banks of each reach are discussed, including historical riverbank fill placement and changes in overwater structures.

3.2.2.1.1 RM 9.5 to 11.8

In 1936 the waterfront hosted a lumber mill, grain elevators, cargo docks, oil and coal exporters, and ship building and ship repair facilities. Rail yards between RM 10 and 12 were present on both sides of the river in 1936 and were more fully developed by 1948 (Map 3.2-2a). By 1961, industrial development had expanded on both sides of the river and log storage areas were present along riverbanks (Map 3.2-2b). Relatively few changes occurred from 1961 to 2000, with the exception of the completion of Interstate 5 and Interstate 405 (Maps 3.2-2c–e). By 2007, dock structures were added along the west bank and a few parcels were converted from commercial to industrial or residential use (Map 3.2-2f).

From approximately RM 9.5 to 10, the original shoreline on the east bank formed a cove. In the 1970s this area was filled (Map 3.1-14e). Significant channel narrowing due to infill on the west bank is observed from 1888 to 1936 (Map 3.1-14a). Beginning on the east side, the riverside area near RM 11.2 to 11.4 where Glacier NW is currently located (plus adjacent nonriparian properties) was the site of the former Albina Engine and Machine Works property, where ship construction and repair was conducted for the U.S. Navy and the War Shipping Administration (see Map 3.2-10). Albina Engine and Machine Works was founded in 1904 as a riverfront repair yard and operated until 1971. During WWII, the shipyard facility was expanded to encompass 16.8 acres and included six shipways, welding and pipe shops, paint storage and shops, warehouses, two outfitting docks, plate storage yards, burning slabs, and a pickling plant.

The shipways were filled beginning in the 1950s and completed by 1963. Most of the riverside buildings associated with the shipyard were demolished. The first new buildings on the former shipyard property appeared in the late 1970s. A portion of the former shipyard was used for expansion of the Pacific Power and Light Albina Substation beginning in the late 1940s.

Docks have been located in the area of the Albina Rail Yard (RM 10–11) and the Glacier facility (RM 11.3) from 1936 to the present day. From the review of aerial photographs, it appears the existing docks at the CLD Pacific Grain facility (RM 11.4) were constructed sometime between 1957 and 1966 (Map 3.1-14f). A large overwater structure called the Irving Dock was present at this location prior to construction of the present-day CLD Pacific Grain dock, as shown in both the aerial photographs and 1924 Sanborn maps reviewed by Integral. A large dock first appears in the 1961 aerial photo at RM 11.8E.

Along the west bank from RM 9.8 to 10.3, encompassing the present-day Terminal 2 and Sulzer Pumps properties, Willamette Iron and Steel Company (WISCO) operated a shipyard for an unknown period up until 1949 (Map 3.2-10). In 1941–1942, the WISCO facility was expanded with public funds from the Defense Plant Corporation. The reconfigured facility was 79 acres in total area, with government ownership of approximately 36 acres. Combined, these facilities provided a complete shipyard for launching and outfitting steel ships. Many of the manufacturing operations associated with the shipyard were located on the current Sulzer property (RM 10.3), which included outfitting operations, a sheet metal fabrication shed, a cable storage building, a machine shop, a paint shop, a coppersmith shop, and the main industrial building. WISCO operations consisted of three shipways with four attendant craneways located at the southern (upstream) end of the property; these shipways were subsequently filled in 1967–1968.

Significant changes occurred along the west bank with dredging of a slip at the WISCO shipyard in the mid-1940s (RM 10); the creation of the Albina Ferry slip (Slip No. 1) at Municipal Terminal 1 (RM 10) in 1914 and Slip No. 2 in 1923; filling of the western shoreline downstream of Terminal 2 (RM 10.6) in the 1950s and 1960s; filling of the

Terminal 1 South slip in the early 1900s; and filling of the Terminal 2 upstream slip by 1987 (Map 3.2-2e). Beginning with the 1936 aerial photograph, a large tank appears on the west bank at RM 12, but is no longer there in photographs taken after 1957.

Overwater features in this reach include the docks along the western shoreline at the former Municipal Terminal 1 and current Terminal 2 (RM 10 and 10.6), and an oil transfer pipeline (south of present-day Sulzer Pumps) at RM 10.4 (Map 3.1-14e). The oil transfer pipeline was used by PGE for transferring Bunker C oil from vessels to tanks at a nearby power plant. Some of these docks remain in place but are no longer in use. Most overwater activity associated with the docks in this reach appears to have occurred in the 1940s and 1950s, when the docks were used for loading lumber, paper products, grain, gravel, and coal. From the 1930s through the 1960s, log moorage rafts were present at approximately RM 9.2 and 10.

3.2.2.1.2 RM 8 to 9.5

This stretch of the river has undergone significant change through the years, as is shown in the six photo mosaics (Map 3.2-2a–f). Swan Island (RM 8.3 to 9.2 on the east bank) was originally a sandbar and marsh separated by two channels of the Willamette River. Prior to 1920, the eastern channel was the river's main channel. The eastern channel was deeper than the western channel, which was wide and shallow with a shoal that hindered boat passage. In the early to mid 1920s, the west channel was deepened and widened in places to facilitate navigation (the west channel was opened to navigation in 1926). In 1927, the diversion of the river's main channel from the east side to the west side of the island was completed through the construction of a causeway at the island's upstream end (creating a lagoon out of the east-side channel called Swan Island Lagoon). The filling of Swan Island, performed by the Port of Portland, was mostly completed by the 1920s before construction began on the airport in 1926.

Mocks Bottom is located in the upland area east of the Swan Island Lagoon. Once a swampy slough, Mocks Bottom was filled by the Port of Portland and USACE to build roads and facilitate industrial development. About half of Mocks Bottom had been filled by 1961 and filling was complete by 1974 (Map 3.1-14d). Although some industrial facilities had developed along the shoreline by 1961, less than half of the area had been developed prior to 1974. The area was fully developed by 2007 with industry related to truck manufacturing, shipping and transportation, marine salvage, and military uses.

The Swan Island peninsula has a long history of commercial and industrial operations that continue today. The Swan Island Municipal Airport functioned until operations moved in 1940 to a location that is now part of the Portland International Airport. Between 1942 and 1949, the U.S. Maritime Commission leased Swan Island from the Port of Portland and contracted with the Kaiser Company to construct a shipyard and associated facilities. The shipyard facilities were used to build T-2 tankers used during WWII. A Kaiser affiliate, Consolidated Builders, Inc., conducted ship dismantling between 1947 and 1949. After the war, the area was redeveloped and used for ship

repair purposes. The redeveloped facilities were used by various ship repair contractors and their subcontractors. In addition, facilities were leased to a number of industrial tenants who conducted a range of activities, including steel fabrication and storage, wood products manufacturing, equipment manufacturing, maritime supply sales, printing, chemical and soap storage, war surplus storage, fire extinguisher service and storage, paint storage, aluminum oil tank manufacturing, service station operation, sheet metal work, roofing supply storage, and general office storage. The eight shipways constructed during the military era were filled with dredged materials between 1950 and 1962. The current configuration of dry docks at the end of the peninsula and berths along Swan Island Lagoon and the Willamette River was largely completed by 1979. Some filling also occurred in the northwestern portion of the shipyard area in the late 1970s, and at the head of the lagoon by 1975 (see Map 3.2-2d).

Up until the 1960s the west side of the river was mostly undeveloped and was used for log raft storage. The present-day Shell Equilon dock occupied the west bank at RM 8.8 in 1936. Operations at Gunderson (RM 8.7 to 9.2) began as early as 1942, and most of the present-day site was constructed by 1966 (Map 3.1-14d); activities have generally included barge and railcar manufacturing. Ship building operations began at Gunderson in the 1960s and are still in operation today. During the 1960s and 1970s, a portion of the Gunderson facility was used by American Ship Dismantlers for ship scrapping. Overwater activities occurred at the barge launchways in Area 2 and the outfitting dock in Area 3. A dock structure and an oil transfer pipeline were located historically at the McCall Oil site (RM 8.2) prior to filling in the late 1960s. Fill was placed along the Gunderson shoreline beginning in the 1950s.

On the west side of the river in this reach, Guild's Lake was a shallow, marshy area located from the present-day Guilds Lake Railroad Yard (otherwise known as "Lake Yard") westward to St. Helens Road. Map 3.2-11 shows the location of the lake in 1888. Filling of Guild's Lake began in approximately 1879 and was partially completed in 1913 by private entities using soil hydraulically sluiced from nearby hillsides, providing space for the rail yard and an industrial center (Oregon Historical Society 2002). The Port of Portland continued filling in the 1920s, using materials dredged from the Willamette River. The filling of the Guild's Lake area was planned in connection with the West Swan Island project, where the channel was diverted from the east to the west side of the island. Construction of the Guilds Lake Yard, which is owned by Portland Terminal Railroad, began in 1916.

3.2.2.1.3 RM 5 to 8

The 1936 photo mosaic (Map 3.2-2a) shows that the east side of the river was largely undeveloped from RM 5 to approximately 5.7 until the period between the 1960s and 1970s. Early features include docks at the McCormick and Baxter site (RM 7), Willamette Cove (RM 6.7) and downstream of Mar Com (RM 5.7). The eastern bank between RM 6.5 and 6.9 was primarily filled in the 1910s and 1920s to create the central and eastern parcels of the Willamette Cove upland facility. Upstream of RM 6.9, the eastern bank remained relatively unchanged until the 1970s, when the

downstream end of the property presently known as Triangle Park (RM 7.4) was filled to create a dock and berth area. From 1888 to 1936, shoreline development is most notable from RM 5.9 to 6.4, due to the construction of the St. Johns Bridge at RM 5.9 and timber processing facilities on the eastern bank at RM 6.2 and on the western shore at RM 6 and 6.4. From 1888 to 1936 the eastern bank shows widening due to development in the vicinity of timber processing plants, including the McCormick and Baxter site (RM 7.1), and narrowing due to installation of the railroad crossing at RM 6.9 (Map 3.2-12a).

The Mar Com facility, which ceased operations in 2004, was situated on land that had been used for ship building and vessel repair since approximately 1905. The central parcel of the Willamette Cove facility was also used for ship repair on dry docks and related ship maintenance between 1903 and 1953. Upland shops and structures and in-water dry docks were used by independent contractors working for various vessel owners. During wartime, U.S. government contractors utilized the dry docks for military ship outfitting and repair. Several of these dry docks have since been removed from this stretch of the river (e.g., Mar Com, Willamette Cove). Dock structures at the former McCormick and Baxter facility were removed during the recent Superfund cleanup of this site.

The 1936 photograph of the west side of the river (Map 3.2-2a) shows the Willbridge Terminal (RM 7.5), U.S. Moorings (RM 6), and Gasco (RM 6.2) facilities with very little other development. Most of the shoreline change occurred on the west side of the river from the 1940s to the 1960s. Fill was placed along the eastern shoreline of RM 5 to 5.7 from the 1950s through the 1970s. By 1975, fill was also placed along the western shoreline and in a larger low-lying area at what is present-day Siltronic (RM 6) and Gasco property. Fill materials for both sides of the river included quarry discards and dredge materials. At the Gasco and Siltronic properties, manufactured gas production (MGP) materials were also included in the fill.

At the Arkema site (RM 7.2), which began operations in 1941, fill consisted of plant debris composed of asphalt, concrete, pipe, soil, and fill from other sources (e.g., City of Portland). Historically, fill materials were used to extend the ground surface out into the Willamette River. By the late 1980s, approximately 12 trenches on Lot 1 were filled with asbestos-containing residue. These trenches were believed to be approximately 60 ft long by 15 ft wide by 15 ft deep (DEQ 2001). The asbestos material was removed from the Arkema site in 1992 under a work plan approved by DEQ and under the agency's oversight (ERM 2003).

A DDT trench was located on Lot 1 and was investigated in the fall of 1992 (ERM 2003). The investigation determined that the trench was approximately 30 ft wide by 80 ft long and approximately 10–11 ft deep. The top of the trench was located 3 ft bgs. Because the trench was a clearly defined, discrete unit, the trench was completely excavated during the summer of 1994. Approximately 1,700 tons of soil were removed

from the site and disposed of at the Waste Management Subtitle C landfill in Arlington, Oregon (ERM 2003).

On Lot 2, brine wastes were directed to a brine residue pile or pond until the early 1990s. The brine pile and pond were completely removed from the site in February 1989 and August 1992, respectively. The material was transported to the Hillsboro Landfill and beneficially used as a soil amendment to the final landfill cap (ERM 2003).The historical 80-acre Doane Lake and associated wetlands were situated in the upland area of this western stretch of the river (see Map 3.2-11).

The lake was divided in 1908 when the Railroad Bridge and southbound rail lines were constructed, and again in 1968 when the northbound rail line was constructed. The 6-acre lake area between these two rail lines is called North Doane Lake. The portion of the lake north of the Railroad Bridge was filled between the 1960s and 1970s for industrial development using 30,000 cubic yards of coal tar from a coal gasification plant.

The portion of the lake south of the Railroad Bridge was used for waste disposal by adjacent industries, including 80,000 tons of battery casings and lead-bearing materials and 6.5 million gallons of sulfuric acid (Gould Industries), pesticide and herbicide manufacturing wastes containing chlorinated phenolic and aromatic compounds (Rhone Poulenc), and foundry waste containing highly alkaline calcium hydroxide and mildly radioactive zirconium sands (ESCO). Between 1945 and 1955, stormwater and untreated wastewater from Rhone Poulenc was discharged to Doane Lake where it commingled with stormwater and releases from Gould/NL Industries, Schnitzer/Air Liquide, and ESCO. Doane Lake was almost completely filled by the late 1990s when the Gould Superfund site completed remediation.

The western shore shows narrowing from RM 6.9 to 7.4 due to upland development and installation of the railroad crossing. Arkema maintained two dock structures for receipt of evaporated sea salt, which contained sodium chloride, and shipping of inorganic chemicals produced onsite. Operations ceased in 2001, and the facility has been dismantled, but the dock structures remain. Petroleum products have been loaded and unloaded at the Willbridge Terminal since the early 1900s. A large dock offshore of the NW Natural facility at RM 6 is used by Koppers Inc. for unloading heated liquid coal tar pitch via cargo vessel. Fuel and Marine Marketing, Inc. also uses the dock to transfer petroleum products from barges to their bulk storage facility.

3.2.2.1.4 RM 3 to 5

Major facilities on the east side of the river started in the early 1920s and included cargo handling, a flour mill, warehousing, and bulk fuel storage. Tank farms were developed on the west bank in approximately 1918 (present-day Kinder Morgan Linnton Terminal) and were expanded in the 1960s to be the predominant land use. The Owens-Corning Linnton facility installed several petroleum product tanks for use in their asphalt production in 1981. Other early west-shore industries included lumber mills,

toy manufacturers, a creosote plant, and lumber storage. The PGE Harborton substation at RM 3.1W was constructed in 1985. Both sides of the river were fully industrial by the 1970s.

The most important shoreline changes in this reach occurred along the eastern shoreline from RM 4.2 to 4.6 (Map 3.1-14b). In the late 1910s and early 1920s, the mouth of Gatton Slough was filled (discussed in the following section), and three slips were dredged forming the Municipal Terminal No. 4 area (present-day Slips 1 and 3 and Wheeler Bay). Between approximately 1948 and 1958, the middle slip (Wheeler Bay) at Terminal 4 (which was never completed) was backfilled and Slip 3 was widened. The Port of Portland's auto storage facility at Terminal 4 was developed in the 1960s and the early 1970s, by placing sand fill to bring the site up to an elevation above the flood level. In the early 1970s, the sand fill was graded and the automobile storage yard and the steel dock and steel yard were constructed (Hart Crowser 2002c).

The Burgard Industrial Park (RM 4E) was the location of a large shipyard operated by the Oregon Shipbuilding Corporation. The deep-draft International Terminal Slip was created during the 1940s, and portions of the marshy, low-lying areas on the site were filled. Ship breaking activities were reported in 1946 (Oregonian 1946). The year in which shipyard was dismantled has not been presented in documents reviewed, but the shipways were filled between the early 1960s and 1972. Post-shipyard industrial uses included metal fabrication, log rafting, and upland log storage. The property was converted for use in 1972 as a metals scrap yard. Automobile shredding operations began in 1980.

Conspicuous historical overwater features within this reach include docks associated with ship building and repair, lumber mills, petroleum product distribution, moorage, and cargo unloading. Port of Portland Terminal 4 tenants that currently (or historically) handle soda ash, new automobiles, and liquid bulk materials from their docks are located on the eastern shoreline. Metal scrap delivery occurs at docks in the International Terminal Slip (RM 3.7). Along the western shoreline, there are bulk petroleum distribution docks (ARCO; RM 4.9) and sand and gravel unloading/loading overwater activities (Columbia River Sand & Gravel; RM 4.5).

3.2.2.1.5 RM 1 to 3

Little change to the shoreline occurred in this vicinity of the river until fill materials were placed at the present-day Evraz Oregon Steel Mills (EOSM) site (RM 2.1E) from the early 1940s to the 1960s; additional filling of the riverbank occurred in the 1970s using EOSM slag materials, onsite soils, dredge material, and imported materials (Map 3.1-14a). Within the larger Rivergate industrial area, approximately 500 acres of the historic Ramsey Lake, located between Smith and Bybee lakes and the Willamette, were filled with dredge material from the 1960s to the 1980s. As shown on Map 3.2-11, this lake and floodplain historically covered approximately 650 acres and included a seasonal stream called Gatton's Slough that flowed west to the Willamette and a channel connecting it to the Columbia Slough to the east (USC&GS 1888). A

dredge/fill map compiled from USACE data shows dredge material from the Post Office Bar and the mouth of the Willamette being placed in the Rivergate industrial area (Port of Portland 1981; USACE 1973).

The primary overwater features along the eastern shore of this reach are docks for distribution of chemicals and petroleum products. From 1936 until the 1960s, the eastern shoreline was utilized for log raft storage. In the 1940s, a dock was constructed at what is now the EOSM site for the transport of oil and bilge water to an upland oil sump. The current dock at Ash Grove is first present in the 1966 aerial photograph (Map 3.2-2c). By 1975, new docks associated with EOSM, JR Simplot, and Port of Portland Terminal 5 are present along the RM 1 to 3 reach.

The only industrial feature on the western bank of the river in this area is Alder Creek Lumber Company (RM 2.9).

3.2.2.1.6 Multnomah Channel

Besides the Alder Creek lumber yard at the mouth of the Multnomah Channel, the only other predominantfacilities in this stretch of the channel are Fred's Marina, the Multnomah Yacht Club, and the ESCO landfill.

Since 1959, floating logs have been delivered to the dock area at the Alder Creek Lumber property near the mouth of the channel. Houseboat and boat moorages and marinas line Multnomah Channel's southern bank, opposite the ESCO landfill, forming a continuous string that extends as far as 1 mile. Approximately 200 of these houseboats and sailboats are used as permanent residences (DEQ 2009a).

Fred's Marina has occupied its site since the 1940s (Parson Brinckerhoff 2004). Presently, the marina contains a boat ramp, fuel dock, a boat trailer storage area, and over 200 slips. A designated dredged material disposal site is located upland directly east of the marina. This disposal site is for the containment of material dredged from the marina and vicinity that is deemed suitable for upland placement. The Multnomah Yacht Club has been in operation since 1961; prior uses of the property are unknown. The ESCO landfill does not have any operations on the shoreline. No further information on historical shoreline and fill placement activities was found.

3.2.2.2 Current Land Use

Portland Harbor is located within a broader region characterized by commercial, residential, recreational, and agricultural uses. A portion of the land adjacent to Portland Harbor is located within the GLISP (City of Portland 2001a) area (from the St. Johns Bridge at RM 5.8 to 10.7, along the west shore). Land use along the Willamette River within the harbor includes marine terminals, various manufacturing facilities, and commercial operations, as well as public facilities, parks, and open spaces. As shown on Maps 3.2-1a–e residential areas on the west side include the Linnton neighborhood in pockets west of St. Helens Road between RM 4.3 and 5W, and in the mixed use Pearl District neighborhood in the vicinity of RM 12W. Most of

the residential land use on the east side is above the bluff, except for the St. Johns neighborhood, which extends closer to the river between RM 5.7 and 6.8E.

Maps 3.2-1a–d illustrate current land use zoning within the lower Willamette River and upper Multnomah Channel and show sites located within study area drainage basins. Waterfront properties are also labeled. Current and previous facility names for these sites are listed in Table 3.2-2.

The current overwater structures, such as wharfs, piers, floating docks, and pilings, were built largely to accommodate or support shipping traffic. These structures along the shoreline are clearly visible in the aerial photographs provided in Maps 3.2-9a–t. Numerous public and private outfalls, including stormwater and CSO outfalls, enter both shores of Portland Harbor, and are described further in Section 3.2.3.1.11.

The St. Johns Town Center is a mixed-use district that extends to the waterfront on the east side of the Willamette River at the St. Johns Bridge. The St. Johns/Lombard Plan (City of Portland 2004) includes a proposed redevelopment of this area near the Willamette River. The Riverfront Subdistrict included in the St. Johns/Lombard Plan is currently zoned as Open Space and as a Central Employment (EX) zone. The development standards of the Central Employment (EX) zone are intended to ensure that the Riverfront Subdistrict is developed in a manner consistent with adjacent areas and to support existing industry by limiting uses that may be less compatible with industry (City of Portland 2004).

Submerged lands are primarily owned by the Oregon DSL and leased to upland property owners for uses such as construction of overwater structures, moorage, etc. The DSL submerged lands boundary can be ordinary high water (OHW), ordinary low water mark (OLW), or arbitrary deed lines specific to each riverfront property. Notable exceptions to DSL ownership include portions of the submerged and submersible lands at the Port of Portland Terminal 4, most of the dry dock area and riverside berths at Swan Island, which are owned by Shipyard Commerce Center LLC, and the International Terminal Slip owned by Schnitzer Steel Industries. DSL owns approximately 94 percent of the submerged lands in the study area. There are also areas within the study area below OLW not owned by DSL or the Port of Portland (DEA 2011).

3.2.3 Site Use

This section describes the current understanding of the physical and biological setting of the study area as it pertains to potential human uses, including specialized groups that may use the river for various activities. Most of the demographic information relating to the study area is based on historical background and documented human uses. This information is used to determine potential receptor populations and to develop the general CSM.

3.2.3.1 Commercial and Industrial

This section provides an overview of Portland Harbor's waterfront land and harbor use. Over the past 100 years, major physical alterations have modified the river hydrodynamics and changed the configuration of the river. Map 3.2-11 shows the configuration of the river and the existence of nearby lakes in 1888 (USC&GS 1888). Shoreline changes are presented by decade on Maps 3.2-12a–e. The first map shows the 1888 shoreline and the remaining maps represent a series of nine historical snapshots of the shoreline starting in the year 1936 and ending in 2007. The land use along the lower Willamette River is currently highly urbanized and industrialized. Some remnant natural areas remain and support habitat for aquatic and terrestrial wildlife.

Significant physical modifications to the river coincided with the development and industrialization of the harbor. Modifications included redirection and channelization of the main river, draining of seasonal and permanent wetlands and lakes in the lower floodplain, extensive filling of wetlands along the shoreline, conversion of agricultural lands, and periodic dredging to maintain harbors and the navigation channel.

Commercial and industrial development in Portland Harbor accelerated in the 1920s and again during World War II, which reinvigorated industry following the Great Depression. Before the war years, industrial development primarily included sawmills, MGP, bulk fuel terminals, and smaller industrial facilities. During World War II, a considerable number of ships, minesweepers, and tankers were built at military shipyards located in Portland Harbor. Additional industrial operations located along the river during the shipyard years, including wood-treatment, agricultural chemical production, battery processing, ship loading and unloading, ship maintenance and repair (e.g., sandblasting, scaling, repair, painting, refueling), and railcar manufacturing. Many of these operations continue today. Coincident with the development and use of Portland Harbor for these industrial purposes were a number of fires that occurred at wood products industries, manufacturing plants, or other waterfront facilities that were constructed predominantly of wood (Oregonian 1958; 1966a,b; 1967).

The development of the harbor centered on several industrial sectors, which are described in the following sections. Each sector discussed below contains a map showing the historical and current facilities included in the industrial sector (Map 3.2-10 and Maps 3.2-13 through 3.2-21). The approximate location of facilities is shown on the maps, based on the current ownership of the property. Mapping of actual facilities or operations was not attempted. Only a few sites in each category are discussed.

3.2.3.1.1 Ship Building, Dismantling, and Repair

Ship-related activities in Portland Harbor include ship building (1800s–present), ship repair (1800s–present), and ship dismantling (1960s–1979). In the early 1900s, ship building plants in the harbor constructed various types of wooden and steel vessels, including ocean-going and river boats. A 1919 Dock Commission map (CPD 1919)

lists seven facilities producing wooden boats, four facilities producing steel boats, and two outfitting companies. The Grant Smith-Porter shipyard, at the present-day Mar Com North parcel, launched 25 wooden cargo ships in 1918 to support the Emergency Fleet Corporation (EFC) during World War I. This shipyard was the most prolific company in the EFC wooden ship program at this time. Prior to World War I, the steel ship building industry in the Pacific Northwest was not extensive due to the distance from steel-producing centers. Only one shipyard, just upstream from the Portland Harbor area, the Columbia River Shipbuilding Yard at RM 14W, produced steel ships for the EFC effort (Hopkins 1994). By 1935, the number of ship building facilities decreased to two: Albina Engine and Machine Works at RM 11E, and WISCO at RM 10W (CPD 1935).

Ship building accelerated again during the World War II years. Map 3.2-10 shows the general location of historical shipyards visible on aerial photographs taken between 1936 and 1969. Approximate areas of the former shipyards include RM 4E (Oregon Shipbuilding Corp.), RM 5.6E (U.S. Shipping Board), RM 6.7E (St. Johns Dry Docks, also called the Port of Portland Dry Docks on the CPD [1935, 1945] maps), RM 7.4E (Peninsula Ship Building Co.), RM 9E Swan Island (U.S. Maritime Commission), RM 9W (American Ship Dismantlers), RM 10W (WISCO), and RM 11E (Albina Engine and Machine Works).

As the demand for new ships increased, industrialist Henry Kaiser built two large shipyards, including the Oregon Shipbuilding Corp. shipyard at the present-day International Slip and the Swan Island shipyard. The Gunderson Brothers Engineering Group (RM 8.5–9.2W) also increased its plant's capacity to build small vessels. Besides Liberty ships, these facilities built small aircraft carriers, T-2 tankers, and a variety of landing craft that delivered troops, tanks, trucks, and supplies to combat zones. The population of Portland increased by a third as people moved into the city to work in the shipyards (Portland Tribune 2009; Oregon Historical Society 2002).

After the war ended, the salvaging of Liberty ships continued to fuel Portland's economy. Zidell Exploration Company salvaged many of the Liberty ship parts, except for the bows, which were reinforced with concrete when they were built. Many of these ship bows were buried along the west side of the Willamette just north of the Broadway Bridge. Ship dismantling and scrapping also took place at other facilities in Portland Harbor, such as Consolidated Builders, Inc., a Kaiser affiliate, which scrapped decommissioned troop landing ships at Swan Island for a short time, and American Ship Dismantlers located at the present-day Gunderson site (Portland Tribune 2009) and in the International Slip.

Ship repair also occurred at several facilities. Ship repair and related maintenance was conducted at the former St. Johns Dry Docks (aka Port of Portland Dry Docks) at Willamette Cove between 1903 and 1953, at Albina Engine and Marine Works between 1904 and 1971, and at Mar Com between 1905 and 2004. Other sites with historical ship repair activities include the Triangle Park and U.S. Moorings sites.

Ship-related activities continue at a much smaller scale in Portland Harbor today, with most work focused on ship maintenance and repair. At Vigor Industrial on Swan Island (formerly Cascade General), current activities at the dry docks include hull repair, maintenance, painting, and other dry lay-up ship repair tasks. The U.S. Moorings site (RM 6W) continued to do vessel repair until 2008. More than 2,000 marine vessels have been built at the Gunderson facility (RM 10.5W) since the 1960s, including ocean-going barges, conventional deck barges, double-hull tank barges, railcar/deck barges, dump barges, and barges for aggregates and other heavy industrial products.[14] Houseboats and sailboats are currently being built at RM 5.8W.

Chemicals such as VOCs, SVOCs, PAHs, PCBs, TPH, copper, zinc, chromium, lead, mercury, phthalates, and butyltins are identified as common contaminants associated with ship building, salvaging, and repair in studies by the National Shipbuilding Research Program (NASSCO 1999) and USEPA's Office of Compliance (USEPA 1997a), as well as USEPA's Industrial Stormwater Fact Sheet Series (USEPA 2006c). The antifouling paint applied to ships during World War I contained significant amounts of both zinc oxides and mercury oxides (Williams 1911). In modern times, antifouling paints are formulated with toxic copper, organotin compounds, or other biocides—special chemicals which impede growth of barnacles, algae, and marine organisms. In the 1960s and 1970s, commercial vessels commonly used bottom paints containing tributyltin ion (TBT), which has been banned by the International Maritime Organization (IMO 2002) due to its serious toxic effects on marine life.

3.2.3.1.2 Wood Products and Wood Treating

The wood product industry has a long presence in Portland Harbor and has included wood-treating facilities (1944–1991), sawmills (1800s–1977), and plywood manufacturers (1905–2001), each with its own unique COIs. A 1919 Dock Commission map (CPD 1919) shows eight docks in the harbor devoted to lumber, the largest of which was Peninsula Lumber Company located at RM 7.4E on the McCormick and Baxter site and a portion of the Triangle Park site. Wood products created during this time included wooden barrels and box shooks (or box parts), which were shipped to fruit-growing areas or filled with local produce and railed to their destinations. The lumber industry grew exponentially during the war years, when barges pulling floating logs were a common sight in Portland Harbor. By 1977, the last sawmill in Portland was dismantled (MacColl 1979).

Lumber mills and wood treatment facilities operated at various locations within the study area historically, primarily RM 6.9 to 7.2E (Map 3.2-13). One of the largest sites was McCormick and Baxter, which produced treated wood for over 45 years. Other facilities that had wood-treating operations include West Oregon Lumber Co. (located at the Owens Corning-Linnton site) and Kingsley Lumber (at the Georgia Pacific-Linnton site). Wood-treating products used at these facilities include creosote/diesel oil mixtures, pentachlorophenol (PCP)/diesel oil mixtures and associated dioxin

[14] Gunderson Marine: http://www.gbrx.com/Marine_Barges_Home.php?expandable=2.

contaminants, and a variety of water- and ammonia-based solutions containing arsenic, chromium, copper, and zinc (Integral and GSI 2005a,b,c; USEPA 2004a, 2006d).

The present-day Georgia-Pacific Linnton facility (RM 3.6W) was formerly occupied by a sawmill, creosote plant, a lumber storage facility, and, before the site was mothballed in 1997, a wood chip transfer facility. The historical sawmill was owned by the Kingsley Lumber Company and ceased operations in the late 1960s. A sawmill also operated at the current Mar Com South property for almost 50 years. An additional sawmill operated in the central parcel of the Willamette Cove site from the 1950s until the early 1960s (Hart Crowser 2003). The Alder Creek Lumber Company in the Multnomah Channel has been the site of lumber-related activities (log storage, sawmill, lumber, planing) since its development in 1959 (Integral and GSI 2005a,b,c). While most of the byproducts of these operations were organic materials, contaminants typically associated with saw mills include wood preservatives (e.g., arsenic compounds, copper compounds, chromium compounds, pesticides, fungicides, biocides, borates, PCP, creosote, etc.), solvents, heavy metals, acid/alkaline wastes, benzene, TPH (oil, grease, diesel, gasoline), and PAHs (USEPA 2006d).

Various pesticides and fungicides have been used in glues and surface treatments in the plywood manufacturing process (Stellman 1998). The first plywood panels to be manufactured from western woods were made in St. Johns, Portland, at the Plywood Manufacturing Co. in 1905 (PPA 1967). The last plywood manufacturer in the harbor, Linnton Plywood, closed in 2001. The St. Johns Lumber Company (aka Portland Lumber Mill, Portland Manufacturing Co.) operated on the present-day Crawford Street and City of Portland Bureau of Environmental Services (BES) Water Pollution Control Laboratory sites from the 1930s until 1974 when the mill was demolished (Integral and GSI 2005a,b,c). A plywood manufacturing plant was also located on the west parcel of Willamette Cove upland facility (RM 6.3E) from 1901 until 1963 when it became a lumber mill. Building materials such as lumber, plywood, and laminated veneer lumber products were produced at Linnton Plywood and the western parcel of Willamette Cove. Linnton Plywood used phenol-formaldehyde resin, sodium hydroxide, and petroleum hydrocarbons, such as oil, diesel, and kerosene in its plywood manufacturing process (Integral and GSI 2005a,b,c). Contaminants associated with plywood manufacturing include VOCs, SVOCs, TPH, and metals (USEPA 2006d). Transformers associated with the operations can include the potential for PCB releases and the use of boilers can result in dioxin/furan releases from burning waste fuels. Additionally, solvents, heavy metals, acid/alkaline wastes, benzene, TPH (oil, grease, diesel, gasoline), and PAHs can be associated with ancillary operations, such as maintenance and repair, at the facility.

3.2.3.1.3 Chemical Manufacturing and Distribution

Within the study area, some facilities manufactured chemicals and some stored, repackaged, and/or distributed chemicals. Chemical plants, including Arkema and Rhone Poulenc (RM 6.8–7.5W) that manufactured pesticides and herbicides, were in place as early as 1941 (Map 3.2-14). The Arkema facility was an organic and inorganic

chemical manufacturing facility that produced sodium chlorate, potassium chlorate, hydrochloric acid, perchlorate and DDT at various times until operations ended in 2001. At the former Rhone Poulenc facility, fertilizers and organic and inorganic pesticide formulations, sodium arsenite liquids, organochlorine insecticides and chlorophenoxy herbicides, acid/esters, and bromoxynil products were produced during its 49-year history (1942–1991). Transloading facilities such as Port Terminal 4 and Slips 1 and 3 have been used for ship loading of fertilizer and soda ash that have been unloaded from rail transport.

The Great Western Chemical Company (aka Quadra Chemicals Western and Brenntag Pacific on the present-day McCall Oil site) at RM 7.9W produces water treatment chemicals, dry and liquid industrial cleaning agents and sanitizers, oxygen scavengers, and steam-line treatment chemicals (Integral and GSI 2005a,b,c). Other manufacturers in the study area included Premier Edible Oils (edible oil), West Coast Adhesives (phenolic resins), JR Simplot (urea and anhydrous ammonia), ACF (waste treatment and disposal), Ash Grove Cement (cement), Master Chemical (janitorial cleaners), Mammal Survey & Control Service (rodenticides), Mt. Hood Chemical Corp. (cleaning supplies), and McWhorter Inc. (varnish, paint, and resins). These sites are also identified on Map 3.2-14.

A number of facilities packaged, stored, and/or distributed chemicals. Van Waters & Rogers (aka Univar) handled a wide range of industrial chemicals, including organic solvents, acids and bases, ammonia, and other materials, until it ceased operations in 1988. Other chemical distributors included Great Western Chemical at RM 9.2W on the Chase Bag site (chemicals unknown), Wilbur Ellis (pesticides and herbicides), Ashland Chemical (primarily solvents), and McKesson (Mt. Hood Chemical Property—food additives, pharmaceuticals, and mineral acids).

Contaminants associated with chemical manufacturing operations can vary, depending on the operations, but could include pesticides, herbicides, VOCs, SVOCs, dioxins/furans, and metals (USEPA 2006e). Transformers associated with the operations can include the potential for PCB releases, and the use of boilers can result in dioxin/furan releases from burning waste fuels. Additionally, solvents, heavy metals, acid/alkaline wastes, benzene, TPH (oil, grease, diesel, gasoline), and PAHs can be associated with ancillary operations, such as maintenance and repair, at the facility.

3.2.3.1.4 Metal Recycling, Production, and Fabrication

Recycling, production and fabrication, and plating of metals occurred at several locations within the study area.

Metal salvage and recycling facilities operated in the study area (Map 3.2-15) at RM 4E (Schnitzer Steel—auto and appliance dismantling), RM 5.8W (Marine Finance), RM 7.2W (Gould/NL Lead), RM 7.3W (Schnitzer-Doane Lake), RM 8.5W (Calbag Metals), RM 8.8W (Gunderson—auto dismantling), RM 9.5E (Portable Equipment Salvage), RM 9.7W (Schnitzer Steel Recycling Yard on NW Yeon), RM 9.8W

(Nudelman & Son), and RM 10.3W (Calbag-Nicolai). The metals recycling business includes cutting, torching, segregating, storing, and distributing metals, as well as recovering metals from wire. The Gunderson facility has manufactured and refurbished railcars since 1913. Railcars were also refurbished at the ACF Industries property (RM 3.7W) for almost 23 years (Integral and GSI 2005a,b,c).

Metal production and fabrication currently takes place in the Burgard Industrial Park, and several sites in the RM 8 to 10.3W reach, including Dura Industries, NW Copper Works, American Machine & Gear (RM 9.8W), and two non-ECSI sites, Portland Bolt & Manufacturing (RM 9.6W) and The Willard Storage Battery Company, which manufactured storage batteries at the Chase Bag site from approximately 1952 to 1958.

The Columbia American Plating site operated as a commercial plating (primarily zinc) facility between 1975 and its closure in 2003. Contaminants associated with metal recycling, production, and fabrication industries are dependent upon the activities conducted, but generally include PCBs, oil and grease, lubricants, paint pigments or additives, ionizing radioactive isotopes, transmission and brake fluids, fuel, battery acid, lead acid, antifreeze, benzene, chemical residue, heating oil, petroleum products, solvents, infectious/bacterial contamination, asbestos, cyanide, phthalates, and heavy metals (USEPA 2006f,g,h,i). Ancillary operations, such as repair and maintenance, can produce these contaminants from hydraulic fluids, oils, fuels, grease and other lubricants, chemical additives, PCBs, fuel additives, antifreeze (ethylene glycol), battery acid, products of incomplete combustion, heavy metals, chlorinated solvents, mineral spirits, industrial solvents, immersion cleaners, dry cleaner solvents, paint solvents, and spent antifreeze.

3.2.3.1.5 Manufactured Gas Production

MGP operations took place between 1860 and 1955. Portland Gas & Coke constructed an oil MGP facility, known as Gasco at RM 6.5W (Map 3.2-16), which operated between 1913 and 1955. The plant initially produced town gas and pressed lampblack briquettes that were sold in the Portland area as fuel. In 1923, the gasification process was modified to optimize aromatic generation and light oil recovery for use as motor fuel. Tar recovery and refining were incorporated into the process in 1925 to provide tar for use as a road binder. During the 1930s, the plant expanded, and in 1941 a coking plant began production of electrode grade coke and high-grade natural gas (HAI 2003). The Pintsch Compressing Company Gas Works at RM 11.7W operated between 1890 and the mid-1930s and manufactured compressed gas from crude oil for railroad train lighting. Just upstream from the study area, the Portland MGP site operated at RM 12.2W between 1860 and 1913. As the wastes produced by former manufactured gas plants are persistent in nature, they often (as of 2009) still contaminate the site of former manufactured gas plants: the waste causing the most concern today is primarily MGP tar (mixed long-chain aromatic and aliphatic hydrocarbons, a byproduct of feedstock carbonization), and purifier waste (composed of "purifier beds" made up of either lime or wood chips impregnated with iron filings and contaminated with sulfur and cyanide compounds from passing the gas through it). Contaminants associated with

manufactured gas operations include VOCs (benzene, toluene, ethylbenzene, and xylenes [BTEX]), SVOCs, PAHs, TPH, metals, and cyanide.[15]

3.2.3.1.6 Electrical Production and Distribution

Electrical transformers and capacitors are associated with nearly all of the major industries in the harbor. Transformers and capacitors historically contained and may continue to contain PCBs. There are seven current substations and one historical substation in the study area (Map 3.2-17). The PGE Harborton Substation at RM 3.3W currently consists of an operating 115-KV switchyard and distribution substation for electrical power regulation and transmission (Integral and GSI 2005a,b,c). PGE also operates Substation E (RM 10.4W), and other substations at Swan Island (RM 9.3E), Siltronic (RM 6.4W), and Willbridge Terminal (RM 7.5W). The PacifiCorp Knott Street substation is located at RM 11E, which is associated with a high-voltage cable crossing at RM 11.3. The remaining active substation is operated by Schnitzer Steel (RM 4E, near the International Slip). Bonneville Power Administration operated a substation at the Arkema site and conducted site cleanup after decommissioning the substation.

Electrical equipment repair, servicing, and salvaging operations occurred on the east bank from RM 11.3 to 11.5, including the Tucker Building (former electrical distribution and limited small transformer repair), Westinghouse (former transformer repair and servicing), and PacifiCorp Albina Substation Properties (Block 71, 81, and 82; electrical distribution only); at RM 3.7W (ACF Industries); RM 9.5E (Portable Equipment Salvage); RM 9.5W (GE Decommissioning); and RM 10W (GE facility at NW 28th Ave). The GE Decommissioning facility handled dielectric fluids containing PCB concentrations greater than 50 ppm up until 1978 after the enactment of the Toxic Substances Control Act (TSCA; AMEC 2004b). These fluids were drained from customer-owned equipment into temporary aboveground holding tanks or drums. Often these fluids were returned to the equipment following service or repair (AMEC 2004b). The GE facility at RM 10W conducted repairs from the mid-1990s to 2001, including decommissioning of custom transformers. From 1943 to 1978, the Westinghouse facility at RM 11.3E conducted electrical transformer repair services and purportedly handled dielectric fluids containing PCBs. Contaminants associated with electrical production and distribution include PCBs, TPH, and PAHs (Pfafflin and Ziegler 2006).

3.2.3.1.7 Bulk Fuel Distribution and Storage and Asphalt Manufacturing

Bulk fuel facilities have a long history in Portland Harbor. By 1936, most of the facilities currently in place between RM 4 and 8 on the west side of the river had already been established (Map 3.2-18). These facilities include ARCO's BP Terminal, Kinder-Morgan, Willbridge Terminal, Christenson Oil, ExxonMobil, Texaco Equilon, and Foss/Brix Maritime. Five additional facilities were located on the east side of the river in the RM 3 to 5 reach: Time Oil owned and operated at two facilities, and three

[15] Heritage Research Center: http://www.heritageresearch.com/documents/More%20About%20Manufactured%20Gas.pdf

facilities were located at the Port of Portland Terminal 4 (Standard Oil, Quaker State Oil, and General Petroleum Corp.).

These facilities have handled a variety of petroleum products, including lubricating and specialty oils, bunker fuel, diesel fuel, gasoline, ethanol, gasoline additives (e.g., methyl *tert*-butyl ether [MTBE], ethylene dibromide [EDB], ethylene dichloride [EDC], lead), aviation fuel, and various lubricants. Petroleum product pipelines are also found throughout the study area.

Another petroleum product, asphalt, is manufactured at several facilities on the west side of the river, including Owens Corning Linnton (RM 3.8W), GS Roofing (RM 7.5W), McCall Oil (RM 7.9W), Chevron Asphalt Refinery (RM 8W), and Trumbull Asphalt (RM 9.1W). The Municipal Paving Plant at RM 10.9E was constructed in 1928 and operated intermittently until its permanent closure in 1966.

Contaminants typically associated with bulk fuel storage operations and asphalt operations include VOCs (benzene), SVOCs, PAHs, TPH (oil, gas and diesel fuels), and metals (USEPA 2006j). Additionally, gas/diesel fuel, fuel additives, oil/lubricants, heavy metals, brake fluids, transmission fluids, chlorinated solvents, and arsenic can be associated with ancillary operations, such as maintenance and repair, at these facilities.

3.2.3.1.8 Steel Mills, Smelters, and Foundries

Since the early 1900s, metal foundries have been located in Portland Harbor (Map 3.2-19). For the first 30 years, these foundries served as suppliers of cast steel alloy products for the logging, construction, and pulp and paper industry throughout the Pacific Northwest. Today, these foundries manufacture products for a multitude of industries, including mining, highway and heavy construction, utilities and general construction, power generation, aerospace, defense, dredging, forestry, rigging, conveying, as well as many other industrial applications. Steel foundries are located at RM 2.8E (Consolidated Metco), RM 9.7W (Schmitt Forge), RM 10.4W (ESCO Main Plant), RM 10.5W (ESCO Plant 3), and RM 11.4W (Gender Machine Works). Lead smelters were located at RM 7.2W (Gould), at RM 9W (National Lead/Magnus Smelter), and at RM 11.6W (RiverTec Property). In addition to lead smelting, facility operations at the Gould site included lead-acid battery recycling, zinc alloying and casting, cable sweating, and lead oxide production. The present-day Wilhelm Trucking site at RM 9.6W was the former location of a lead bearing rehabilitation plant. Steel mills were located at RM 2.4E (EOSM) and at RM 8.3W (former Oregon Steel Mill operation at Front Ave LP). Only the EOSM property is currently operating, confined to steel production, steel processing, and related ancillary operations.

Besides metals, other contaminants associated with these types of operations include TPH (from oil, gas, and diesel fuels) and PAHs. PCBs were a component of hydraulic fluid for high temperature applications (machining, die casting) where fire resistance was important. PCBs were also a component of heat transfer fluid used in big applications like heat exchangers and recirculating cooling systems (USEPA 2004b).

Additionally, gas/diesel fuel, fuel additives, oil/lubricants, heavy metals, brake fluids, transmission fluids, and chlorinated solvents can be associated with ancillary operations, such as maintenance and repair, at these facilities (USEPA 2006g).

3.2.3.1.9 Commodities Maritime Shipping and Associated Marine Operations

At the turn of the 19th century, Portland Harbor accommodated steamboats that transported farm products and natural resources from Idaho, eastern Washington, and Oregon. This cargo was then loaded onto sailing ships for markets in Asia, the eastern and western United States, and Europe. Portland Harbor also served as the gateway for incoming trade goods to the region. On the 1919 Dock Commission map (CPD 1919) there were docks dedicated to the distribution of shingles, cans, asphalt, sand and gravel, cereal, flour, grain, and vegetable oil.

The Port of Portland facilities have had a prominent presence in the maritime commodities shipping industry in Portland Harbor since 1891. Over the years, export/import of agricultural products, dry/liquid bulk products (pencil pitch), forest products, and other bulk commodities have passed through Port facilities (Terminals 1, 2, 4, and 5). Currently, the Port operates two deep-water marine terminals, Terminals 4 and 5, within the study area that handle thousands of tons of cargo each week. Major exports handled at Terminals 2 and 4 (Map 3.2-20) include wheat, soda ash, potash, and compressed hay. The Port's operations in Portland Harbor constitute the third-largest export center for grain in the world and the largest wheat export port in the United States (Williams 2007). Major imports include automobiles, steel, and limestone.

Other privately owned commodity shipping facilities in the harbor include or have included the grain handling operations at CLD Pacific Grain (RM 11.4E) and Centennial Mills (RM 11.3W), edible oils at the former Premier Edible Oils facility (RM 3.6E), scrap metal export at International Terminals (RM 4E), cement import and distribution at Glacier NW (RM 11.3E), as well as other non-ECSI sites. JR Simplot in the South Rivergate Industrial Park (RM 3E) has been distributing anhydrous ammonia and solid and granular urea to the Pacific Northwest since 1968. Goldendale Aluminum at RM 10E was used as an offloading facility (alumina, electrode binder pitch, and grain) from 1957 until 2001 (Integral and GSI 2005a,b,c). Sand and gravel operations have occurred at the Ross Island Sand & Gravel facility at RM 11.1E since at least 1920 (Landau 2002b).

Contaminants for the commodities maritime shipping industry include spillage of raw materials during transport to and from vessels; butyltins, copper and zinc from ship hull paints; and oil, lubricants and grease from overwater transport equipment (USEPA 2006k). Supporting maritime activities include overwater tug and barge moorage, maintenance and repair facilities, overwater bunkering and lightering, tug-assisted and independent maneuvering of vessels in and around marine facilities, and stevedoring (loading and discharging) product at vessels. Contaminants such as gas/diesel fuel, fuel additives, oil/lubricants, heavy metals, brake fluids, transmission fluids, and chlorinated solvents can be associated with these support activities (USEPA 2006k).

3.2.3.1.10 Rail Yards

In addition to the construction of commodity shipping facilities, railroads were constructed in the early 1900s to support the overland transport of farm products and natural resources from Idaho, eastern Washington, and Oregon. Rail tracks, yards, and terminals are located in the Portland Harbor area. Rail yards are found on the eastern side of the river at approximately RM 9.8 to 11.1 (Union Pacific Railroad [UPRR] Albina Yard) and RM 4.6 (UPRR – St. Johns Tank Farm), and on the western side of the river from RM 8.6 to 9.5 (Portland Terminal Railroad Guilds Lake Yard) and RM 8.1 (Burlington Northern Santa Fe Railway Co. [BNSF] Willbridge Switching Yard) (Map 3.2-21). These rail yards support the interstate railroads, BNSF, and UPRR.

Primarily operating as switching yards, some rail yards offer locomotive fueling and servicing, railcar maintenance, and trailer-on flatcar storage. Railcar switching yards (RM 8.1W—BNSF Willbridge Switching Yard) are locations where trains are assembled and disassembled (and this type of operation typically does not result in releases or produce waste streams). Historical rail yard operations were also located on the western side of the river at RM 11.6 (BNSF Hoyt Street Railyard, and UPRR Union Station operations). BNSF owned and operated the Hoyt Street Railyard from the early 1900s until 1988. The rail yard has been abandoned and dismantled, and much of the site has been developed as condominiums and commercial businesses. Historical railcar maintenance operations were also located at RM 3.7W (ACF Industries).

Contaminants associated with rail transportation facilities are dependent upon the activities conducted, but could include PCBs, oil and grease, lubricants, paint pigments or additives, transmission and brake fluids, fuel, battery acid, lead, antifreeze, chemical residue, petroleum products, solvents, asbestos, phthalates, and heavy metals (USEPA 2006l). Ancillary operations, such as repair and maintenance, can produce these contaminants from hydraulic fluids, oils, fuels, grease and other lubricants, chemical additives, PCBs, fuel additives, antifreeze (ethylene glycol), battery acid, and products of incomplete combustion, heavy metals, chlorinated solvents, mineral spirits, industrial solvents, immersion cleaners, paint solvents, and spent antifreeze. Contaminants associated with fueling activities and freight car repair operations at rail yards could include VOCs, SVOCs, TPH, PCBs, and metals (USEPA 2006l; DEQ 2011a).

3.2.3.1.11 Conveyance Systems

This section describes the historical and current conveyance systems in the study area, including both municipal and non-municipal systems. Non-municipal systems are either private or part of other public systems, such as ODOT or the Port of Portland.

General Description of Conveyance Systems

There are three types of conveyance pipes in Portland Harbor. The following is a description of the types of flows each pipe carries and its discharge points:

- **Sanitary Pipes:** These pipes convey sanitary wastes from domestic and industrial sources, and may also carry industrial wastewater. Flows in these pipes discharge to the Columbia Boulevard Wastewater Treatment Plant (CBWTP), which discharges to the Columbia River at two discharge points (RM 105.5 and 105.6), approximately 4 miles upstream of the Willamette River confluence. Sanitary pipes are typically part of the City of Portland's collection system, although there are sanitary pipes on private property that connect to the municipal system.
- **Stormwater Pipes and Other Point Discharges:** Stormwater conveyance systems typically consist of ditches, swales, storm drains, inlets and catch basins connected to an outfall through pipes or lines. Flows in these pipes typically discharge to the river, although some may discharge to lakes or infiltration facilities. Stormwater pipes can be part of the municipal collection system or part of a non-municipal system.
- **Combined Pipes:** Combined pipes convey sanitary wastes from domestic and industrial sources and stormwater, and may also carry industrial wastewater. Historically, these flows typically discharged to the river. After combined pipes were connected to the sanitary interceptors, the outfalls draining these pipes were either converted to CSO outfalls or to storm-only outfalls. Historically, combined pipes were both municipal and non-municipal, but currently most combined systems are part of the City's collection system. Additional detail on how combined pipes function and the types of CSO outfalls is provided below.

Outfalls

Within the study area, outfalls have been installed by a variety of entities, including private landowners, the Port of Portland, the State of Oregon, and the City of Portland. Most of the outfalls currently convey primarily stormwater, although historically some also conveyed industrial and sanitary discharges.

Some outfalls also currently convey nonstormwater discharges. Some nonstormwater discharges, such as noncontact cooling water, must be permitted, while other nonstormwater discharges, such as landscape irrigation, are exempt under federal regulation. As discussed below, some outfalls include a CSO component as well.

The City of Portland identified over 400 potential public and private outfalls along both shores of the study area (City of Portland 2006c). Using site-specific information and field reconnaissance, the LWG independently verified these outfalls and researched areas that potentially had additional outfalls. Incorporating results of the field reconnaissance, a total of 436 outfalls were identified; of these approximately 313 are active, 44 are inactive, 30 are abandoned, 15 have been removed, 27 are unknown outfalls, and 7 were determined to not be outfalls (Integral 2008h).

The types of outfalls are defined as follows:

- **Active** = outfall is currently in use
- **Inactive** = outfall pipe exists, and is not filled, plugged, or disconnected, but discharge is presently not occurring
- **Abandoned** = outfall pipe exists but it is filled, plugged, or disconnected, and discharge is not occurring
- **Removed** = outfall pipe has been removed
- **Unknown** = despite best efforts, the status of some outfalls cannot be determined.

Attributes for some outfalls in the data set remain flagged despite repeated attempts by the LWG to verify during fieldwork or due to conflicting information from the facility and the City. The location and status of the outfalls within the study area are shown on Maps 3.2-22a–m.

Stormwater Runoff

Stormwater enters the river via stormwater conveyances, overland flow, and infiltration to groundwater. Stormwater conveyance systems typically consist of ditches, swales, storm drains, inlets, and catch basins connected to the outfall through pipes or lines.

Overland flow of stormwater occurs at some locations immediately adjacent to the river. In many of these areas, the extent to which rainwater falling on pervious ground near the river shoreline results in runoff versus infiltration into the ground is unknown. In some impervious shoreline areas, stormwater appears to be transported to the river via overland flow, with little chance for infiltration into the ground. A preliminary assessment of outfall drainage basins conducted for the Round 2 Report indicated that the area drained by overland flow appears to be relatively small compared to the area in which stormwater is discharged via outfalls. Given the difficulties of defining all stormwater conveyance drainage basins along the river, the proportion of overland flow to the river has not been further quantified for this RI. Nevertheless, this pathway may represent a significant contaminant transport pathway route, especially as it relates to riverbank erosion.

Additionally, stormwater can enter the river indirectly via infiltration into pervious ground (or through dry wells, sumps, and other infiltration facilities), where it is then mixed with groundwater and discharged to the river as groundwater. Groundwater discharges are further discussed in Section 3.1.3 and Section 4.

Most of the stormwater from the west side of the river drains from Forest Park, an area which consists mostly of undeveloped parkland. Streams from Forest Park generally enter underground pipes at the base of the West Hills, near U.S. Highway 30. At this point, the highway stormwater drainage often enters these same conveyance systems. This runoff is comingled with industrial stormwater runoff as it moves through industrial properties between the park and the river. On the east side of the river, there are few open channel drainages, and most of the stormwater is discharged via

conveyance systems. Most properties adjacent to the river on both sides do not discharge through shared conveyance systems but directly discharge to the river via their own stormwater conveyance systems and outfalls or overland flow.

Just under half of the stormwater drainage to the study area is through shared conveyance systems; open space comprises about 60 percent of these basins. These systems are further discussed in Section 4.4.1.3 and include shared conveyance systems owned by the City, by Burgard Industrial Park, and by ODOT; multiparty outfalls with unknown ownership; and Saltzman Creek. In some locations, stormwater is captured by the City of Portland combined conveyance systems and is routed to CBWTP.

Section 4.4.1.2 further discusses the stormwater basins and the types of stormwater discharges, including a map showing a categorization of the different drainage types within the study area (i.e., shared conveyances, direct discharge, no discharge, and uncertain drainage).

Figure 3.2-1 shows the hydroboundary, the approximate overall area draining stormwater to the study area. The delineation of the overall drainage basin area between RM 1 and 11.8 was provided by the City of Portland (2006d). An analysis of stormwater flow contributions to overall river flows estimated that the Portland Harbor area runoff volume contributions are between 0.06 percent for the wet year conditions (1997) and 0.08 percent for dry year conditions (2001) of the total Willamette River flow. The average annual runoff volume for the Portland Harbor is 0.06 percent of the total Willamette River flow (City of Portland 2006d).

Municipal Conveyance Systems

This section summarizes information regarding the City of Portland's municipal conveyance system development in the study area. There are four major time periods discussed below. The initial period (1880–1947) was when most of the conveyances were combined systems. From 1948 to 1955, interceptors were installed and connected to most of the City's combined system (converting these outfalls to CSOs) and some separated systems were constructed. During the period from 1956 to 1990, sanitary service was extended to the northwest area and more separated systems were created. The final period describes the current conveyance systems and system development changes after 1990.

These pipe types are currently configured into three general types of conveyance systems in the study area, as shown in Figure 3.2-2: 1) separated systems, 2) combined systems that discharge to the CBWTP (with no discharge to the river), and 3) combined systems with overflow diverters designed to reduce discharge to the river to a maximum of four times per winter and once every three summers (City of Portland 2001b). Separated systems have stormwater-only lines that discharge to the river and sanitary-only lines that discharge to the treatment plant. In combined systems, the stormwater and sanitary lines join and flow in a combined line. Most of the study area is currently served by separate storm lines and separate sanitary sewers. Only a limited portion of

the area is served by the combined system, and not all of the combined system has the ability to overflow to the river. Stormwater and combined systems are further described below.

Historically, municipal and non-municipal combined and storm pipes discharged directly to the river. When sanitary interceptors were constructed, parallel to the riverbanks, they intersected the municipal combined trunk lines. The combined trunk lines were connected to the interceptor system. Diversion structures in the combined pipes, essentially dams, direct flows that exceed the interceptor capacity to overflow to the river as illustrated in Figure 3.2-3.

The overflow system was built to prevent the interceptor system from being overwhelmed during a storm event. This overflow system allows flows to breach the diversion dams and discharge the combined storm and sanitary sewage flows through an outfall to the Willamette River. Any sewer connections at points in the trunk lines above the diversion structures would overflow to the river only when rainfall caused an exceedance of the approximately three-times-dry-weather flow capacity of the system (City of Portland 1969). Discharges to connections at points in the trunk line downstream of a diversion or connections directly to the interceptor could not overflow to the river during a CSO event. On average, a typical CSO contains about 80 percent stormwater and 20 percent wastewater. Once the interceptors were put in place, the outfalls were referred to as CSO outfalls (CH2M Hill 1992; City of Portland 1952a, 2001b; Stevens & Thompson 1964).

Diversions from the combined system to the river (i.e., CSO events) occur before flows reach the interceptor. Once flows have entered the interceptor, these flows are directed to the treatment plant. During construction of the interceptor system, pump stations were added, some of which included emergency overflow lines that were connected to outfalls, which are known as sanitary sewer overflow (SSO) outfalls. Thus, after the interceptor connections were made, any sewer connections made directly to the interceptor pipe could not overflow to the river unless there was an emergency failure at a pump station. Figure 3.2-4 shows the location of the interceptors and the SSO outfalls.

1880–1947

The first municipal sewers in Portland Harbor were constructed by the cities of Portland, Linnton, and St. Johns, starting in the 1880s. These sewers were located in the downtown areas of each of these cities. The Linnton and St. Johns outfalls were transferred to the City of Portland when these cities were annexed into Portland, in 1905 and 1915, respectively. These combined sewers collected both surface drainage and sanitary wastes (including domestic and industrial discharges) and, as all private and public sewers did during this time period, discharged directly to the Willamette River (City of Portland 1966a).

In 1936, 48 municipal outfalls directly discharged to the Willamette River (City of Portland 1936), located between RM 4 and 17. Nineteen outfalls discharged within the study area; these were located in the downtown core (between RM 9.6 and 11.8 on both sides of the river), in the St. Johns area (between RM 5.2 and 5.9 on the east shore), and in the Linnton area (between RM 4.3 and 5.3 on the west shore).

During and immediately after WWII, the City operated six additional combined conveyance systems. Two of these were constructed by the City to serve residential-only areas in St. Johns (OF-48 and OF-49). Two were constructed by the Federal Housing Authority, built to serve temporary housing for wartime workers (OF-18 and OF-19). Two were constructed by private parties to drain their site and then were transferred to the City under Public Works permits (OF-20 and OF-21). OF-20 was abandoned in 1949 and flows were redirected to OF-19. Table 3.2-3 identifies the locations of outfalls, including those constructed during this time period.

Initial scoping of the Sewage Disposal Project included several interceptor sewers and a treatment plant discharging to the Columbia River (Smith 1936). Construction of this project began in 1947 (City of Portland 1952a).

1948–1955

During this time period, the CBWTP and the northeast and downtown interceptors were constructed, and combined flows from the municipal trunk lines were connected to the interceptors. As shown in Table 3.2-3, within most of the City CSO basins in the study area, industrial areas were separated so that industrial wastewater would not overflow to the river during CSO events. The exception to this was the industrial area in the north part of downtown on the west shore, where separation was more difficult because the area had already been heavily developed. Primary treatment (solids removal) was also added to the two Linnton outfalls as part of the effort to reduce loading to the river. Also during this time period, the City constructed new outfalls or accepted existing outfalls.

In 1947 the City Sewage Disposal Project began the construction of two interceptor lines (the east side and the west side) and a treatment plant (OSSA 1964). Construction of the interceptor lines diverted most flows to the newly constructed CBWTP.

The interceptor system in Portland Harbor, as of 1952, is presented on Figure 3.2-5 (City of Portland 1952a); additional work that continued through 1954 is not shown in this figure. The first unit of the interceptor sewer system (serving northeast Portland) was completed in 1947. The CBWTP and the interceptor system on the east side of the Willamette River were completed in 1952. The eastside interceptor system extended from the southern limits of the city north to the treatment plant but did not include the Rivergate area, which was outside the city limits at that time (City of Portland 1952b). Of the eastside CSO outfalls, OF-43 through OF-53 discharged to the Portland Harbor

study area.[16] During construction of the interceptor system, the City separated the sewers serving most of the industrial areas near the riverfront by building separated sanitary and industrial wastewater sub-basins connected directly to the interceptor, and separated stormwater systems that discharged directly to the river.

Some of these outfalls still had a combined system upgradient of the nearshore industrial separated area that served primarily residential areas. After the interceptors were installed, some properties that formerly discharged through private outfalls directly to the river had the opportunity to connect to the City's sanitary system (either to the new sanitary system installed or directly to the interceptor).

Also during this time, the City constructed a local treatment facility to provide primary treatment (solids removal) for the two Linnton outfalls (OF-23 and OF-24) that served primarily residential areas (City of Portland 1999).

By September 1955, the City had completed construction of the westside (including downtown) interceptors incorporating outfalls designated OF-1 through OF-17 (OSSA 1953, 1954a,b, 1955). Of these west side outfalls, OF-11 through OF-17[17] discharge to the Portland Harbor study area. Portions of the industrial area that had been connected to the combined system were connected to a separate sanitary sewer that discharged directly to the interceptor.[18] The areas with no separate storm and sanitary systems available continued to discharge to the combined system or discharged directly to the river. The interceptors and associated facilities reduced the volume of untreated sewage discharging to the Willamette from the City's combined system.

1956–1976

Once the eastside and downtown interceptors were installed, the only areas not served by City sanitary sewer system in Portland Harbor were the northwest (from Guild's Lake to Linnton), Swan Island, Mocks Bottom, and Rivergate areas (see Figures 3.2-5 and 3.2-6). The latter two areas were mostly undeveloped except for a few shoreline facilities. Conveyance systems in the northwest area were operated by private and City systems, and conveyance systems in the Swan Island area were operated by the Port of Portland.

During the time period of 1956 to1976, the City implemented a number of system changes to further reduce combined sewer discharges to the river, including programs to assure that properties connected to the City system were discharging to the appropriate pipe. The City constructed several separate sanitary and storm systems in areas that were undeveloped or were served by non-municipal combined systems. Also during this period, the City completed the northwest interceptor system, which separated stormwater and sanitary sewers in the northwest industrial areas and converted the

[16] OF-43 is at RM 11.4 and OF-53 is at RM 5.2.
[17] OF-11 is at RM 11.4 and OF-17 is at RM 9.6.
[18] Based on City as-built drawings for the interceptor and other separation projects. As-built drawings are available on the City's website: http://PortlandMaps.com.

Linnton neighborhood service areas to CSO areas. By 1975, the City's service area included both separated systems and CSO systems, including new separated systems in the Mocks Bottom/Swan Island and St. Johns areas to support industrial development.

Although the east side interceptor was operational by 1952, studies performed by the Oregon State Sanitary Service Authority (OSSA) in 1953 identified three outfalls upstream of Portland Harbor where bypass of sewage to the river occurred during dry weather periods (Stevens & Thompson 1964). For example, Stevens & Thompson (1964) estimated as much as 17 million gallons a day (dry weather flows) discharged from diversion structures south of the Sullivan Gulch Pumping Station upstream of Portland Harbor. After completion of the eastside and downtown interceptors, the City implemented a number of efforts to further reduce discharges to Portland Harbor, including the following (City of Portland 1966b):

- Expanding existing systems
- Adding pumping stations to pick up low areas below the interceptors
- Reconstructing or adjusting diversion structures (e.g., raising dams, adjusting orifice diameters, raising or lowing weirs)
- Rerouting combination sewers to discharge above rather than below diversions, thus eliminating dry weather (sanitary) flows from entering the river
- Where separated systems were constructed, requiring property owners to separate and reroute site sanitary and storm discharges to the appropriate system
- Requiring installation of pretreatment systems for industrial wastes
- Design of the Linnton-Guild's Lake sewerage system to provide facilities for diversion of dry weather flow for existing public sewers and to allow industry to connect to the City system, thus eliminating private industrial and sanitary outfalls to the river
- Design of a stormwater and sanitary system on Swan Island to replace the existing combined system.

In those areas where the City provided separate sanitary and stormwater systems, most properties rerouted their sanitary and stormwater discharges to the appropriate City conveyance. In 1967, the City established additional efforts to ensure compliance with the City's requirements for the separation of storm and sanitary wastes and connection to an approved sewer (City of Portland 1967a). These efforts included review of connection and plumbing records, field inspections, and dye testing to verify that property owners had appropriately rerouted their discharges within the City system. Only stormwater and uncontaminated cooling water could be discharged to the storm system, and only sanitary waste and approved industrial wastewater could be discharged to the sanitary sewer system. For example, in the fiscal year 1967–1968, 77 properties were investigated in Portland Harbor and 23 of these were required to reroute either their stormwater or wastewater (City of Portland 1969). By 1976, investigations and

rerouting of wastewater from storm lines to the sanitary sewer were completed (City of Portland 1976).

In the 1960s, the City replaced an existing non-municipal system with a separated sanitary and storm system on Swan Island and Mocks Bottom. In 1969, the City constructed sanitary lines to the International Slip area. In 1972, the City also built a storm system in the St. Johns area to allow development to occur in a previously undeveloped area (depicted in as-built drawings on Portland Maps).

A 1964 study by Stevens & Thompson focused on the sewer systems in the Guild's Lake-Linnton area in northwest Portland and in the area served by the east side interceptor (Stevens & Thompson 1964). Eight combined sewage/stormwater collection systems were identified in the Guild's Lake-Linnton area on the west side of the Willamette River, all within the current study area of the Portland Harbor Superfund Site. Most of the collection systems were noted to drain areas dominated by industrial and commercial activities and discharge directly to the Willamette River. This area encompassed drainage to outfalls currently designated OF-17 through OF-24A. Stevens & Thompson also indicated that there were 12 private outfalls in this area discharging industrial wastes (several discharging only cooling water) directly to the Willamette (Stevens & Thompson 1964).

Stevens & Thompson estimated future volumes in the system to assess design parameters for the needed new diversion structures. The analysis compared the 1964 capacities for different interceptor lines/areas against population and flow projections for 1980. Stevens & Thompson determined that increased flows in the southeast and northwest sections, roughly comprising outfalls OF-11 through OF-17 (west side, in the study area) and OF-26 through OF-38 (east side, upstream of the study area), respectively, would exceed capacity of the interceptors during periods of maximum flow in the future. However, Stevens & Thompson determined that other sections of the system would be overloaded even if the volume of sewage allowed to bypass diversions in these outfalls were reduced (i.e., if more sewage was diverted to the treatment plant). Based on the results of this study, Stevens & Thompson recommended new and renovated facilities to alleviate overloading and meet the Sanitary Authority's capacity requirements (Stevens & Thompson 1964).

In 1968, the City initiated sewer projects to direct sanitary sewage discharges directly to the CBWTP, including industrial wastewater discharges that were discharging directly to the river in the Guild's Lake-Linnton area. The 1968 projects included construction of a pumping station, the Portsmouth Tunnel, which crossed under the river to the CBWTP, and the northwest interceptor. Construction was completed the following year for the tunnel, pump station, and a portion of the northwest interceptor (from Guild's Lake to the Railroad Bridge) (City of Portland 1969). By 1973, the northwest interceptor (from the Railroad Bridge to Linnton) had been completed.

In summary, all City outfalls served by the northwest interceptor were separated, except for the two small residential combined basins in Linnton. Much of this northwest area was not previously served by City outfalls but rather discharged industrial waste directly to the river or to Doane Lake. The interceptor provided a means for industries to eliminate discharges to water bodies by routing their wastewater to the interceptor, although some industries continued to discharge to the river, including some under permits from the State.

1977–1990

During this time period, the City conducted studies to determine design parameters for future CSO controls and continued implementing programs to detect illicit connections. The City also constructed additional stormwater systems to provide storm service for areas that were being redeveloped or to improve existing drainage. The City incorporated into the municipal system some existing storm and sanitary lines in the newly annexed Rivergate area.

In 1972, the City estimated that the amount of combined sewage overflowing to the Willamette River and Columbia Slough was over 10 billion gallons per year (City of Portland 2001b).

In 1977, the CRAG undertook a study of the greater Portland area to evaluate municipal and industrial wastewater and urban stormwater, including the quality of the overflows from the City of Portland CSO system (CRAG 1977). The study provided a baseline for reevaluating Portland's CSO system. (Several of the reports cited below state different numbers of outfalls in the combined system; this most likely is due to the combination of two outfalls into one or the elimination of some outfalls during the time these reports were completed.) At the time of the CRAG study, there were 43 CSO outfalls in the City's entire Willamette River CSO system (25 on the east side and 18 on the west side), each draining a basin. Of the 43 outfalls discharging to the Willamette River, 16 discharged within the study area, and 27 were upstream of the study area up to RM 17.2. The resulting report contained descriptions of each outfall drainage basin, including acreage served, land-use type, pipe size, interceptor, diversions, and details on specific diversions, where applicable. The report also distinguished, in acreage, the type of collection system for each drainage area/outfall. Table 3.2-4 summarizes that information (CRAG 1977).

The CRAG study calculated the average annual runoff of suspended solids, settleable solids, biological oxygen demand (BOD), ammonia, phosphorus, and bacteria from CSOs in the City's entire CSO system, based on historical rainfall data. The study area focused on municipal outfalls discharging to the Willamette River that were within the City of Portland's boundary, and provided discharge estimates for 1975 and projected land use and conditions for the year 2000. Table 3.2-5 lists the 1975 results for suspended solids from the lowest downstream location to the highest upstream location measured.

In 1986 the City issued a Sewer Outfall Report, the purpose of which was to gather information to design future pollution abatement programs (City of Portland 1986). In the 1986 report, the City stated that the CSO system included 57 CSO outfalls, with 44 of the CSOs discharging to the Willamette River (16 of which were in the Portland Harbor study area), and 13 discharging to the Columbia Slough (City of Portland 1986). An outfall inspections program was instituted to include observations of the outfalls during the dry season to identify the condition of the outfall and to determine if the dry weather flow had any sanitary component. Dry weather flows could include groundwater infiltration, permitted and non-permitted process water (such as cooling water discharges and landscape irrigation), or illicit connections of sanitary discharges downstream of diversions. These dry weather flows were, and continue to be, analyzed for bacteria to determine if there is any sanitary contribution, and flow volumes are estimated where dry weather flows were evident (City of Portland 1986).

1990–Present

Sanitary interceptor lines run south to north through the main trunk lines, paralleling the riverbanks. Interceptors are large lines that collect sanitary and combined flows and direct them to the treatment plant. Some combined lines have diverters that allow excess flow to discharge to the lower Willamette River during heavy storms for a portion of the rainfall event; this is called a CSO. The diverters are designed to protect the interceptor from excess stormwater inflow by diverting the peak portions of the flow. Combined systems without CSO diverters direct all sanitary and stormwater flow to the treatment plant.

In 1991 the City began to further reduce the CSO events to the Willamette from about 100 events per year to four events per year in winter and one event every three summers by 2011 (City of Portland 2001b).

In 1994, it was estimated that the CSO system discharged an average of 4.8 billion gallons of stormwater (~80 percent) and untreated sewage and pretreated industrial waste (~20 percent) to the river between RM 4 and 17 (CH2M Hill 1994). The discharges occurred through 42 outfalls to the Willamette River, some of which overflowed nearly every time it rained (150 days), while others only overflowed 30 days per year (City of Portland 2001b). The City estimated an average of 50 CSO events (encompassing up to a total of 112 days) per year in the entire CSO system (City of Portland 1998).

Around this same time, it was determined that dry weather discharges of untreated sewage (including pretreated industrial wastewater discharges) were also still occurring in some portions of the City system due to periodic failure of the system to function properly, vandalism, illicit discharges, blockages caused by a variety of sources, and groundwater infiltration, which resulted in the discharge of untreated sanitary sewage through CSO outfalls directly to the Willamette River. These dry weather discharges involved relatively small volumes and are different than wet weather CSO events, which occur when the combined sanitary sewage and stormwater flows exceed the

system's capacity during rain events. The City completed improvements to the CSO system between 1992 and 1996, and signed a Stipulation and Final Order with DEQ in 1992 in which it agreed to eliminate the dry weather discharges by 1996 (DEQ 1996).

In 1994, the City prepared a CSO Management Plan with recommendations to address wet weather overflow discharges, including the following:

- Implementation of "Cornerstone Projects" focused on reducing the volume of stormwater to the system
- Implementation of storage and treatment facilities to eliminate the CSO discharges to the Columbia Slough as required in the Stipulation and Final Order
- Implementation of storage and treatment facilities along the Willamette River ("Big Pipe project") to control the CSO discharges as required by the Amended Stipulation and Final Order.

The City completed for the 20-year project in 2011 (City of Portland2012). As described in Table 3.2-3, the CSO abatement projects include one or more of the following for each outfall (City of Portland 2008b):

- Completely separating storm and sanitary to create stormwater-only outfalls with stormwater treatment prior to discharge, where possible
- Completely sealing and abandoning outfalls or diversions to prevent overflows
- Reducing stormwater flows to the CSO system to minimize flow through the system during a storm event, such that the system meets the Amended Stipulation and Final Order standard
- Increasing the storage capacity for the CSO system to reduce the frequency of overflows to meet the Amended Stipulation and Final Order standard.

The primary means for increasing the storage capacity was through construction of the West Side Tunnel (completed in 2006) and the East Side Tunnel (completed in 2011). The City also controlled 16 CSO outfalls by 2006 and all remaining CSO outfalls by 2011. The goal of the abatement projects was to meet the design standard to control CSO discharges to an average of four events in the winter (November 1 to April 30) and one event in three summers (May 1 to October 31; City of Portland 2005). Between 2006 and 2009, there were a total of five events for all Willamette River outfalls that were controlled by 2006—fewer than an average of two events per winter since completion of construction of the West Side tunnel. The overflow points in the study area were outfalls OF-11 and OF-47.

The abatement projects, including the West Side Tunnel and the final selected design for the East Side Tunnel, are projected to meet the current CSO system demands and design standard through the year 2025. This projection is based on the assumption that other City programs will continue to implement mitigation measures to reduce stormwater flow to the overall CSO system by initiating additional projects (e.g.,

infiltration basins, green roofs, and other such stormwater reduction measures). The City has noted that additional efforts would be required to control CSO demands beyond 2025 (City of Portland 2005). The configuration and dates of the abatement project for the separate and combined sewer systems is shown on Figure 3.2-4.

The location and status of CSO outfalls, including a summary of abatements completed within the study area, is provided in Table 3.2-3 and shown in Maps 3.2-22a–m.

Table 3.2-3 also identifies whether stormwater from fully separated CSOs (i.e., where sanitary wastewater is sent to the CBWTP and stormwater is discharged to the lower Willamette River) was diverted to a different outfall or still utilizes the former CSO outfall; whether a partially separated CSO system conveys the combined sanitary and industrial wastewater and significantly reduced stormwater to the CBWTP except during extreme wet weather events when a portion of the combined flow overflows to the Willamette River due to capacity limitations; and shows the combined or CSO outfalls that were abandoned before the City's 20-year abatement program was initiated.

Non-Municipal Conveyance Systems

As described in Section 3.2.2, most historical industrial development occurred along the shoreline. At least through the 1960s, very few shoreline facilities were connected to the municipal systems; nearly all managed their own stormwater and wastewater. Most of these discharges were combined (i.e., included stormwater and sanitary and/or industrial wastewater) (OSSA 1950; DOI 1967; Stevens & Thompson 1964). Figure 3.2-6 shows the areas not served by the interceptors in 1963; these areas were predominantly shoreline properties (OSSA 1963). Many of the non-municipal conveyance systems served a single property, but there were several larger shared conveyance systems noted in historical reports such as the Oregon Terminals (currently International Slip) (OSSA 1963) and Swan Island (CH2M Hill 1957).

The Rivergate area was undeveloped until about the 1960s. Separate sanitary and storm systems were installed by the Port of Portland to provide conveyance services to this developing area. The Rivergate area was annexed into the City of Portland beginning in 1979 and was completed in 1989, and some of these conveyance systems were transferred to the City after annexation.

The OSSA conducted several surveys of industrial dischargers in Portland Harbor (OSSA 1963, 1966), and beginning in 1967, required waste permit applications to be submitted by dischargers (OSSA 1967a). Additional information about the State discharge permits is provided in Section 4.3.1.4.

National Pollutant Discharge Elimination System Permits

The Clean Water Act (CWA) prohibits any entity from discharging "pollutants" through a "point source" into a "water of the United States" unless they have an NPDES permit. The permit contains limits on what can be discharged, monitoring and reporting requirements, and other provisions to ensure that the discharge does not hurt water

quality or people's health. In essence, the permit translates general requirements of the CWA into specific provisions tailored to the operations of each permittee discharging pollutants.

The NPDES Stormwater Program, which commenced in 1992, regulates stormwater discharges from three potential sources: municipal separate storm sewer systems (MS4s), construction activities, and industrial activities. Most stormwater discharges are considered point sources, and operators of these sources may be required to receive an NPDES permit before they can discharge. The State of Oregon is authorized by USEPA Region 10 to implement the NPDES Stormwater Program and administer its own stormwater permitting programs.

Current discharges to the lower Willamette River within the study area are regulated by a variety of NPDES permits, including multiple general NPDES stormwater permits (e.g., 1200-Z, 1200-C); the City of Portland, Port of Portland, and Multnomah County MS4 NPDES discharge permits; the City of Portland NPDES wastewater discharge permit (primarily for the discharge from the CBWTP to the Columbia River, but also including CSOs and sewer system overflows into the lower Willamette River); individual stormwater NPDES permits; and individual wastewater NPDES discharge permits. ODOT also has its own MS4 NPDES discharge permit for runoff from state highways. These permits are described further in Section 4.4.1.4. Many stormwater discharges are not regulated through MS4 or NPDES permits.

3.2.3.1.12 Federal Navigational Channel

Congress authorized the lower Willamette River as a federal navigation project through the Rivers and Harbors Act in June 1878. Its purpose was to deepen and maintain parts of the Columbia and Willamette rivers to a 20-ft minimum depth. The USACE maintains the channel for both rivers, both of which have been deepened at various intervals since that time. Most significantly, the authorizations affecting the lower Willamette River depth occurred as follows: –25 ft CRD in 1899, –30 ft CRD in 1912, –35 ft CRD between 1930 and 1935, and, finally, –40 ft CRD in 1962.

The current project authorization, as modified by Congress in 1962, encompasses 11.7 miles of the Willamette River in Portland and 103.5 miles of the Columbia River below Vancouver, Washington. Work on the authorized –40-ft-deep CRD channel from Portland and Vancouver to the Pacific was completed in 1976. The Willamette River channel from the Broadway Bridge (RM 11.7) to the mouth (RM 0) varies in width from 600 to 1,900 ft, with an average width of approximately 1,700 ft.

In 1999, Congress authorized the Willamette River (and Columbia River) deepening to –43 ft CRD. The existing 600-ft-wide, 40-ft-deep Willamette River navigation project channel would be deepened from RM 0 to RM 11.6 (USACE 1999c).

3.2.3.1.13 Dredging and Capping Activities

This section presents Portland Harbor dredging and capping activities since 1997. This date corresponds to the oldest data used in the presentation and evaluation of analytical data in this report. This section also notes ongoing and upcoming dredging projects in Portland Harbor.

In certain areas of Portland Harbor, periodic dredging is necessary to maintain the authorized depth of the navigation channel, as well as to maintain operational depths at docks and wharfs. Major changes in the river's bathymetry from 1888 to 2001 are depicted on Map 3.1-13. This map shows how the original shoreline was altered and filled, where material was excavated to create new uplands, and how most of the original channel has been deepened by at least 10 to 20 ft to reach the authorized federal navigation channel depth of –40 ft CRD. Historically, periodic dredging was needed to maintain this depth in two major shoaling areas, between RM 8 and 10, particularly in the western half of the channel, and from RM 2 to 2.5 in the eastern portion of the channel. The navigation channel has not been dredged since January 1997, although dredging at various docking facilities has occurred on an as-needed basis (Map 3.2-23).

Currently, maintenance dredging has been suspended until issues are resolved regarding dredging within the boundaries of the Portland Harbor Superfund Site. The lack of maintenance dredging over the past 10 years has resulted in significant shoaling of the channel. Many areas of the channel are now less than 40 ft deep, which is a significant navigation hazard to large cargo ships that require a minimum draft of 40 ft. A critical area of shoaling in the river that needs immediate attention is Post Office Bar at RM 2. According to the USACE (2010a), this dredging was proposed for completion in the summer of 2011.

Dredging projects undertaken since 1997 by the Port of Portland, USACE, the City of Portland, and private parties are listed in Table 3.2-6. This table is an update of a similar compilation provided in the Programmatic Work Plan (Integral, Windward, Kennedy/Jenks, Anchor, and GSI 2004) and the Round 2 Report. The dredging projects that are italicized in the table indicate recent projects for which a USACE public notice has been issued, but specific information about dredging dates and amounts was not available in time for this report. Note that the issuance of a permit does not mean that the project was implemented or that the volume of dredged material indicated in the table was dredged. Furthermore, the table does not distinguish between single events and multi-year permits. Map 3.2-23 shows the locations of dredging and capping operations between RM 1 and 11.8, since the most recent USACE-sponsored dredging of the federal navigation channel in January 1997.

Since 1997, the Port of Portland has performed maintenance dredging at its marine Terminals 2, 4, and 5 (Table 3.2-6). Maintenance dredging has also been performed by Schnitzer Steel Industries, Inc. (Schnitzer berths in International Terminal Slip, RM 4), Chevron (Willbridge Terminal, RM 7.5), the City of Portland (Portland Fire Bureau Station 6 Dock, RM 9.7), the former Goldendale Aluminum Company (Goldendale

Aluminum facility dock, RM 10), and CLD Pacific Grain (Irving Elevator Terminal, RM 11.4). The City of Portland project also included cap placement, as noted below. Brief descriptions of these dredging projects are provided below:

- Schnitzer performed maintenance dredging of its berths located inside the International Terminal Slip in 2004 under two separate permits. Approximately 77,000 yd^3 of material was dredged from Berths 1, 2, and 3 under Permit #199100099. Maximum target dredge depths were –42, –38, or –24 ft CRD, depending on the location within the slip. Outside the slip, Schnitzer dredged approximately 61,000 yd^3 of material from Berths 4 (to –42 ft CRD) and 5 (to –36 ft CRD) under Permit #199200812. The permits for both projects allow for biannual maintenance dredging through January 31, 2009 (USACE 2004a,b).
- In 2001, Chevron Products removed approximately 15,000 yd^3 of material from both sides of its pier at Willbridge Terminal. The dredging was performed under a maintenance dredging permit issued in 1997. Sediments were removed to a target dredge depth of –40 ft CRD (PNG 2001).
- The former Goldendale Aluminum Company conducted maintenance dredging at its dock in 2000. Dredging volumes were not provided, but material was removed to –38 ft CRD (CH2M Hill 2000).
- The City of Portland performed maintenance dredging of the Portland Fire Bureau Station 6 Dock in 2005. The area approaching the dock was dredged to –12 ft CRD, and the area adjacent to the dock was dredged to –10 ft CRD. Altogether, 4,130 yd^3 of dredged material was removed. In accordance with the permit, both areas were capped to bring the bottom grade to between –10 and –11 ft CRD. Approximately 1,190 yd^3 of capping material was used (CH2M Hill 2005).
- CLD Pacific Grain performed maintenance dredging at two separate locations at the Irving Elevator Terminal in 2009. The dredge volume was approximately 1,430 yd^3 (NRC 2009). In 2001, approximately 5,000 yd^3 was removed to a permitted depth of –40 ft CRD (Harding ESE 2001).
- The dock area offshore of Glacier NW (RM 11.3E) was dredged in 2004, but no as-built drawings are available to determine the volume removed and the exact footprint.
- As part of the Terminal 4 Early Action removal, approximately 13,000 yd^3 of contaminated sediments were dredged from Slip 3 in 2008 (discussed further below).

As of 2011, maintenance dredging was planned for the dock areas offshore of Gunderson, the Portland Shipyard (Cascade General), and at ConocoPhillips and Chevron properties in the Willbridge Terminal complex.

Dredging and/or capping have also been completed or are in process as part of remedial actions at selected Portland Harbor locations. Interim removal action activities at Terminal 4 are underway and are scheduled to occur in two phases. The first phase, which was completed in the fall of 2009, included dredging of approximately 13,000 yd^3 of contaminated sediment and placement in an offsite disposal facility, isolating contaminated sediment in the head of Slip 3 with a cap made of an organoclay-sand mix, and re-contouring the slope of the bank along Wheeler Bay and planting native vegetation to minimize erosion and improve stability. The second phase of the Terminal 4 project includes a combination of dredging, capping, and monitored natural recovery (MNR) in areas not completely addressed by the first phase, as well as construction of a confined disposal facility in Slip 1. The second phase design and implementation of the Terminal 4 removal action will be implemented after the Portland Harbor Record of Decision (Port of Portland 2011b).

At the ARCO BP terminal, a new steel sheetpile wall was installed in 2007 to stabilize the facility and prevent migration of contaminants to the river. The following year, the concrete revetment riverward of the new sheetpile wall was removed, along with 13,293 yd^3 of underlying and nearshore contaminated sediment, which was disposed of offsite. Clean fill was placed in the excavated area (DEQ 2010b).

Two in-river sediment capping projects (McCormick and Baxter and Gasco) have taken place since 2003. McCormick and Baxter was a remedial action project following a CERCLA Record of Decision, and Gasco was an interim removal action. Both projects are described below.

Sediment cap construction activities at McCormick and Baxter, a former wood treating facility, were completed in September 2005. (Subsequent modifications to the cap were performed in October 2005 and July 2007.) The cap's shoreward boundary extends from the south end of the property north into Willamette Cove (RM 6.8). Its offshore boundary extends up to approximately 700 ft from the shoreline. In Willamette Cove, the cap extends offshore up to approximately 600 ft. Approximately 23 acres of contaminated sediments were capped with 2 ft of sand. More highly contaminated areas were capped with 5 ft of sand. In addition, multiple areas of the cap overlying seeps were constructed with a total of 600 tons of organoclay, a bentonite or hectorite clay altered to be hydrophobic. The cap design incorporated different types of armoring (i.e., articulating concrete block mats and rock) in the nearshore areas to reduce erosion (DEQ 2005).

In 2005, pursuant to a USEPA Administrative Order, approximately 15,300 yd^3 of tar and tar-contaminated sediment were removed by dredging from the riverbank and nearshore area adjacent to the Gasco facility and disposed of at the Chemical Waste Management landfill in Arlington, Oregon. After the removal action, an organoclay mat was placed along an upper-elevation band of the shoreline dredge-cut. This mat was secured with placement of cap sand and quarry spalls over the clay mat. The remainder of the removal area (0.4 acres) received 1 ft of cap sand and 0.5 ft of erosion protection gravel. In addition, 2.3 acres of the area surrounding the removal area

received 0.5 ft of "fringe cap" sand material. The removal action also created a depression into which potential seepage could be captured and localized for future response. Construction activities took place between August and October 2005 (Parametrix 2006).

3.2.3.2 Cultural Resources

The Portland Basin historically offered access to abundant natural resources in the rivers and on land, and many of these resources are still present. The following discussion will focus on some of the resources known to be of historic and contemporary cultural significance to Native peoples.

Fish are among the resources most frequently utilized by Tribes in the Portland Basin. Culturally significant species include salmonids, lamprey (eels), eulachon (smelt), and sturgeon. Native peoples also fished for a variety of other resident species, including mountain whitefish (*Prosopium williamsoni*), chiselmouth (*Acrocheilus alutaceus*), northern pikeminnow (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), and suckers (*Catostomus* spp.) (Butler 2004; Saleeby 1983).

In addition to fish, the river provided harbor seals (*Phoca vitulina*) and sea lions (*Eumetopias jubatus* [Steller sea lion] and *Zalophus californianus* [California sea lion]). These marine mammals were historically found on the Columbia River as far upstream as The Dalles and in the lower Willamette River to Willamette Falls. These migratory marine mammals followed the migrations of eulachon, the winter and spring salmon runs, and the lamprey runs up the rivers. Although difficult to hunt, they were a favored resource, especially sea lions.

Rivers, sloughs, and wetlands also provided habitat for a great variety of waterfowl. The Portland Basin lies on the Pacific Flyway and supports large populations of both migrating and resident ducks, geese, and swans. Modern waterfowl populations in the lower Columbia-Portland Basin area number between 200,000 and 250,000 during the winter. The most abundant species today are Canada geese (*Branta canadensis*), mallards (*Anas platyrhynchos*), northern pintails (*Anas acuta*), and American wigeons (*Anas americana*). Winter populations begin gathering in October and peak in December, and then decline into late winter and early spring. Resident populations consist primarily of Canada geese, mallards, and wood ducks (*Aix sponsa*) (Oregon Wetlands Joint Venture 1994:4–5; Tabor 1976:2A:294–295, 310–311).

Of land mammals historically found in the Portland Basin, deer and elk were the most frequently utilized by Native people. In addition to their meat, deer and elk hides were widely used for clothing, and deer and elk bones and antlers were transformed into a wide variety of tools, weapons, and ornamental objects. There are two species of deer native to this area, the more common black-tailed deer (*Odocoileus hemionus*) and Columbian white-tailed deer (*O. virginianus leucurus*). The latter is a subspecies found only in the lower Columbia River drainage. Both species would have lived on the floodplain, but the Columbia white-tailed deer was especially well-adapted to brushy

riparian areas. Elk (wapiti, *Cervus elaphus*) were also common on the floodplain, especially in the winter, but, like black-tailed deer, preferred grasslands and prairies rather than the brushier woodlands that extended across much of the river bottoms.

Other animals that were hunted primarily for their furs and hides (and which could have been found in the Portland Basin) included black bear, mountain lion, bobcat, wolf, raccoon, fox, beaver, river otter, weasel, muskrat, mink, gray squirrel, wood rat, and mountain beaver (Franchère 1967:110; Gough 1992:664; Merk 1968:97; Moulton 1990:208, 327, 329, 344–345, 351, 434–435, 439; Ross 1986:104 [1849]; Spaulding 1953:41). These were used chiefly in making blankets, robes, and other articles of clothing.

Of equal importance in both subsistence and trade were a variety of plants. The best known of these was wapato (*Sagittaria latifolia*), the tubers of which were a major food source. Wapato grows in marshes and shallow ponds and lakes on the floodplains of the lower Columbia and Willamette valleys (as well as in some scattered wetlands in the interior valleys), but it was nowhere as abundant in this region as in the Portland Basin. The other plant-food staple was camas bulbs (*Camassia quamash*). This plant grew profusely in the wet prairies of the lower Columbia and in the interior valleys of western Oregon and Washington, although the historical abundance of camas on the Columbia and Willamette river floodplains is uncertain.

Other native plants were and continue to be gathered for food and medical purposes as well. These include a variety of roots, bulbs, nuts, and berries. Herbaceous plants, root bark, and sticks of woody stemmed plants are also gathered as raw material for making items like fishing nets, cordage, baskets, mats, and woven hats.

Historical and contemporary uses of these resources overlap, and access to suitable patches continues to be both a challenge and an essential element of maintaining local Tribal cultural knowledge, practices, and traditions. It is important to note that locations that are and were used for hunting, fishing, and gathering, are likely locations for archeological sites containing important cultural artifacts. There may be multiple strata of artifacts at some locations reflecting different eras of site usage.

3.2.3.3 Recreational

The lower Willamette River provides many natural areas and recreational opportunities, both within the river itself and along the riverbanks. According to the Oregon State Administrative Rules, OAR 340-041-0340, Table 340A, the designated beneficial use of the lower Willamette River includes hunting, fishing, boating, and water contact recreation. Adults and children use the lower Willamette River for boating, water skiing, swimming, and other water activities. Recreational fishing is conducted throughout the lower Willamette River basin and within the study area, both by boaters and from locations along the banks.

Within the study area, Cathedral Park, located under the St. Johns Bridge, includes a sandy beach area and a public boat ramp and is used for water skiing, occasional swimming, and waterfront recreation. Recreational beach use also may occur within Willamette Cove, which is a riverfront natural area; in Swan Island Lagoon; and on the southern end of Sauvie Island, which is within the study area. Swan Island Lagoon includes a public boat ramp. Additional recreational beach areas exist on the northern end of Sauvie Island and in Kelley Point Park, both of which are downstream of the study area. Willamette Cove is currently used by transients and recreational beach users that approach the area by uplands access or by boat, but is planned to be turned into an open greenspace that will serve as an extension of the Willamette River Greenway. Potential human use beach areas in the study area are shown in Map 3.2-24.

3.2.3.4 Transients

Transients have been observed along the lower Willamette River, including some locations within the study area. The observation of tents and makeshift dwellings during RI sampling events confirms that transients were present along some riverbank areas. Transients are expected to intermittently utilize this area in the future. Transients may be using the lower Willamette River as a source of drinking water. Conversations were conducted with transients about their consumption of fish or shellfish from the Willamette River as part of a project by the Linnton Community Center (Wagner 2004, pers. comm.). The transients that were contacted reported harvesting and consuming various fish species as well as crayfish and clams. It should be noted that the most common clam species in the Portland Harbor is an invasive species, the harvesting of which is illegal. Many of the individuals indicated that they were in the area temporarily, move from location to location frequently, or have variable diets based on what is easily available. However, the interviews did not quantify the frequency or duration of transient presence along the shoreline.

3.2.3.5 Diving

Diving activity also occurs in the lower Willamette River. In the study area, the majority of divers are expected to be commercial divers. Some diving for scientific purposes, including some aspects of site characterization for this RI, has occurred in the study area. Diving is done by several groups of people, including the public for recreation and gathering of biota for consumption; the sheriff's office for investigations and emergency activities; and, commercial divers for a variety of purposes, including marine construction, underwater inspections, routine operation and maintenance, and activities related to environmental work.

3.2.3.6 Commercial Fishery

The Oregon State Administrative Rules, OAR 340-041-0340, Table 340A, includes fishing as a designated beneficial use of the lower Willamette River. The exact extent to which commercial fishing occurs within the study area is currently not known. No reports of commercial fisheries for anadromous salmonids on the Willamette River have been found. A commercial crayfish fishery exists in the lower Willamette River. Crayfish landings must be reported to ODFW by water body and county. Per ODFW,

the crayfish fishery is not considered a large fishery (Grooms 2008, pers. comm.). Based on ODFW's data for 2005–2007, no commercial crayfish landings were reported for the Willamette River in Multnomah County.

3.2.3.7 Drinking Water

Under Oregon State Administrative Rules, OAR 340-041-0340, Table 340A, the designated beneficial use of the lower Willamette River includes private and public domestic water supply after adequate pretreatment to meet drinking water standards. There are no known current or anticipated future uses of the lower Willamette River within Portland Harbor as a private or public domestic water supply. According to the City of Portland, the primary public domestic water source for the City of Portland is the Bull Run watershed, which is supplemented by a groundwater supply from the Columbia South Shore Well Field (City of Portland 2008a). In addition, the Willamette River was determined by the Portland City Council not to be a viable water source for future City of Portland water demands through 2030 (City of Portland 2008a); further action by the Council would be needed before any exploration of this source could begin (City of Portland 2010). Upstream of Portland Harbor, the City of Wilsonville uses the Willamette River as a domestic water source following treatment, and the City of Sherwood will be using the Willamette River beginning in 2013.

3.2.3.8 Residential

Residential areas in the vicinity of the study area include the neighborhood districts of Linnton, Northwest, Pearl, Old Town, Overlook, University Park, Cathedral Park, Eliot, and Lloyd. Several of these communities have been established for decades, although the Pearl District is a recent name for a former warehouse and industrial area just north of downtown where many of the warehouses have been converted into lofts, and new multistory condominiums have also been developed on previously vacant land. Most of the residential areas in the study area are not located in the riparian zone adjacent to the river, with the exception of homes on Sauvie Island and some condominiums in the Pearl District.

3.2.3.9 Restoration

There have not been any restoration projects within the Portland Harbor study area, although there has been some planning for a restoration project at Alder Point at the former Alder Creek Lumber site on the southern tip of Sauvie Island. Despite the area's urbanization, the combination of existing stream channel and open space provide greater opportunity for watershed rehabilitation on the Willamette's west side than on the east side.

4.0 IDENTIFICATION OF SOURCES

The lower Willamette River and its adjacent upland areas have been used for industrial, commercial, and shipping operations for over a century. During this time, contaminants associated with those practices were released from various sources through migration pathways to the lower Willamette River, which may pose risk to receptors. Many environmental investigations by private entities and state and federal agencies have been conducted, both in the lower Willamette River and on adjacent upland properties, to further characterize the nature and extent of contamination in the river, as well as to identify potential sources of contaminants that could continue to enter the river.

The primary focus of this section is the discussion, by pathway, of the historical and current sources that contributed to in-river contamination within the study area. Section 4.1 discusses the potential migration pathways of sources to the lower Willamette River. The process used in identifying sources and pathways within the study area is described in Section 4.2. Historical sources of contamination are presented in Section 4.3, and current sources of contamination, including ongoing secondary releases and controls, and DEQ's role in identifying, evaluating and controlling current ongoing sources, are presented in Section 4.4. Potential sources outside the study area from upriver reaches of the lower Willamette River and above Willamette Falls are identified in Section 4.5. The relationships between the historical and current sources of contamination discussed in this section and the contaminant distribution in abiotic (e.g., sediments) and biotic media in the study area are addressed in Section 10 of this report.

Although this section and its associated tables identify many specific sources of contamination, neither this section nor this RI report generally is intended as an exhaustive list of particular facilities that are current or historical sources of contamination. Identification and evaluation of potential sources is still ongoing by DEQ, and USEPA is continuing its potentially responsible party search. All historical sources may never be known, and current sources likely will continue to be discovered into the future. However, sufficient information about the most likely significant historical and current sources is available for the development of a cleanup plan for the study area.

4.1 POTENTIAL MIGRATION PATHWAYS

Contaminants released to media such as air, soil, ground water, surface water, or impervious surfaces may migrate to the lower Willamette River via the following pathways[1]: direct discharge, overland transport, groundwater, riverbank erosion, atmospheric deposition, overwater activities, and upstream watershed. This section

[1] This section addresses external contaminant sources and migration pathways to study area sediments. Internal processes, such as bedded sediment resuspension and erosion, are important internal contaminant fate and transport mechanisms and these are discussed in RI Sections 6 and 10.

briefly highlights these potential pathways to the river. In-depth information on specific sources and migration pathways is provided in Sections 4.2 through 4.5.

4.1.1 Direct Discharge

Direct discharge of contamination occurs through conveyance systems, which include municipal or other publicly owned drainage systems, privately owned and managed drainage systems, and sanitary/combined sewer systems. Today, many of these discharges are permitted under NPDES authorized by the CWA. Permitted discharges under the NPDES program include industrial wastes, stormwater runoff, and CSOs.[2]

Based on a survey conducted by the City of Portland in 2002, approximately 300 individual outfalls that discharge into the Portland Harbor study area have been identified. These individual outfalls are defined here as locations of discharge of stormwater, combined sanitary sewage and stormwater, and/or industrial wastewaters transported via a collection system, although most of the latter two are now routed through the sanitary sewer and no longer discharge directly to the waterway.

Historically, waste disposal in upland pits, lagoons, or lakes also directly discharged to the river through pipes, ditches, and creeks. In addition to direct discharge, contaminated soil, stormwater, and groundwater from past and current spills and leaks of hazardous substances can infiltrate these conveyance systems and be transported by direct discharge systems. Discharges of treated industrial wastes are sometimes discharged to municipal and non-municipal storm drain systems. The classifications of direct discharges include industrial waste systems, CSOs, and public and private storm drain systems.

4.1.2 Overland Transport

Contaminated surfaces in the upland areas can carry erodible soils and particulates directly to the river via sheet flow of stormwater runoff from a site (i.e., not through a conveyance system). Overland transport was likely to have been more important historically, prior to the development of extensive stormwater conveyance systems within the study area. However, specific historical information on overland runoff is lacking for most upland properties in the study area.

4.1.3 Groundwater

Groundwater flow in the greater Portland Basin within the study area is generally towards the lower Willamette River, although the direction varies locally depending on the nature of subsurface materials, hydrostratigraphy, and proximity to the river. Near the river, tidal action can greatly alter groundwater flow directions, rates, and water quality.

[2] CSO events are untreated discharges of combined stormwater and sanitary sewage from residential, commercial, and industrial sources that overflow from the sewer system into the river during heavy rainfall periods when the amount of stormwater and sewage exceeds the capacity of the collection system.

Groundwater may be contaminated from waste disposal practices, product storage practices, spills and leaks from pipes, storage tanks, industrial equipment, and process operations. Contaminated groundwater may enter directly into the Portland Harbor study area via discharge through sediments or bank seeps, or it may infiltrate into storm drains/pipes, ditches or creeks that discharge to the river. Contaminant migration may occur as NAPLs or as dissolved phase transport.

4.1.4 Riverbank Erosion and Leaching

Contaminated riverbank soil, fill, or debris may release contaminants directly to the Portland Harbor study area through bank erosion or leaching caused by groundwater and tidal action flux. Unprotected shoreline banks are susceptible to erosion by wind, river flows, wave action, tidal changes, and surface water runoff. Shoreline armoring and vegetation reduce bank erosion. Bank slope is also a factor where steeper banks are more susceptible to erosion.

4.1.5 Atmospheric Deposition

Contaminants are emitted to the air from point, mobile, biogenic and area sources.[3] Point sources include emissions from power plants, refineries, incinerators, stationary power sources, emission stacks, liquid and petroleum storage tanks, etc. Today, many point source air releases are permitted under the Clean Air Act. Mobile sources include emissions from motor vehicles and non-road equipment, such as railroads, marine vessels, and recreational off-road equipment. Biogenic sources include emissions from natural sources and area sources that are too small to be treated as point sources (footnote 3). Point sources include industrial releases from power plants, incinerators, stationary power sources, emission stacks, liquid and petroleum storage tanks, etc.

Contaminants emitted to the air may be transported over long distances, generally in the direction of the area's prevailing winds. They can be deposited from the atmosphere to land and water surfaces through wet deposition (precipitation) or dry deposition (as particles). Air pollutants can be deposited to water bodies through either direct or indirect deposition. Direct deposition occurs when contaminants are deposited onto the surface of a water body. Indirect deposition occurs when contaminants are first deposited on land and then transported to the water body via stormwater runoff.

4.1.6 Overwater Activities

Contaminants from overwater activities (e.g., sandblasting, painting, unloading, maintenance, repair, and operations) that may have dumped, sprayed, spilled, emitted or otherwise resulted in releases at or from riverside docks, wharfs, or piers; spills or releases from vessels (e.g., gray, bilge, or ballast water); and fueling station (e.g., barge to uplands) releases have the potential to impact the lower Willamette River.

[3] http://www.epa.gov/oaqps001/emissns.html

4.1.7 Upstream Watershed

Upstream sources include or have included sewers, stormwater runoff, and direct discharge of industrial wastes; agricultural runoff; and aerial deposition of global or regional contaminants on the river water surface and drainage areas within the Willamette Valley.

4.2 INFORMATION COLLECTION PROCESS

A goal of the RI report is to identify sources of contamination to the in-water portion of the Site, including those sources identified based on information obtained through investigations conducted under DEQ authority. Sources of contamination are often hazardous substances contained in drums, storage tanks, surface impoundments, waste piles, and landfills. Heavily contaminated media (such as soils and groundwater) may also be considered secondary sources of contamination, especially if the original source (such as a leaking tank) no longer exists or is no longer releasing contaminants. Finally, as described in Section 4.5, regional sources outside of the study area, such as the widespread use of pesticides/herbicides, fertilizers, and other chemicals, may also contribute to background conditions both within and outside of the study area.

Sources can be either historical or current in origin. Historical sources have released COIs[4] to the river in the past, but no longer have an upland source to control. Current sources are direct and indirect releases of COIs from historical or current activities that are migrating to the river through a migration pathway that needs to be controlled. These sources might include discharges from industries, spills, precipitation runoff, erosion of contaminated soil from stream banks or adjacent land, contaminated groundwater and NAPL contributions, discharges from stormwater and combined sewer outfalls, upstream contributions, and air deposition. For the purposes of this RI only, current sources are defined as those that are known to be present after 2004, which is the year that LWG began reviewing upland source information.

In February 2001, DEQ, USEPA, and other governmental parties signed an MOU that provided a framework for coordination and cooperation in the management of the Portland Harbor Superfund Site to optimize federal, state, tribal, and trustee expertise and available resources. Under the February 2001 MOU, it was agreed that the DEQ, using state cleanup authority, has lead technical and legal responsibility for the upland contamination and for coordinating with the USEPA on upland contamination that may impact the river (e.g., sediment, groundwater, TZW, and/or surface water). However, there are some instances where USEPA has the lead role for source control at the site. The cleanup of known or potentially contaminated upland sites is tracked in DEQ's ECSI database, which is available online at http://www.deq.state.or.us/lq/ECSI/ecsi.htm. It is important to note that sources of contamination in Portland Harbor may include ECSI and non-ECSI sites.

[4] COIs are hazardous substances that have been released into the environment and are of interest in the RI at this Superfund site.

4.2.1 Site Summaries

Site summaries are the primary resource of information on upland sources for the Portland Harbor RI, and are integral to the CSM for the study area. Summaries have been prepared for 86 upland sites that were generally located within 0.5 mile of the lower Willamette River between RM 1.9 and 11.8, where DEQ-led investigations confirmed releases occurred. Table 4.2-1 presents a list of sites investigated by DEQ and indicates which sites had summaries prepared by the LWG. Map 4.2-1 depicts the locations of the sites being investigated by either DEQ or USEPA within the study area, and also specifies if site summaries were prepared for these sites.[5]

The information from the site summaries indicates that the majority of the sources have released or may be releasing hazardous substances to the study area, and if continuing sources are not controlled, they would likely recontaminate or contribute to unacceptable risk at the Site. The information in the site summaries also indicates that detailing the pathways and potential COIs associated with the sources within these boundaries in the site summaries (see Table 4.2-2) would provide an adequate assessment of where the majority of contaminants found in the water and sediment at the site came from. However, where other significant historical or current sources outside of these geographical boundaries (i.e., sources outside 0.5 mile of the river between RM 1.9 and 11.8) are known, such sources are discussed in the text of Section 4.5 and shown in Table 4.2-3 and on Maps 4.2-2a–d.[6]

It is important to note that site summaries have not been prepared for all DEQ environmental cleanup sites within the Portland Harbor hydrographic basin or for all historical sites with releases that have contributed contamination to the study area. Also, potential sources of contamination may exist that have not been reported or included in the DEQ ECSI database or DEQ's upland site files. The information presented in the site summaries is primarily based on publicly available documents; a full list of all sources of information relied upon is provided in each site summary. Information presented in the site summaries ranges widely in the scope, detail of information, and time frames. The accuracy of the information in the site summaries has not been assessed by USEPA, nor has the USEPA conducted any independent work to evaluate or verify the information presented.

Each site summary listed in Table 4.2-1 describes general site information (location, physical description); owner history; current and historical site uses; potential sources (overwater activities, recent and historical spills); the nature and extent of contaminants in soil, groundwater, surface water, and sediment; stormwater and wastewater permit

[5] ECSI sites in Map 4.2-1 are as of February 2011. The locations shown on the map are based on the DEQ GIS data augmented by GIS data provided by the City of Portland. The locations of the sites on the two GIS data files can be different.

[6] Neither this section nor the site summaries present all of the information or evidence that may exist regarding any particular person or entity's potential liability for response costs incurred at this Site.

information; and a summary of cleanup actions. Site summaries have been updated periodically, primarily from information on file with DEQ.

Site summaries were originally published in 2004–2005 (Integral and GSI 2005a,b,c), and a subset of the summaries was updated in 2007 (Integral 2007r). The status of the ECSI sites within the study area is tabulated in Table 4.2-1. For each site listed in the table, the following information is shown:

- The site name and DEQ ECSI number
- The site status (e.g., RI, expanded preliminary assessment, not in DEQ cleanup program)
- The site summary documents prepared (e.g., site summary, site summary addendum, no site summary prepared) and dates of documents. It should be noted that site summaries were not prepared for all ECSI sites, but only for a subset (see Table 4.2-1).

The site summaries are based on a review of information in the associated DEQ ECSI files and other readily available public information, as well as information provided by the upland site's current owner. It is important to note that the development of site summaries and the source information presented here are highly dependent on whether a site is involved in DEQ's cleanup program and the degree of investigation and data generation, as well as the level of detail provided in DEQ's ECSI files. As shown on Table 4.2-1, several sites adjacent to or near the study area are not in the cleanup program, and it is likely that many sites, particularly those that are the location of historical facilities that operated outside the boundaries of current properties, are not fully addressed in the site summaries. As a result, this section does not represent a complete inventory of sites and operations that contribute or have contributed to contamination in Portland Harbor. These limitations on source information primarily affect historical sources, and the understanding of current significant sources is adequate for the purposes of developing a cleanup strategy for this Site.

4.2.2 Source Table

The Source Table (Table 4.2-2) summarizes information from both the LWG's site summaries and addenda and DEQ's Milestone Report, which is DEQ's mechanism of reporting to USEPA on the status of source control at the sites.

In Table 4.2-2[7], a contaminant is listed as a pathway COI if it was detected in sampled media, identified as having been released to site media, identified as a site COI, or documented to have been released directly to the river from site operations. The LWG

[7] The information in Table 4.2-2 of the RI is a compilation of public information available from site owners and operators and from DEQ, and is based upon information provided through September 2010. In some instances DEQ provided specific language to the LWG. The LWG has not independently verified all information provided by DEQ, and to the extent parties and DEQ disagree with language in this table, those differences will be worked out as part of the DEQ Source Control process.

has not separately screened the results against DEQ's JSCS values or any other screening criteria. Note that the LWG and non-LWG stormwater sampling data (as described in Section 4.4.1.2) were not reviewed or screened for the purposes of this table.

COIs for a pathway in Table 4.2-2 were assigned one of four categories (a–d), as defined below, for both historical (H) and current (C) impacts:

Category a. **Documented evidence of a complete transport pathway**—Data demonstrate that the pathway is complete; DEQ, the responsible party, or both concur that the pathway is complete.

Category b. **Likely a complete pathway**—Data suggest that the pathway is complete, but in the absence of confirming data (e.g., investigations are incomplete, nearshore wells are not yet installed, overwater operations are present and active). DEQ, the responsible party, or both have not concurred that pathway is complete. Although DEQ and responsible party evaluations are considered, LWG's analysis may support a different conclusion.

Category c. **Insufficient data to make determination**—Either a release has been documented but there has been no sampling of the potentially affected media, or a release has been documented but transport pathways have not been investigated, or no sampling has been conducted at the site or for a given pathway. Although DEQ and responsible party evaluations are considered, the LWG may have, for the purposes of the CSM, assumed that the pathway is complete.

Category d. **Not a complete pathway**—Information indicates with reasonable certainty one of the following:

- The relevant media for a given pathway likely are not affected by site-related COIs (e.g., site-related COIs are not detected in groundwater)
- A current or historical complete pathway as defined above likely is not present (e.g., riverbank is not present at a site away from the river, COIs were not detected in downgradient groundwater)
- The pathway is determined by DEQ to be insignificant in the Table 1 of the Milestone Report (DEQ 2010a).

The overall importance and relative contribution of the pathway is not evaluated in Table 4.2-2. DEQ's Milestone Reports (see Section 4.4.7) rank sites and pathways in terms of priority for investigation and cleanup, but the ranking is not chemical-specific.

For each potential migration pathway that is known or likely to be complete (categories a and b), Table 4.2-2 also shows whether the site's releases are current (C) or historical (H). The overwater pathway is designated H-a or C-a when a release has been

documented in the DEQ Emergency Response Information System (ERIS) database, U.S. Coast Guard (USCG) records, the Port of Portland's 104(e) responses, or other similar documentation. If no spills have been reported for a facility that had or has active overwater operations, the pathway was modified to H-b or C-b.

For the groundwater pathway, Table 4.2-2 includes a column for the presence of NAPL. A "Y" is shown where the pathway is known or likely to be complete. An "N" is shown where the pathway is known to be incomplete. A question mark is shown if the presence or absence of NAPL cannot be evaluated because of insufficient data.

To help readers track the assessments tabulated in Table 4.2-2, Table 1 from DEQ's Milestone Report is reproduced here as Appendix B. The DEQ Milestone table, which was considered in the development of Table 4.2-2, provides information on the status of DEQ's source control evaluations, decisions, and measures for ECSI sites within the original study area as of 2010. The 2010 DEQ table does not list the new ECSI sites in the expanded study area (RM 11–11.8) or recently identified sites within the shared stormwater conveyance basins. For the most up-to-date DEQ source information, DEQ's January 2013 Source Control Milestone Report is available online at http://www.deq.state.or.us/lq/cu/nwr/PortlandHarbor/jointsource.htm.

An important difference between DEQ's Milestone Report and LWG's Source Table is that the Milestone Report focuses on current and potential sources of pollution to the river, whereas the Source Table considers both current and historical releases when information is readily available. As a result, DEQ may identify a source as "insignificant" in the Milestone Report based on the current condition, while LWG may have characterized the same source as a known or potentially complete pathway because of historical conditions or as insufficient data to support a release determination. Additionally, DEQ's Milestone Report prioritizes pathways (high, medium, low) but does not present COIs. The LWG's Source Table identifies COIs for each pathway, but does not prioritize pathways or releases.

4.3 HISTORICAL SOURCES WITHIN THE STUDY AREA

Historical releases from upland or overwater activities within the study area likely contributed to the majority of the observed chemical distribution in sediments within the study area. Table 4.2-2 provides an assessment for the upland ECSI sites of whether the predominant impact for each of the pathways was historical or current. All the pathways have a historical release component and many can be attributed entirely to historical operations or releases (e.g., historical discharge of waste to Doane Lake, direct discharge of manufacturing waste to the river, and historical discharge of MGP effluent ponds). This section discusses by pathway the major historical operations that contributed to in-river contamination within the study area. Note that in this context, the term "pathway" refers only to the physical transport of a contaminant of interest to the study area. It does not include identification of exposure points, receptors, or exposure routes.

4.3.1 Direct Discharge—Industrial Wastewater, Stormwater, and CSOs

In the early 1900s, rivers in the United States were generally used as open sewers, which was also true for the Willamette (Carter 2006). The process water from a variety of industries, including slaughterhouses, chemical plants, electroplaters, paper mills, and food processors, was discharged directly into the river. Potential hazardous substances associated with these activities may have included VOCs, SVOCs, PAHs, petroleum hydrocarbons, metals, PCBs, pesticides, and herbicides.

From 1926 to 1929, the U.S. Public Health Service collected samples from seven mid-river locations on the Willamette River. Although the studies focused on bacteria and oxygen levels from domestic waste, the sewage discharges also included municipal, industrial, and commercial waste products and stormwater runoff. Conclusions from the study indicated that although oxygen levels were sufficient to support fish life in all but two months of low water in late summer, the overall water quality probably was "not sufficiently pure" to justify recreational uses at any time (Laurgaard 1929, pers. comm.). By the 1930s, the water pollution was so severe that workers refused to work on riverside construction projects because of the foul odors and the risks to their health. Loggers even went on strike because they did not want to handle the scum accumulated on logs (Blalock 2008).

In response to enacted legislation, municipal conveyance systems included interceptors and associated facilities were installed in the 1950s to reduce the volume of untreated sewage discharging to the Willamette from the City of Portland (see discussion in Section 3.2.3.1.11). The OSSA (1955) concluded that in spite of the fact that considerably less raw sewage was being discharged into the river by the City of Portland [than the year before], the degree of pollution in the harbor was "approximately the same" in 1954 in terms of dissolved oxygen (DO) and BOD levels. The OSSA noted, however, that based on weekly measurements from seven stations between Willamette Falls and S.P. and S. Railroad Bridge,[8] the BOD levels at Willamette Falls were the highest in the OSSA study and that the DO levels at the S.P. and S. Railroad Bridge were the lowest. This OSSA observation indicates that there were sources with high BOD upstream of Willamette Falls.

A special survey of Portland Harbor disclosed that significant quantities of untreated domestic sewage and industrial wastes were being discharged into the river from at least 20 separate outfall sewers and estimated that oxygen demand from industrial sources was three times greater than that from domestic sewage (OSSA 1957). A 1958 OSSA report estimated that "89 percent of the total oxygen depleting pollution load, prior to

[8] The reference to the S.P. and S. Railroad Bridge appears to be BNSF Railroad Bridge located at RM 6.9. The 1957 OSSA report says (Page 6), "Stream samples were collected once each week … located above the Willamette Falls and extending 20 miles downstream to the S.P and S. Railroad Bridge." Further, OSSA (1957) references the S.P. and S. Railroad Bridge at river mile 7.0 (Page 2).

treatment, is from industrial sources and only 11 percent from domestic sewage" in the Willamette basin (OSSA 1958).

A 1967 federal report on Willamette River water quality stated that low DO was due in large measure to the discharge of untreated wastes of pulp and paper mills upstream of the City of Portland (DOI 1967). Another federal report summarized the water quality problems in the rivers of the Northwest (Figure 4.3-1) and identified the major sources of pollution as reservoir management procedures, agriculture, and factory wastes (DOI 1968). Stevens & Thompson (1964) estimated that the maximum dry-weather flow of 6.3 million gallons per day was discharging through eight City outfalls and 12 private outfalls. This could have been a combination of sewage, industrial waste, cooling water waste, stream flow, and groundwater.

Valuable insight into the magnitude of historical releases is provided by Glen D. Carter, an aquatic biologist employed between 1956 and 1988 by the OSSA, a forerunner to Oregon's DEQ. By the time he was hired in 1956, "fish kills were common in the river, massive rafts of decaying algae floated downstream, and a thick layer of bacterial slime covered much of the river bottom and shoreline. Rotting vegetation, bacterial slime, and countless dead fish produced highly unpleasant sights and odors. Large deposits of sewage sludge accumulated around sewage outfalls" (Carter 2006). In water quality tests performed during this period, fish often suffocated within minutes after being exposed to the water (Carter 2006).

4.3.1.1 Industrial Wastewater

Historical industries directly discharged a variety of COIs based on site-specific commercial and industrial activities, which are described in Section 3.2.3.1. The industrial discharge pathway is not included in Table 4.2-2; however, sites with active individual NPDES wastewater permits discharging industrial wastes directly to the river are identified in Table 4.2-2 by footnote "b" in the pathway status column. Additional information for these sites, including chemical testing requirements and mixing zones, is presented in Table 4.3-1.

Other industries that lined the banks of the river most likely had direct industrial discharges as well. Until the late 1960s and 1970s, it was routine practice for chemical plants to dump waste tars and sludges along or directly into the river. Chemical plants, petroleum terminals, lumber and steel mills, and various other industrial operations within the harbor also directed untreated industrial wastes and wastewaters to the river. Because of the vast number of various industrial discharges to the river, a large variety of COIs potentially associated with these plants and other industries were released to the river including, but not limited to, herbicides, pesticides, perchlorate, dioxins/furans, mercury and other heavy metals, VOCs, SVOCs, PAHs, TPH (oils, greases, diesels, gasoline), acid/alkaline wastes, phthalates, butyltins, MGP tars, creosote, cyanide, and PCBs.

Examples of industries with known historically complete pathways in the harbor include the former McCormick and Baxter site, where wastewater and non-contact cooling water were discharged directly into the Willamette River between 1945 and 1969 (PTI 1992). The manufactured gas plant effluent ponds along the current Gasco and Siltronic riverbank had drainage or overflow features leading to the river from 1913 to 1956 (HAI 2005a,b). At the former Rhone Poulenc facility, treated and untreated stormwater/wastewater and waste materials were historically discharged to Doane Lake, where they commingled with stormwater and waste material releases from Gould/NL Industries, Schnitzer/Air Liquide, and ESCO (AMEC 2002). Historical aerial photographs indicate that the former Doane Lake periodically discharged to the lower Willamette River through a historical drainage ditch. Historically, surface water collecting in a topographically low area of the Linnton Oil Fire Training Grounds may have periodically discharged to the Willamette River via a series of drainage features.

The OSSA surveyed industrial discharges from private outfalls to Portland Harbor for 3 years and estimated dry weather flow (i.e., non-stormwater) of 9.9 million gallons per year (mgy) in 1963, 8.92 mgy in 1964, and 0.5 mgy in 1965[9] (OSSA 1966). As discussed in Section 3, once the interceptors were installed in the municipal conveyance systems, many industries routed their industrial wastewater to the sanitary system. A survey of industrial users and wastewater characteristics was conducted in 1974 (City of Portland 1974). Fifty-seven industries were identified in Portland Harbor; 33 of these discharged to the municipal sanitary system, 17 discharged to a CSO system, and 7 did not connect to a municipal system (Table 4.3-2). Of the 7 industries not connected to a municipal system, 5 discharged directly to the river (some with pretreatment) and 2 did not.

4.3.1.2 Stormwater

Many of the historical direct discharges were combined flows of stormwater, industrial wastewater, and sanitary wastewater. Stormwater has historically run off to the river through outfalls and as sheet flow. Most of the flows from shoreline properties were discharged through non-municipal outfalls or sheet flow, while flows from non-shoreline properties discharged through municipal, private, or other public agency outfalls or via drainage ditches. The outfalls and drainage basins for the historical shipyards in the area were most likely separate stormwater drainage systems consisting of multiple outfalls that discharged directly to the Willamette. Swan Island also had combined and separated storm and sanitary systems that discharged directly to the river from 1942 to 1953.

Potential contaminants found in stormwater were likely associated with outdoor activities, such as sandblasting, metal plating and surface finishing, painting and sealing, fiberglass construction, leaking hydraulic or pump equipment and transformers, dust suppression activities, maintenance and repair operations, wood treating, leaking

[9] Survey did not include outfall sewers in the Guild's Lake-Linnton area in 1965.

storage tanks, spillage or stockpile runoff of raw materials, stockpiling of waste material, and machining and metal working activities. COIs potentially associated with these activities were released to the river including, but not limited to, herbicides, pesticides, dioxins/furans, heavy metals, VOCs, SVOCs, PAHs, TPH (oils, greases, diesels, gasoline), acid/alkaline wastes, phthalates, butyltins, MGP tars, creosote, cyanide, and PCBs.

Based on LWG studies of stormwater (Integral 2007a; Anchor and Integral 2008a), it is clear such stormwater picks up COIs as it flows across industrial and commercial properties with outdoor process activities, across transportation corridors and residential neighborhoods that have vehicular traffic and parking, and even across open spaces that are subject to atmospheric deposition.

In summary, until about the 1930s a large majority of the land draining to Portland Harbor was undeveloped. Of the developed land, the industrial land use was dominant. As time progressed, more industrial development occurred as wetlands and lakes were filled in the lands adjacent to the river, especially in Mocks Bottom and at the base of the Tualatin Hills. COIs associated with industrial wastewater (described above) could also be found in runoff from these sites, as stormwater comes into contact with industrial operations and ancillary activities. As shown on Maps 3.2-3 through 3.2-8, residential, commercial, and major transportation land uses comprised a smaller percentage of the overall drainage.

Twenty-five sites have been identified as having a known complete historical migration pathway for stormwater (Table 4.2-2). Another 38 sites have been identified as having likely complete historical pathways for stormwater but lack confirmatory data. Historical stormwater information does not exist for most of the historically and currently present sites discharging to the Portland Harbor.

4.3.1.1.3 Combined Sewer Overflows and Sanitary Sewer Overflows

As discussed in Section 3, prior to the construction of the interceptor system beginning in the early 1950s, 19 municipal and numerous non-municipal sewers discharged sewage (including industrial waste) and stormwater directly to the Willamette River within the study area (City of Portland 1936). Once interceptors and pump stations were installed, all the municipal outfalls were converted to storm-only outfalls or to CSO outfalls, which reduced the frequency of the discharge to the river. Many of the industrial areas draining to the municipal system were separated when interceptors were constructed so industrial waste that had previously discharged to the municipal system was connected directly to the interceptors (i.e., could not overflow to the river). In some cases, dry weather flow (industrial or sanitary waste) continued to discharge to the river from municipal outfalls after the interceptors were constructed until the City implemented additional programs to assure that diversion structure performance was maximized, properties had appropriately connected their pipes to the municipal system, and connections were rerouted (see Section 3.2.3.1.11).

Historically, direct measurement of contaminants in CSO discharges focused on DO, TSS, bacteria, and BOD rather than chemicals and hazardous substances. Assumptions about COIs associated with historical discharges from the municipal sewer system (including direct discharges prior to construction of the interceptor system, wet-weather CSO events after construction of the interceptor system, and dry weather overflows through the CSO outfalls) can be made based on the types of industries and activities (e.g., transportation corridors, parking) that discharged to the system and whether those industries and activities discharged to the combined system at a location that could overflow a diversion structure, as well as from pretreatment records.

As summarized in Section 3.2.3.1.11, most of the municipal CSO outfalls in the Linnton, St. Johns, and Albina (across from downtown) areas served primarily residential customers, with some commercial land use; COIs in those discharges would be similar to those for stormwater and domestic and commercial sewage. The other municipal CSOs present in the harbor were located in the downtown and north downtown areas, which included industrial, commercial, and residential land uses. COIs associated with industries in CSO basins are dependent on the type of industry discharging to the combined system.

Detailed information on specific industries discharging industrial wastewater to the CSO sewer system prior to the 1980s is limited. However, some historical documents provide information about the types of industries discharging to the system during this time. The City of Portland Waste Discharge Permit application to OSSA identified all industries with a significant waste load; 11 industries were located in Portland Harbor. Seven of these industries did not connect to municipal treatment facilities (i.e., not connected to interceptor) and two industries were connected to a separated sanitary system (City of Portland 1967b). Industrial wastewater from the remaining two industries (an industrial laundry and a flour mill) discharged to the municipal combined system, which could reach the river during CSO events. No toxic wastes were reported for these industries (typically during this time only pH, BOD, and suspended solids were reported).

A 1974 Survey of Industrial Users (City of Portland 1974) indicated that facilities were discharging wastewater to the CSO system. The industry types are associated with metals, transportation, laundries, food, rubber, and bag manufacturing, and a flour mill.

Since the majority of CSO discharge consists of stormwater, COIs in overflows could also be associated with contaminants exposed to stormwater. Based on the 1967 and 1974 industrial surveys (City of Portland 1967b, 1974), COIs associated with these industrial wastewaters and/or stormwater within CSO basins may have included metals (iron/steel manufacturing, electroplaters), solvents (various manufacturing industries), PAHs (combustion emissions, road tar, treated wood), and PCBs (transformers, paints, rubber, and plasticizers after 1930).

CSO discharges also include a component of domestic sewage. The constituents in domestic sewage are primarily fecal bacteria and nutrients (which can decrease DO). Studies of mixed domestic sewage and industrial discharges from other cities have also found low concentrations of contaminants including PAHs, polybrominated diphenyl ethers (PBDEs), phthalates, and selected VOCs (Gasperi et al. 2008; Pham and Proulx 1997; North 2004; Song et al. 2006; Wilkie et al. 1996). Although no data are available for Portland Harbor, domestic sewage that may occasionally enter the study area through CSOs may contain trace amounts of contaminants from consumer products and other compounds reflecting the ubiquitous presence of some industrial chemicals at low concentrations in urban environments.

4.3.1.4 Direct Discharge Regulatory History

In the mid-20th century, cities and industries began efforts to improve the quality of wastewater discharged to the Willamette. Flood control reservoirs created by the federal government increased summer flow in the river, which contributed to the dilution of wastes. The State of Oregon and the City of Portland regulated wastewater discharges before the enactment of the CWA in 1972, but there was minimal regulation of stormwater discharges before the passage of CWA amendments in 1987. State and municipal regulatory programs relevant to wastewater (sewage and industrial) and stormwater discharges are discussed below.

4.3.1.4.1 State of Oregon Wastewater Permits

At the state level, the Water Purification and Prevention of Pollution Law,[10] one of the first comprehensive state water pollution laws in the country,[11] was passed in 1938. The following year saw the creation of the OSSA, which began implementing wastewater treatment requirements. In 1967, the state legislature required a permit for sewage and wastewater discharges from any sewer system and imposed liability for pollution-related injury to fish and wildlife or their habitat.[12] In 1967, the OSSA issued water quality standards for the Willamette River. For the area including Portland Harbor, the water quality standard required that the daily average DO concentration could not be less than 5 mg/L. The standards included "not to exceed" concentrations for several metals and total dissolved solids, the latter of which could not exceed 100 mg/L (OSSA 1967b). Also in 1967, OSSA issued an Implementation and Enforcement Plan to detail the facilities or actions needed to achieve compliance with the standards, a time schedule for such compliance, the controls and surveillance to be used in measuring compliance, and the measures to be taken for ensuring compliance. Part of this plan included identification of major municipal and industrial waste sources; in the Portland Harbor area, this included the City of Portland and the industries identified in Table 4.3-3 (OSSA 1967b).

[10] Oregon Laws 1939, c. 3.
[11] Oregon Dept. of Environmental Quality, Administrative Overview, 2 (Mar. 2003), *available at* http://arcweb.sos.state.or.us/recmgmt/sched/special/state/overview/19970007deqadov.pdf (last visited May 6, 2009).
[12] Oregon Laws 1967, c. 426.

The OSSA meeting minutes from 1967 and 1968 indicate that a number of these industries were approved for discharge permits from OSSA. The minutes also identified other industrial facilities to be permitted, including Northwest Sand & Gravel, Willamette Western-River St, Ash Grove Lime and Portland Cement, Centennial Mills, Phillips Petroleum, Richmond Tank Car Manufacturing, Pacific Building Materials (OSSA 1967c), Oregon Steel Mills (aka Gilmore Steel) (OSSA 1968a), Shipper's Car Line (OSSA 1968b), and Oregon Steel Mills at Rivergate (OSSA 1968c). In many cases, the permits were issued on a temporary basis in order to collect additional information to develop permit conditions. When the northwest interceptor was completed in the early 1970s, many of these industries in the northwest area connected to the municipal sanitary interceptor, thus preventing these wastes from entering the river except during an SSO event.

The focus of OSSA was predominantly on pollutants for which water quality standards were established, and no information was found cataloging toxic waste materials in historical discharges. Beginning in 1973, industrial and municipal point source dischargers were required under the CWA to obtain NPDES permits for their wastewater and process water discharges. The federal program was delegated to the State of Oregon in 1973. NPDES permits for wastewater and process water are administered by DEQ and set effluent limits, monitoring requirements, and other conditions on the discharges. The requirements can be individual, written for a specific facility, or general, applicable to a group of dischargers having similar characteristics.[13] In some cases, stormwater discharges were also included in these individual NPDES permits.

Since 1973, the City of Portland CSOs that discharge to the Willamette River are regulated under an NPDES permit for the CBWTP, which discharges effluent to the Columbia River.

4.3.1.4.2 City of Portland Industrial Pretreatment Municipal Permits

At the municipal level, the City of Portland regulated industrial wastewater discharges (which could be either continuous or batch discharges) to the City sanitary and combined systems. The City of Portland's specific authority to prohibit discharges of contaminants to the Willamette River within the City of Portland dates to at least 1942.[14] Revisions to the City Code in 1960 prohibited discharges to the public sewer of specific materials, including gasoline and other petroleum products, solvents, acids, and toxic wastes, and required pretreatment of industrial wastes prior to discharge to the public sewer.[15] Restrictions on the discharge of commercial and industrial wastes were added and preliminary treatment was required for a number of contaminants before discharging wastewater to the municipal system.[16] Between 1969 and 2006, the City

[13] http://www.epa.gov/npdes/pubs/101pape.pdf.
[14] City of Portland Charter, § 9-604(22) (1942)
[15] City of Portland Ordinance No. 111595 (1960).
[16] *Id.*

Code was amended 10 more times to further limit discharges of untreated wastes to the City's storm and sanitary sewer systems.

Starting in the 1960s, the City began working with industries connected to the City system to reduce discharges of wastes to the City of Portland's sanitary or combined sewer, such as requiring the installation of pretreatment systems for industrial wastes (City of Portland 1966a). Wastewater monitoring typically included pH, BOD, and suspended solids; other monitoring parameters (heavy metals, phenols, cyanide) were added, depending on wastes identified by the industry (City of Portland 1980). Regulation was through wastewater permits or administrative enforcement actions (City of Portland 1980; SAIC 1987).

In order to identify industries that needed pretreatment controls, the City compiled a list of businesses and Standard Industrial Classifications in Portland whose discharges could have an effect on the treatment plant or receiving waters. As of 1972, the City had identified 300 industries that had discharges potentially damaging to the treatment system (code compliance violator) and 55 high strength (BOD or TSS) dischargers. Evaluation of the discharges was prioritized to address the most critical industry groups first, such as the metal plating industry (City of Portland 1980).

Early pretreatment efforts had less impact in the study area, since there were few CSO areas that contained industrial properties and their discharges (see Section 3.2.3.1.11), but they likely reduced overall discharges to the Willamette River. As discussed in Sections 4.3.1.1 and 4.3.1.3, only 2 of the 11 industries identified in 1967 and 17 of the 57 industries identified in 1974 were connected to a CSO system. All identified industries discharged at or upstream of RM 9.8 (wastewater from Centennial Mills would actually overflow upstream of the study area). All but 1 of the industries were located on the west side of the river (see Table 4.3-2).

USEPA first issued regulations for the National Pretreatment Program in 1978 and revised these regulations in 1981 (USEPA 1983). The federal pretreatment program required publicly owned treatment works with greater than 5 million gallons per day design flow to establish a pretreatment program as a condition of their NPDES permits.

The City submitted a report to DEQ in 1980 outlining its pretreatment program and identifying modifications needed to comply with the new federal requirements (City of Portland 1980). The City of Portland's NPDES pretreatment program for the CBWTP was approved in March 1983 (SAIC 1987). In the early 1980s, 260 industrial users were discharging to the City's interceptor system throughout the city and from six outlying areas (SAIC 1987). Based on the 1985 Industrial User Survey, there were 62 industrial users identified in Portland Harbor; 41 of these discharged to a municipal sanitary system, 15 discharged to a municipal CSO system, and 6 did not discharge industrial waste to any City system (City of Portland 1986). The City used these industrial surveys to identify potential facilities subject to federal categorical and

prohibited discharge standards or to local standards to comply with the new federal pretreatment requirements.

4.3.1.4.3 Stormwater Permits

Stormwater discharges had very little control and/or monitoring before the passage of the CWA amendments of 1987, which specifically addressed stormwater discharges, and USEPA stormwater rules became effective in 1990.[17] These rules ultimately required stormwater permits for industrial dischargers, discharges from construction activities, and discharges from municipal separate storm sewer systems serving urban areas.[18]

Since the State of Oregon has been delegated federal authority to administer the federal stormwater program under the CWA, DEQ administers several types of NPDES stormwater permits in Oregon, covering municipal, industrial, and construction-related operations. Municipal entities, such as the City of Portland and the Port of Portland, that discharge in the study area are regulated by MS4 NDPES stormwater permits; industrial dischargers that discharge into the study area are regulated by 1200-Z NPDES stormwater or individual NPDES permits; and discharges from construction activities are regulated under 1200-C or 1200-CA NPDES stormwater permits. Current municipal and industrial permittees that discharge in the study area are listed in Table 4.3-4 and shown on Map 4.3-1.[19]

Point source stormwater discharges from certain types of businesses and industries—such as manufacturers, hazardous waste treatment facilities, and publicly owned treatment works[20]—are regulated by NPDES Industrial General Stormwater Permits, which were first issued by DEQ in 1991. Industrial activities that are subject to permitting requirements are determined by Standard Industrial Classification or Industrial Activity codes listed in the federal regulations 40 CFR 122.26(b)(14) and (15). Since the National Multisector General Permit has only identified 29 industrial sectors to be regulated for stormwater, many properties are not required to have an NPDES permit because they do not fall within the regulated industrial activities and are therefore unregulated with respect to stormwater discharges.

Activities regulated under the industrial stormwater permits include:[21]

- Heavy manufacturing (such as paper mill, chemical plants, petroleum refineries, and steel mills)

[17] 55 Federal Register 47,990 (November 16, 1990).
[18] *Id.*
[19] ECSI sites shown in Map 4.3-1 are as of June 2011. The locations shown on the map are based on the DEQ GIS data augmented by GIS data provided by the City of Portland. The locations of the sites on the two GIS data files can be different.
[20] For the full list, see USEPA, Categories of Industrial Activity that Require Permit Coverage, http://cfpub.epa.gov/npdes/stormwater/swcats.cfm (accessed May 5, 2009).
[21] http://cfpub.epa.gov/npdes/stormwater/swcats.cfm

- Light manufacturing (such as food processing, printing and publishing, electronic manufacturing)
- Coal and mineral mining and oil and gas exploration and processing
- Hazardous waste treatment storage and disposal facilities
- Landfills, land application sites, and open dumps with industrial wastes
- Metals scrap yards, salvage yards, automobile junkyards, and battery reclaimers
- Steam electric power generating plants
- Transportation facilities that have vehicle maintenance, equipment cleaning, or airport de-icing operations
- Treatment works treating domestic sewage with a design flow of 1 million gallons a day or more
- Other facilities subject to federal stormwater effluent discharge standards under 40 CFR Parts 405-47.

However, some categories (e.g., mineral extraction industry, transportation, and light industry) have special conditions or exceptions that may exclude a facility from the stormwater permitting requirements. Also, stormwater discharges associated with the wholesale, retail, commercial, or service industries are exempt.

The NPDES stormwater program requires a regulated facility to develop a stormwater pollution control plan that identifies pollutant sources and specifies best management practices (BMPs) to minimize impacts on stormwater quality.

In 1994, the City of Portland entered into a memorandum of agreement (MOA) with DEQ to administer industrial stormwater NPDES permits for discharges to the City's MS4. In 1999, the MOA was revised to cover all industrial NPDES stormwater permits in the City's urban services boundary. The City administers the general 1200-Z permits in the Portland Harbor and inspects sites for compliance; DEQ maintains responsibility for enforcing permit conditions.

DEQ's 1200-C and 1200-CA stormwater permits cover construction activities. NPDES 1200-C Stormwater Discharge Permits, first issued by DEQ in 1991, are required for any construction activities that disturb 5 or more acres of land to control erosion and reduce sedimentation in waterways. In 2002, the threshold for construction activities was lowered to include projects that disturb 1 or more acres of land.

While the development and implementation of stormwater regulations have resulted in significant reductions in uncontrolled releases to the river, both permitted exceedances and unpermitted releases continue to occur.

4.3.2 Overland Transport

Contaminated surface soils exposed in the upland areas can be carried directly to the river in uncontrolled runoff (e.g., non-channelized or non-piped stormwater runoff). Overland transport was likely to have been more important historically, prior to the development of extensive stormwater conveyance systems within the study area. However, specific historical information on overland runoff is lacking for most sites. At former shipbuilding facilities with shipways, the upland site drainage patterns were conducive to the migration of contaminants to the river through stormwater sheet runoff (USEPA 1997a).

Overland transport has been identified in Table 4.2-2 as a complete historical pathway for only three ECSI sites within the study area: Gasco, Gunderson, and McCormick and Baxter. The historical overland transport pathway has been identified as likely complete at eight other ECSI sites, but confirmatory data are lacking. As with other historical pathways, very little information is available on the details of operations and COIs, and it is more than likely that there were many more sites contributing COIs to this pathway.

4.3.3 Groundwater

Contaminated groundwater may have entered the river historically via discharge through sediments or bank seeps, or it may have infiltrated into storm drains/pipes, ditches, or creeks that discharge to the river. Contaminant migration may have occurred as NAPLs or as chemicals dissolved in the groundwater itself. Though insufficient data are available to evaluate the historical groundwater pathway at most sites reviewed (Table 4.2-2), significant contaminant migration via the historical groundwater pathway has been identified at a small number of upland ECSI sites within the study area. At a limited subset of these sites, the upland groundwater may have loaded upland chemicals to the local transition zone, including sediment and pore water. Because several of these sites are considered current sources of contamination as well, they are discussed in detail in Section 4.4.3. At McCormick and Baxter—the historical pathway was complete, but recent groundwater source control efforts from the comprehensive remedial action at this site have been effective at reducing or eliminating the impacts from this pathway.

4.3.4 Riverbank Erosion

As discussed in Section 3.2.2, the majority of the shoreline sites in Portland Harbor have been filled to extend the land surface into the former river channel. In many areas, the fill approaches 30 ft in thickness. In some locations, materials used for fill extend to the riverbank and may not be protected from river flows and erosion (see Maps 3.1-14a–f). The most common fill materials are hydraulically placed sands and silts dredged from the river, although upland investigations have shown waste materials (e.g., concrete, slag, asphalt shingles, sandblast grit, etc.), quarry materials, and clean soil have also been used as fill. Though there are no records of the quality of dredge

material used for fill, it is likely that the fill materials included contaminated dredge spoils at some locations.

Bank soils can be eroded directly into the river (especially from unarmored or unprotected banks) by in-water forces due to fluctuations in river levels, currents, floods, boat wakes, and propeller wash from ship activities. Over the past 150 years, the Willamette River has experienced numerous floods. Most recently during the floods of 1964 and 1996, the river fully occupied its historical floodplain in the lower, narrower portion of the river and much of the mid-river portion as well.

In some locations, low-lying contaminated riverbank soils can be prone to erosion, and potentially contribute to sediment contamination in the river. These low-lying bank areas are particularly prone to erosion during periodic flooding events. The occurrence and relative importance of riverbank contamination is not well characterized for all parts of the study area, but is a focus of DEQ's source control investigations.

Because of the limited historical data, riverbank erosion has been identified on Table 4.2-2 as a "known" historical pathway for six ECSI properties within the study area: Arkema; Gasco; McCormick and Baxter; Port of Portland Terminal 4 Slips 1 and 3; and EOSM.[22] This identification is based upon the detection of elevated concentrations of COIs in riverbank soils. Ten additional ECSI sites are likely complete historical pathways for riverbank erosion but lack confirmatory data, and 38 sites lack enough information as to determine the completeness of the pathway.

4.3.5 Atmospheric Deposition

Air pollution comes from both natural and manmade sources and can be in the form of either gasses or particulates. Historical air pollution sources were much greater prior to the creation of the Oregon Air Pollution Control Agency in 1952 and the Clean Air Act of 1970, which required air pollution controls. A partial list of principal historical anthropogenic pollution sources in Portland Harbor include chemical plants, manufactured gas plants, petroleum and natural gas storage, flour mills, asphalt plants, incinerators, metal smelters, boiler furnaces, ship repair/refurbishing, recycling activities, and mobile sources such as motor vehicles, marine vessels, locomotives, and aircraft.

Regional sources included automotive emissions, lead smelters, pesticide application, combustion sources, volcanoes, and energy generation. Chemicals commonly acknowledged to play an atmospheric source role in urban river settings within the broader geographic region of the Pacific Northwest include PCBs, dioxins/furans, PAHs, and mercury. For example, extensive examination of the role of atmospheric deposition of such chemicals has been performed for the Columbia River Basin (USEPA 2009a). From the study, it has been found that:

[22] See also Map 4.4-4a.

- Atmospheric deposition from sources inside and outside the region is thought to be a major pathway for mercury
- Incineration and atmospheric deposition bring PCBs from distant sources which are then contributed to the basin.

Global atmospheric transport and subsequent deposition has also been documented as a significant transport mechanism for dioxins and furans (Commoner et al. 2000; Augusto et al. 2004).

Table 4.2-2 does not address atmospheric deposition, although several of these facilities likely were historical sources of air pollution. Information on the importance of this pathway is provided in Sections 6 and 10 of this report.

4.3.6 Overwater Releases

Historically, overwater releases were common occurrences for industries on the banks of the Willamette that relied on maritime shipping to get commodities to and from market. Overwater releases are important contributors to in-water contamination at sites that have long histories of overwater operations and product transfers.

Historical overwater releases were likely to have been associated with refueling, loading/offloading of hazardous materials, activities conducted on docks or piers, and overwater ship maintenance. It was common practice before controls were put in place for ship repairers and repair facilities to allow sand blast grit to go directly from docks and dry dock to the river by paint scraping and abrasives blasting directly overwater and by lowering the dry dock and allowing any materials on the surface of the dry dock to wash into the Willamette River.

The overwater release pathway is complete historically for approximately 29 ECSI facilities and is a likely complete pathway at 14 ECSI facilities within the study area. Any spills that occurred prior to January 1, 2004, are considered historical. (Spills that occurred after January 1, 2004, are considered current overwater releases and are discussed in Section 4.4.6.) Of these facilities, some of the largest spills of commodities have occurred at bulk fuel facilities (e.g., ARCO, Kinder Morgan Linnton, Willbridge Terminal), commodity shipping facilities (Goldendale Aluminum, Port of Portland Terminal 4), and ship repair facilities (Schnitzer Steel, Cascade General). Other types of spills include aviation fuel, diesel, Bunker C fuel, gasoline, asphalt, lube oil, hydraulic fluid, crude oil, sandblast grit, scraping wastes, ballast/bilge water, waste oil, and generator fuel.

Table 4.3-5 lists documented overwater spills for the ECSI sites within the study area based on information from DEQ, the USCG, the Port of Portland, and the National Response Center's centralized federal database of oil and chemical spills. Table 4.3-6 provides information on additional spills in the study area, primarily from vessels, that are not associated with known ECSI sites. Overwater releases were generally not

regulated prior to the 1980s; therefore, few records are available for inclusion in the tables.

4.4 CURRENT SOURCES WITHIN THE STUDY AREA

Current sources of COIs to the study area are discussed in this section. Some of the most significant current sources are the result of historical industrial operations, waste disposal, spills and leaks that contaminated soil, groundwater, or the banks that continue to be released to the Site. Identifying current sources is critical to understanding remedy effectiveness and recontamination potential for the FS and subsequent cleanup. Information presented in the following subsections varies in detail because of differences in the level of understanding and quantitative investigation of the various pathways associated with the upland sites. Information on the relative contributions from overland runoff, riverbank erosion, atmospheric deposition, and overwater releases is limited, and these potential sources are described in general terms.

4.4.1 Direct Discharge—Industrial Wastewater, Stormwater, and CSOs

Pollutants from commercial, industrial, private, or municipal outfalls are being discharged directly to the study area. Some discharges are permitted under the CWA NPDES program, while some non-municipal outfalls and pipes are not permitted or the status is unknown. Discharges from outfalls include industrial wastewaters, stormwater runoff, and CSOs. The City has tracked SSOs (emergency overflows from sewage pump stations) since 1996: there are no records of SSO events in Portland Harbor.

As presented in the Section 3.2.3.11 discussion of conveyance systems, stormwater and wastewater enter surface waters via pipes, culverts, ditches, catch basins, and other types of channels. In the study area, both stormwater and treated wastewater generally enter the river via constructed conveyance systems and outfalls. All wastewater discharges and stormwater discharges from certain types of facilities require a NPDES permit.

Oregon DEQ issues two types of NPDES permits: general and individual. General permits are issued to dischargers with similar operations and type of waste. Individual permits are issued to facilities whose processes or wastewater/stormwater flows merit unique monitoring requirements. There are 14 individual industrial wastewater permit holders amongst 13 facilities (Columbia River Sand and Gravel – Linnton Facility holds two permits) discharging to the study area. There are no municipal wastewater treatment plant discharges in the study area. However, the 2011 NPDES permit for the CBWTP permitted the City of Portland to discharge CSO and pump station overflows (SSOs) into the study area from designated outfalls. The 2011 permit is currently in effect. The Port of Portland, ODOT, Multnomah County, and the City of Portland discharge stormwater under MS4 permits, which include discharges to the study area.

As of February 2011, there were approximately 114 general NPDES stormwater and 14 general NPDES wastewater permitted discharges to the study area, as listed in

Table 4.3-4. Map 4.3-1 shows permitted facilities and the type of permit. Note that multiple permits may be associated with a single outfall. The number of NPDES-permitted discharges by type of permit is shown in Table 4.4-1.

Individual permits are specifically tailored to an individual facility's unique discharge and contain more than just unique monitoring requirements. They also contain specific limitations or conditions for that facility. Individual permit limits may be based on either effluent concentrations or total loadings, incorporating factors such as mixing zones or available technologies. Thirteen facilities within the study area have individual permits and are denoted with a footnote in Table 4.2-2. Discharge monitoring requirements, effluent limits, and information on mixing zones are provided for these 14 individual permits in Table 4.3-1.

The vast majority of permitted discharges to the study area (by number of permits) are for industrial stormwater discharges under general permits (NPDES GEN12Z). Instead of flow or chemical limits, these permits specify benchmark concentrations to help permittees evaluate the effectiveness of their stormwater management practices. Table 4.4-2 lists the permit discharge requirements for each type of general permit. Monitoring parameters for NPDES GEN12Z are limited to pH, oil and grease, TSS, copper, lead, zinc, and sometimes E. coli. The monitoring data generated under these permits provide some data regarding metals and TSS but are otherwise are of limited value in identifying sources. General stormwater permits are limited to a handful of parameters, most of which are not related to Portland Harbor COIs. Individual wastewater permits are specific to the individual process at the facility. Therefore, the data collected from general stormwater and individual wastewater permit facilities are not a good gauge of study area contaminants.

Other tools that have been used to control active discharges include industrial process changes, pollution prevention practices, and technology-based effluent controls. These tools, in addition to the development and implementation of stormwater regulations, have resulted in significant reductions in uncontrolled releases to the river. However, not all industrial operations and many other operations near the study area (wholesale, retail, commercial, or service industries) are not currently regulated.

4.4.1.1 Industrial Wastewater

Discharges of industrial wastewater to the study area are required to have a permit. The facilities with permits discharging to the study area are authorized to discharge process water, oil/water separator discharge, petroleum hydrocarbon cleanup wastewater (tank cleanup and groundwater treatment), vehicle and equipment washwater, boiler blowdown, filter backwash, cooling water, heat pump wastewater, and rinse water of various types. Permitted wastewater discharges are generally required to be treated before discharge.

Information on wastewater discharges, including a list of the hazardous substances being discharged to the river, the concentrations and loads per day, information on

mixing zones, and the COIs that may pose risk to the river, is included in Section 6 of this report.

4.4.1.2 Stormwater

The following sections provide a brief description of the stormwater basins, the types of stormwater discharges, potential sources, currently available data.

Maps 4.4-1a–d present the following information:

- Municipal and non-municipal stormwater and CSO and SSO outfalls
- Stormwater conveyance system piping
- Streams discharging to the study area.

The maps also contain a characterization of the study area showing areas:

- With shared conveyances (e.g., City and Schnitzer-International Slip outfalls)
- With direct discharge (either through outfalls or sheet flow)
- Known to have no stormwater discharge, such as a site where there is specific information that the site/area only has infiltration and no ability to discharge stormwater (e.g., PGE-Harborton, which has a berm around it so no stormwater runoff occurs)
- With uncertain drainage.

4.4.1.2.1 Summary of Stormwater at ECSI Sites

Oregon DEQ began in approximately 2004 to include stormwater evaluations as part of source control evaluations under the DEQ/USEPA JSCS program for Portland Harbor. Of the 114 facilities in the study area with permitted stormwater discharges (see Section 4.4.1), most have not yet conducted a stormwater source control evaluation or are recently in the process of conducting one. Of those ECSI sites for which stormwater source control evaluations have been completed, stormwater discharge has been determined to be a complete and current pathway at 9 sites and a likely complete pathway at 24 sites. For a site to have a complete or likely complete stormwater pathway, COIs have been identified in site-reported stormwater data. No screening of stormwater COIs has been performed by the LWG. However, as noted in Section 4.4.1.2.3, JSCS screening values for stormwater were exceeded in every land use sampled for at least some chemicals based on the LWG sampling program discussed below.

4.4.1.2.2 Potential Sources to Shared Conveyances Draining Stormwater from Multiple Properties

Just under half of the stormwater drainage to the study area is through shared conveyance systems. The majority of these private, non-municipal outfalls are not monitored nor were they sampled for the RI/FS. To qualitatively evaluate potential

COIs from these systems, the LWG evaluated COIs from ECSI sites within the basins, public records, and, where available, from sampling data. Table 4.4-3 identifies 39 City outfalls, 8 outfalls for Burgard Industrial Park, 4 owned by ODOT, and 15 unknown multiparty active and inactive outfalls, including multiple properties that discharge to Saltzman Creek. In addition, information on the outfall structure is included (e.g., location, affiliated organization, outfall size, outfall material, outfall status, basin area). Analytes shown in bold font are permitted under the NPDES 1200Z permit (City of Portland 2010). ECSI sites within each basin and sites immediately upstream of the outfall on the main stem of the river are identified in the table.

For each of these sites, COIs were determined either through review of site summaries, public records, or DEQ's ECSI database. Sites for which the stormwater pathway has been independently investigated (e.g., DEQ's site discovery process or JSCS pathway evaluations are being conducted) are identified in Table 4.4-3. Sites that have not had stormwater pathway evaluations (which typically include sites where cleanup occurred before the JSCS, inactive sites, and sites in former CSO basins) are shown as Other Potential Sources in Table 4.4-3. There was insufficient information on these sites to include them in Table 4.2-2, but they are included in Table 4.4-3 to provide a list of potential historical sources.

The non-municipal shared conveyance systems draining to the study area basin areas are typically not defined, so potential sources in these basins are unknown. As described in Section 4.4, Table 4.4-3 provides a compilation of known and potential sources but is not an exhaustive list of current or historical sources of contamination. Identification and evaluation of potential sources is still ongoing.

COIs were identified through investigations at or adjacent to sites draining to 21 outfalls and included PCBs, TPH, metals, VOCs, PAHs, phthalates, and DDx[23] at one or more outfalls (see Table 4.4-3; DEQ 2009b; Anchor 2006e, 2008f; Anchor QEA 2009d; GeoDesign 2008, pers. comm.; MWH 2009; City of Portland 2006e, 2009b; PES 2008; SES 2008; Evren Northwest 2007; CH2M Hill 2008; Consolidated Metco 2008, pers. comm.).

4.4.1.2.3 Summary of Stormwater Sampling

Stormwater sampling data are presented below from two sources. The LWG sampling program data are used in Section 6 to generate estimated stormwater loads to the study area for the purposes of fate and transport modeling and recontamination analysis. The non-LWG stormwater data were provided by DEQ in early 2008 for sites collecting data under the JSCS program and are presented for reference purposes in this section but will not be used in estimating stormwater loads, as directed by USEPA. Stormwater sample locations and analyses are summarized in Section 2.1.4.1.3, with tabular detail for LWG and non-LWG collected stormwater data in Appendix C1.

[23] DDx represents the sum of the 2,4'- and 4,4'- isomers of dichloro-diphenyl-dichloroethane (DDD), dichloro-diphenyl-dichloroethene (DDE), and dichloro-diphenyl-trichloroethane (DDT).

LWG Sampling Program

Land use classifications for the overall study area by drainage basin include parks and open space/vacant; light industrial; heavy industrial; residential/commercial; and major transportation. Maps 4.4-2a–d indicate the distribution of land uses through the study area. Further discussion on how various City zoning classifications were grouped into land uses is included in Section 6.1.2.1. Generally, areas adjacent to the river are dominated by industrial land uses. The largest combined areas of Heavy Industrial land use are on the east bank from RM 1 to 5 and on the west bank from RM 7 to 10. From RM 8 to 10 on the east bank of the river is the largest area of Light Industrial land use. Extensive areas of Parks and Open Space land use occur slightly away from the west bank from approximately RM 1 to 10. Similarly, much of the area east and away from the river from RM 5 to 12 is Residential/Commercial land use. Although Major Transportation thoroughfares extend throughout the study area, the largest areas tend to be at the upper reaches of the study area.

Stormwater composite water and sediment samples were collected from a subset of drainage basins/outfalls within each land use category in the study area. These locations were sampled by LWG during two sampling efforts in the spring/summer of 2007 (Round 3A) and the fall/winter of 2007–2008 (Round 3B), Port of Portland (Terminal 4 composite water and sediment trap samples at outfalls 52C and 53), and City of Portland (OF-53 composite water samples). One additional site (GE Decommissioning) was sampled by GE during the same time frame. Results from the GE investigation are used in the overall LWG stormwater data set. The stormwater composite water and sediment trap data were collected in accordance with the Round 3A Stormwater FSP and Addendum (Anchor and Integral 2007b,c) and its companion document, the Round 3A Stormwater Sampling Rationale (Anchor and Integral 2007d), and analyzed in accordance with the QAPP Addendum 8 (Integral 2007m).

Table 4.4-4 provides summary statistics for contaminants in stormwater collected by the LWG. Appendix C1, Table C1-1, provides summary statistics for composite water and sediment traps for all stormwater chemicals analyzed during LWG stormwater investigations. Summary statistics for the LWG data include all LWG data, plus Terminal 4 catch basin and stormwater data (including City outfalls that are not part of Terminal 4), and GE Decommissioning stormwater data used for the stormwater loading analysis provided in Section 6 of this report.

Concentrations of certain contaminants, such as total PCBs, total PAHs, DDx pesticides, non-DDx pesticides, bis(2-ethylhexyl)phthalate (BEHP), hexachlorobenzene, and metals, in the LWG stormwater sampling results were compared by land use. For the vast majority of these contaminants, including composite water and sediment data collected for total PCBs, total PAHs, DDx and non-DDx pesticides, and metals, samples taken from Heavy Industrial land use locations had the greatest concentrations. Exceptions include isolated metals (i.e., lead) in Light Industrial sediment trap data. Analyte concentrations collected from Open Space and

Residential land uses were generally lower than other land uses. JSCS values for stormwater were exceeded in every land use sampled for at least some chemicals. The analysis of this data in terms of projected loads (which takes into account acreage of the various land use types) is contained in Section 6 of this report.

Non-LWG Sampling Program

In addition to the LWG stormwater data, at LWG's request, DEQ provided stormwater data in early 2008 for sites that had thus far collected data under the JSCS program. Table 4.4-5 provides a summary of the locations, sampling dates, data quality, and parameters analyzed. Table 4.4-6 provides summary statistics for contaminants in stormwater collected by non-LWG parties. Appendix C1, Table C1-2 provides summary statistics for all stormwater chemicals collected during non-LWG stormwater investigations. Summary statistics for the non-LWG stormwater data are limited to data collected after January 1, 2004, and before early 2008, and are Category 1 data.

In addition, Table 4.2-2 summarizes ECSI sites being investigated by DEQ through its site cleanup program and Table 4.4-5 provides specific information regarding the characterization of stormwater in Portland Harbor; not all properties listed on Table 4.4–5 are listed on Table 4.2-2.

4.4.1.3 Combined Sewer Overflows

In 1990 the City of Portland modeled approximate annual volumes for historical CSOs in preparation for development of a facilities plan for its Combined Sewer Overflow Plan. Estimated CSO volumes in Portland Harbor are shown in Figure 4.4-1. Based on these modeled volumes, in 1970 approximately 1.6 billion gallons of combined stormwater and wastewater (sanitary sewage and some industrial wastewater) overflowed in the Portland Harbor study area. By 1990 the overflow volume had decreased to approximately 925 million gallons annually.

By 2001 the overflow volume was reduced to approximately 628 million gallons annually, as a result of the elimination of several outfalls, downspout disconnections, some sewer separation projects, and infiltration of stormwater to sumps in some areas served by combined sewers. In 2006, the West Side CSO Tunnel Project was completed and the annual CSO volume was reduced to approximately 195 million gallons. Upon completion of the East Side CSO Tunnel Project in 2011, the annual estimated CSO volume in the Portland Harbor area will be approximately 20 million gallons.

Contaminants in CSO discharges identified in a 1997 DEQ report for sampling are bacteria,[24] copper, and lead (DEQ 1997). A review of Annual Pretreatment Reports to DEQ was conducted to determine other potential COIs. Table 4.4-7 shows only those

[24] Bacteria is not a risk-based COI in Portland Harbor.

industries that currently discharge pretreated industrial wastewater to a portion of the combined sewer system that can overflow in the Portland Harbor study area. All of these permittees discharge to a CSO located at or upstream of RM 9.8, and most are located on the west side of the river, where industrial areas were not separated when the interceptors were installed.

Although there are 21 permitted industries, 11 permittees do not discharge to the City's conveyance system. Fifteen industries were required to have permits based on the potential to exceed local limits, and their industrial activities are related to food and beverages, laundries, rubber processing, bag manufacturing, photographic processing, press and printing, and transportation. COIs[25] based on the permit discharge limits for these 15 industries include metals, oil and grease, and volatile organics. Four permits are for discharge of groundwater (either from remediation sites or construction dewatering) to the combined system, and COIs are identified as oil and grease, BTEX, and metals. Three permitted discharges are for metals-related industries, and COIs are identified as metals, oil and grease, cyanide, and total toxic organics. Industrial dischargers are required to list all potential pollutants in their permits even if they do not pretreat and discharge those constituents. The City prohibits discharge of many toxic wastes to its combined and sanitary system, including PCBs and pesticides.[26]

A CSO is composed of approximately 80 percent stormwater and 20 percent sanitary and pretreated industrial wastewater and, therefore, CSO water quality can also be affected by the exposure to stormwater and contaminants in domestic sewage (see Section 4.3.1.3). Table 4.4-3 (see italicized sites) shows the identified potential stormwater sources in the CSO basins and associated COIs.

4.4.2 Overland Transport

Overland transport has been identified as a complete and current pathway at two facilities: Gunderson and Triangle Park. This pathway is likely complete at Gasco. The other sites or portions of these sites lack stormwater conveyance systems, and stormwater either infiltrates the ground or discharges to the river via sheet runoff. This pathway is rarely investigated and could occur at other sites in the study area.

4.4.3 Groundwater

Based on the conceptual understanding of the regional hydrogeology (see Section 3.1.3), groundwater discharge to the river is expected to occur over most of the study area. However, this does not mean that all upland areas represent sources of contamination to the river via the groundwater pathway. Understanding the

[25] BOD and pH listed in permits are not included as COIs because they are not risk-based COIs in Portland Harbor.

[26] Portland City Code Chapter 17.34; Industrial Wastewater Discharges Administrative Rules ENB-4.03. These are current discharge prohibitions. General discharge prohibitions have been in City Code since the 1960s and the City Charter since as early as 1942.

groundwater pathway as a source of contamination to the river requires an understanding of the distribution of upland plumes in relation to the river and the hydrogeologic factors affecting the migration and discharge of groundwater and groundwater contaminants to the river.

4.4.3.1 Assessment of the Groundwater Pathway during the Remedial Investigation

In cooperation with the USEPA and DEQ, the LWG initiated the GWPA for the study area in 2003. The scope of the GWPA was to identify facilities where existing information indicated there was contaminated groundwater that likely was discharging to the river and selecting locations adjacent to the facilities where transition zone samples would be taken to see whether known groundwater contamination could be detected in the river. The GWPA was not scoped nor implemented in a fashion to fully characterize every plume discharging to the river or to investigate every potential source of groundwater discharging to the river. The GWPA consisted of detailed file reviews on upland contaminated groundwater at ECSI sites and consultation with DEQ site managers; selection of a subset of high-priority sites for inclusion in GWPA field investigations; agreement by USEPA to those sites for transition zone confirmatory investigation; performance of these field investigations; and detailed, site-specific evaluation of the results of these investigations, using multiple lines of evidence to reach conclusions with respect to the existence of complete groundwater transport pathways to the lower Willamette River and their potential significance as a source of contamination to TZW and sediment in the lower Willamette River. The primary findings of the GWPA are summarized below. Detailed documentation of the GWPA is provided in Appendix C2. Complete and updated information about facilities with current groundwater contamination is discussed in DEQ's September 2010 Milestone Report (see Appendix B) and January 2013 Milestone Report available online at http://www.deq.state.or.us/lq/cu/nwr/PortlandHarbor/jointsource.htm.

Nine sites were included in the Round 2 GWPA field investigations because they met certain established criteria, such as the upland source of COIs is present, COIs have been detected in upland groundwater, and a groundwater pathway from the upland site to the river is complete or is reasonably likely to be complete. This last criterion is met when COIs present in upland groundwater are either confirmed or, based on professional judgement, believed to have a reasonable potential to discharge to the river (via sediment, the transition zone, surface water, or a combination thereof). A summary of the evaluation of each site against the inclusion criteria is presented in Table C2.3-1 of Appendix C2, and complete summaries for the nine selected GWPA sites, including general background, hydrogeology, and the nature and extent of COIs in groundwater, are presented in Appendices A-1 through A-9 of the GWPA SAP (Integral, Kennedy/Jenks, and Windward 2005).

4.4.3.1.1 Distribution of Upland Groundwater COIs at GWPA Study Sites

For each of the nine sites included in the GWPA field investigations, a series of figures has been prepared displaying the distribution of NAPL (if present) and COIs in upland

groundwater, based on available upland data. These sites and associated COIs are listed below:

- Kinder Morgan Linnton—NAPL, total BTEX, total PAHs, arsenic (Figures 4.4-2a–d)
- ARCO— NAPL, total BTEX, total PAHs, lead, arsenic (Figures 4.4-3a–e)
- ExxonMobil— NAPL, total BTEX, arsenic, lead, zinc (Figures 4.4-4a–e)
- Gasco— NAPL, total BTEX, naphthalene, total cyanide (Figures 4.4-5a–d)
- Siltronic—NAPL, total BTEX, trichloroethene, *cis*-1,2-dichloroethene, vinyl chloride (Figures 4.4-6a–e)
- Rhone Poulenc— NAPL, 1,2-dichlorobenzene, trichloroethene, Silvex, arsenic (Figures 4.4-7a–e)
- Arkema— NAPL, chlorobenzene, perchlorate, total of 4,4'-DDx, chromium (Figures 4.4-8a–f)
- Willbridge Terminal— NAPL, total BTEX, total PAHs, total chromium (Figures 4.4-9a–d)
- Gunderson—1,1,1,-trichloroethane, 1,1-dichloroethene, total lead (Figures 4.4-10a–c).

The COIs presented in these figures are not intended to be inclusive of all contaminants detected in upland groundwater at the site; rather those presented represent the occurrence, distribution, and concentrations of select COIs for a given site.

4.4.3.1.2 Summary of Major Findings of the GWPA

Based on consideration of the multiple lines of evidence discussed above and presented in detail in Appendix C2, the GWPA reached the following overall conclusions with respect to the potential role of the groundwater transport pathway as potential source of contamination to sediments and TZW in the lower Willamette River for the nine GWPA study sites:

- **Kinder Morgan Linnton Terminal (GATX).** The combined lines of evidence suggest some possibility that low levels of PAHs in upland groundwater may be migrating to the transition zone in the groundwater discharge zone offshore of the Kinder Morgan Linnton site. For other upland groundwater COIs at this site, however, there is no evidence of a complete and significant transport pathway to the TZW environment. (See Section C3.1.5 of Appendix C2.)
- **ARCO.** Migration of chemicals in upland groundwater to the transition zone is likely complete. (See Section C3.2.5 of Appendix C2.)
- **ExxonMobil Oil Terminal.** The findings of the Round 2 GWPA suggest that BTEX and metals in upland groundwater at the ExxonMobil site may have been

transported to the TZW via groundwater flow. In 2005, an upland groundwater source control measure was implemented. It is also plausible that the chemicals detected in TZW samples collected at this site during the RI reflect chemical partitioning from sediment to pore water rather than transport from upland groundwater. (See Section C3.3.5 of Appendix C2.)

- **Gasco.** The findings of the Round 2 GWPA and NW Natural's in-water investigation at the Gasco site indicate a complete groundwater pathway for VOCs and PAHs to the transition zone. (See Section C3.4.5 of Appendix C2.)
- **Siltronic.** The pathways for chlorinated VOCs in the offshore zone and PAHs, BTEX, and TPH in the nearshore zone are complete. (See Section C3.5.5 of Appendix C2.)
- **Rhone Poulenc.** A complete pathway for transport of two upland groundwater COIs (1,2-dichlorobenzene and Silvex) to the transition zone is present. (See Section C3.6.5 of Appendix C2, as well as the November 19, 2010 RI/SCE Report for the Rhone Poulenc Portland Site; AMEC 2010b.)
- **Arkema.** The pathway for transport of chlorobenzene, perchlorate, DDx, and chromium from the upland groundwater to the transition zone within the nearshore and intermediate zones is complete. (See Section C3.7.5 of Appendix C2.)
- **Willbridge Terminal.** Based on concentrations and spatial patterns in TZW, a complete groundwater transport pathway from the upland to the transition zone does not appear to be present. (See Section C3.8.5 of Appendix C2.)
- **Gunderson.** Chlorinated solvents measured in nearshore TZW off Area 1 was a complete pathway. In 2006, remediation system extraction wells were installed. (See Section C3.9.5 of Appendix C2.)

4.4.3.2 Study Area-Wide Summary of the Groundwater Transport Pathway

Table 4.2-2 presents the study area-wide understanding of the current groundwater transport pathway at DEQ ECSI sites based on late 2010 information from DEQ on the status of the sites and pathways. Maps 4.4-3a–h provide a river-mile-scale view of groundwater areas identified by DEQ to be affected by upland COIs in the vicinity of the Portland Harbor and the identified zones of in-river groundwater plume discharge, both interpreted and potential.

The groundwater pathway has been reasonably well-characterized at about half of the sites listed in Table 4.2-2, as summarized by category below:

- Documented evidence of a complete current pathway (a): 12 sites
- Likely a complete current pathway (b): 1 site

- Insufficient data to make determination (c): 80 sites[27]
- Not a complete current pathway (d): 27 sites.[28]

In addition, groundwater discharging to stormwater pipes has been identified at 11 facilities. DEQ's evaluation of pathways, which has been reproduced in Appendix B, reaches similar conclusions with respect to the groundwater evaluation of the current status of the sites, with a few areas of potential disagreement:

- DEQ determined that the groundwater pathway was "insignificant" at several sites based on "screening" in an earlier version of the Milestone Report (i.e., July 2006); however, in Table 4.2-2, sites without groundwater investigations are classified as category c (insufficient data to make determination). These sites identified by DEQ include Alder Creek, Babcock Land Company, Chase Bag, Ryerson & Son, McWhorter Technologies, Olympic Pipeline, RK Storage, Schnitzer – Doane Lake, and Transloader International. LWG identifies all sites with no groundwater data as having insufficient data to make a determination. Sites for which insufficient data were available to determine if any of the GWPA inclusion criteria are met were referred to Oregon DEQ for additional upland groundwater characterization.
- Conclusions about complete pathways reached in the GWPA differ from the late 2010 designations. Specifically, the GWPA did not confirm that complete and/or significant (in terms of influence on TZW and sediment chemistry) groundwater transport pathways exist at ARCO, ExxonMobil, Kinder Morgan, Willbridge Terminal, Premier Edible Oils, ST Services, Port of Portland Terminal 4, Slip 3, and Triangle Park, whereas the Milestone Report identifies complete pathways for these sites. DEQ reduced the status of the groundwater pathway at ARCO and Willbridge Terminal from known (a) to likely (b).

4.4.4 Riverbank Erosion

Currently about 75 percent of the riverbanks within the study area are stabilized and armored with various engineered materials, including seawalls, riprap, structures, and engineered soil (Map 3.1-17). Riverbank erosion from unstabilized bank areas may represent an ongoing release mechanism in the study area. Riverbank erosion is identified on Table 4.2-2 as a "known" current pathway at six ECSI sites: Arkema, Gasco, EOSM, Gunderson, Triangle Park, and Terminal 4 (Slip 3).[29] This identification is based upon the detection of elevated concentrations of COIs in riverbank soils. Many other ECSI sites have not been evaluated as to the completeness of this pathway and if a bank has not been armored (e.g., sea walls and rip-rap) and there have been significant

[27] Reflects EOSM's C-c pathway for metals only, see Table 4.2-2.
[28] Reflects EOSM's C-d pathway for TPH only, see Table 4.2-2.
[29] See also Map 4.4-4a.

releases, it should be assumed that this pathway has the potential to release contamination to the Willamette River.

Today, riverbank stabilization and remediation plans are underway at several of these facilities.

4.4.5 Atmospheric Deposition

Similar to historical sources, current regional sources include automotive emissions, pesticide applications, and energy generation. Chemicals commonly acknowledged to play an atmospheric source role in urban river settings within the broader geographic region of the Pacific Northwest include PCBs, dioxins/furans, PAHs, and mercury (see Section 4.3.5). Air pollution (e.g., vehicle and industrial emissions, other combustion products, fugitive dust, etc.) can enter the river directly through the processes of dry and wet deposition. Agricultural air pollution comes from contemporary practices which include clear felling and burning of natural vegetation as well as spraying of pesticides and herbicides. Atmospheric deposition is known to be a source of contamination globally, and its relative importance in the study area in terms of atmospheric loading to the study area is evaluated in Section 6 of this report.

4.4.6 Overwater Releases

Given the industrial and marine uses within the study area, overwater spills are likely to occur directly into the river either intentionally or unintentionally. As discussed in Section 4.3.6, current overwater spills are those that have occurred since January 1, 2004. As shown in Table 4.3-5, documented spills have occurred since January 1, 2004 at approximately 22 facilities located within the study area. The nature of reported spills ranges widely, from dropped bottles to sheens of unknown origin to a 100-gallon spill of lubricating oil in April 2007, as a result of equipment failure at the Cascade General facility. Not all spills are reported or reflected in Table 4.3-5.

The activities most commonly associated with spills in the study area are product handling, overwater activities such as refueling, and vessel leaks:

- **Product handling**. Many facilities are now required to maintain spill prevention plans and have instituted practices to reduce spills.
- **Overwater activities.** Overwater activities, including ship repair or vessel refueling, are potential sources to surface water and sediment contamination. Regulations and BMPs have reduced such contributions in recent years. Spills during refueling are the most common type of overwater spill, but incidents during transfer of other materials (e.g., paint, hydraulic fluid, coal tar pitch) have also been reported. Furthermore, the operation of boat motors may contribute to surface water and sediment contamination.
- **Vessel leaks.** On average, 20 spills from vessels directly into the lower Willamette River are reported to the USCG each year (NRC 2010), nearly all of which are diesel fuel, gasoline, hydraulic oil, lubricating oil, or waste oil. Bilge

and ballast water from vessels has also been released. A detailed list of vessel spills is included in Table 4.3-6. In addition to the types of releases above, the spills include sandblast grit, sewage, paint mixtures, sulfuric acid, and grain in volumes ranging from unknown sheen quantities to barrels. Reasons for spills vary, but are primarily related to equipment or operator error.

Utility crossings are a potential source of spills in the study area. One petroleum pipeline crosses the Willamette River within the study area. It is located between the Willbridge bulk fuel terminal and south end of Triangle Park (approximately RM 7.7). Gasoline lines cross the river at RM 2.8 and near the Sauvie Island Bridge in the Multnomah Channel. Two sewer lines cross the river, one at RM 7 and the other near RM 10. There are no records of spills or leaks from these crossings.

4.4.7 Source Control Measures

Under the 2001 MOU, DEQ is the lead agency responsible for identifying and controlling upland sources of contamination. USEPA is the lead agency for overseeing the investigation and cleanup of the in-water portion of the study area. Together, these two agencies developed the Portland Harbor JSCS in 2004 with the goals of identifying, evaluating, and controlling sources of contamination that may affect the lower Willamette River.

Upland source control is necessary to allow cleanup of the river to proceed without the risk of recontamination. Source control measures are implemented at a given site to address ongoing sources of contamination. Currently, DEQ is investigating or directing source control work at over 80 upland sites in Portland Harbor.

For DEQ, upland source control is an iterative process, where conclusions determined earlier may be refined by information gathered later in the process. The 2010 Milestone Report lists the following combination of tools that DEQ uses to control a source(s):

- Technical assistance.
- Cleaning up contaminated upland areas by removing highly contaminated soil areas, stabilizing or capping contaminated bank areas, treating or containing contaminated groundwater, and extracting contaminated sediment from storm sewer systems.
- Source control of active discharges using BMPs, industrial process changes, pollution prevention practices, and technology-based effluent controls. Compliance is achieved voluntarily or through administrative actions, including permits or enforcement.
- Source control of stormwater.
- Administrative actions and enforcement, such as licenses, permits, deed restrictions, requirements for site development plans, and enforcement actions, which may be necessary when administrative actions are violated.

Table 1 of the 2010 Milestone Report (reproduced as Appendix B) summarizes, for a given site, the status and type of source control activities, the basis for determining if source control is needed, and the schedule for implementing source control measures. Sites listed in the table are only those sites for which DEQ is actively overseeing upland investigations or source control activities (also including sites for which source control decisions have been made). Several ECSI sites are not included in the table because DEQ does not believe these sites are contributors to Willamette River contamination, because there is insufficient information to determine if the site is a contributor but the site has not entered DEQ's cleanup program, or because DEQ had not amended the Milestone Report to align with the expanded study area (e.g., ECSI sites in the RM 11 to 11.8 reach). The January 2013 Milestone Report is available online at http://www.deq.state.or.us/lq/cu/nwr/PortlandHarbor/jointsource.htm.

Information from Table 1 of the 2010 Report has been graphically displayed in Maps 4.4-4a–e for each of the major pathways of a particular site: riverbank erosion, groundwater, overland transport, overwater activities, and stormwater/wastewater. Sites on the maps are shaded different colors to correspond with the status of the following DEQ source control activities:

- Red – Source control evaluation is ongoing
- Blue – Source control evaluation has not started yet
- Green – The source control evaluation is complete or under DEQ/USEPA review
- Yellow – A "No Further Action" determination has been made for the site
- Gray – The pathway does not exist for a site
- White – Site is not included in Table 1 of the Milestone Report.

For each ECSI site on Maps 4.4-4a–e, a symbol is included that corresponds with DEQ's interpretation of the potential for that pathway to impact in-water media. The priority levels for sites and pathways, as described in the footnotes to DEQ's Table 1, are provided below:

> **High** = High priority pathways and sites are those where a complete migration pathway exists and the upland source is significantly impacting the river or poses a significant and imminent threat to the river based on initial evaluation of key source control prioritization factors (see p. 4-3 of the JSCS). A primary consideration is that one or more media (soil, water, air) significantly exceed applicable Screening Level Values (SLVs) at the point of discharge to the river (e.g., water at the end of a discharge pipe, or soil or material at the riverbank) or the most reliable and cost-effective data point (e.g., groundwater measured at the shoreline), or where a bioaccumulative chemical is detected at concentrations significantly above the SLV. In addition, if an upland source is violating DEQ narrative water quality criteria for the Willamette River, the site may be considered a high priority. High priority sites are expected to move forward with aggressive source control measures without delay or be subject to enforcement action.

> **Medium** = Medium priority pathways and sites are those where a complete contaminant migration pathway exists and the upland source is impacting the river or poses a significant and/or imminent threat to the river based on an initial evaluation of key source control prioritization factors (see p. 4-3 JSCS). A primary consideration is that one or more media exceed applicable SLVs, but not significantly, at the point of discharge to the river, or where a bioaccumulative chemical is detected at concentrations above the SLV. Although exceedance of SLVs does not necessarily indicate a site poses a significant and/or imminent threat or needs to immediately implement source control measures, it does indicate that the site may pose a threat to human health or the environment and that additional evaluation may be needed to determine if source control measures are required to prevent, minimize or mitigate the migration of hazardous substances to the river. If the site exceeds one or more SLVs, the need for further characterization or for implementation of source control measures will be based on a site-specific weight-of-evidence determination. Medium priority sites are expected to perform a weight-of-evidence evaluation to determine if source control measures are required.
>
> **Low** = Low priority pathways and sites are those where upland data indicate, based on an initial evaluation of key source control prioritization factors (listed on p. 4-3 JSCS), that the site likely poses a low threat to the river (e.g., concentrations are near or below SLVs) or where DEQ, in consultation with EPA, may issue an upland "No Further Action" (NFA) determination or lower the State's priority of the site for further upland investigation or remedial action under DEQ's cleanup authority. Source control measures will not be required at low priority sites unless determined necessary by the results of the Portland Harbor RIFS or ROD.

As of September 2010, the ECSI sites were categorized, according to DEQ's source control efforts, into the following categories:

- High-priority sites—11
- Preliminary high-priority sites—5
- Medium-priority sites—24
- Low-priority sites—23
- Priority to be determined—3
- Sites with source control decisions—24.

Additionally, DEQ and the City (under an Intergovernmental Agreement) are jointly working together to identify and control upland sources draining to the study area through City outfalls.

4.5 HISTORICAL AND CURRENT SOURCES OUTSIDE THE STUDY AREA

Point and nonpoint discharges within the Willamette River Basin are potential sources of contamination in sediment, surface water, and biota in the study area. Chemicals in discharges and runoff from diverse land uses in the basin eventually make their way to the river by the time it flows into the study area. Contaminant loading from sediment

transport and water from upstream areas throughout the last century also contributed to the conditions currently observed in the study area.

4.5.1 Non-Study-Area Sources in the Lower Willamette River

Sources in the lower Willamette River, both downstream and upstream of the study area, may contribute to chemical deposition within the study area. The study area is at the downstream end of a large basin with a long history of industrial, municipal, and agricultural inputs. Significant agricultural runoff persists upriver, and together with inputs from other industries and cities upstream, as well as atmospheric deposition in the watershed, the river's chemical burden is already elevated before entering the study area.

These upstream and downstream areas are prone to flooding, as evidenced during the major flood events of the past century. Flooding contributes to in-water contamination by eroding contaminated riverbank areas and other surface soils, and potentially breaching historical wastewater containment ponds proximal to the river. Today, many riverbanks have been armored with seawalls, riprap, and other engineered materials. The 32-ft-tall seawall that extends approximately one mile from the Hawthorne Bridge to the Steel Bridge was constructed by the City from 1923 to 1929 as a bulwark against floods (Blalock 2008).

Shoreline facilities upstream of the study area that are included in DEQ's ECSI database are listed in Table 4.2-3, with locations shown in Maps 4.2-2a–d. Note that unless a pathway was identified as a complete pathway to the river in the ECSI database, the LWG has not independently confirmed that sites listed on Table 4.2-3 and Maps 4.2-2a–d have had a confirmed pathway to the river.

The downtown reach is immediately south (upstream) of the study area. It is described as (GSI 2009b):

> The downtown reach of the Willamette River has been used and modified for more than 150 years. Various industrial activities have occurred on the banks of the river, including ship building and ship breaking, heavy manufacturing, pesticide formulating, manufactured gas production, power generation and distribution, lumber processing, and commodities importing and exporting. The river banks have been significantly modified and used for automotive transportation, particularly in the lower half of the downtown reach. Waterfront and upland facilities and roadways may have contributed contaminants to the Willamette River via direct discharges (e.g., stormwater and non-stormwater flows), groundwater discharges, overwater activities, overland runoff, or bank erosion.

The downtown reach has been the focus of a collaborative effort by DEQ, the City of Portland, ZRZ Realty Company, Portland General Electric, and TriMet to evaluate the potential presence of contaminants in sediment from RM 12 to 16, immediately upstream from the RI study area. The focus of this effort is to determine where source control measures or cleanup activities should be implemented at riverfront properties

(as well as facilities discharging to shared conveyances) to minimize potential contamination (GSI 2009b).

One of these sites, the former Portland MGP facility at RM 12.2W has been the focus of an upland and in-water source control investigation under a Consent Order with DEQ executed in April 2009. This facility operated between 1860 and 1913 for manufacturing gas from coal, carbureted water (water enriched with oil), and, briefly, oil. Initial review of sediment results shows that MGP-related contaminants including PAHs, VOCs, and cyanide are present in the Willamette River adjacent to the former gas manufacturing site, most notably in subsurface sediments adjacent to Block 5 of the former site. Limited impacts were observed in shallow upland wells (to 56 ft bgs) installed along the riverfront to assess the potential for ongoing impacts to the river from historical upland releases. Phase 2 follow-up investigations found elevated VOCs and PAHs in deeper upland groundwater zones (to approximately 130 ft bgs), in particular in the 65 to75-ft bgs zone, which appears to coincide with the fill/native sediment interface. The latest proposal is to install deeper wells at four riverside locations corresponding to the former Block 5 of the MGP operation, and adjoining locations to the north and south.

Another site, the former 17-acre Zidell property (owned by the ZRZ Realty Co.) is located on the west bank of the Willamette at RM 14. The Zidell site was used for ship building, ship dismantling, welding, and other ship activities from 1916 until the 1960s. Barge building activities are currently ongoing. As a result of these activities, the onsite soils and offshore sediment are contaminated with asbestos, metals, petroleum hydrocarbons, PAHs, butyltins, and PCBs above state-mandated cleanup levels. According to DEQ (2013) this property is the focus of a major cleanup effort involving the removal or capping of 17,000 yd^3 of contaminated soils and sediment, updates to the stormwater management system, removal of invasive species, removal of treated wood pilings and a floating dock, and bank stabilization. Cleanup activities began in the summer of 2011 (DEQ 2013).

At the PGE Station L site (RM 13.1 to 13.5E), PCB oils were generally used in electrical equipment from the mid-1930s to the 1970s. Soils, various structures onsite, and Willamette River sediments were found to be contaminated with PCBs that were released from transformers. Dredging and capping of river sediments was conducted from 1990–1991. The multi-layer cap was constructed with sand, gravel, and riprap to a thickness of greater than 6 ft. A Record of Decision for No Further Action at the site was issued by DEQ in 1994 (DEQ 2011b). As a result of DEQ's 2009 downtown reach sediment evaluation, PGE is currently evaluating sediment and upland sources between RM 13.1 and 13.5 to determine if additional sediment remediation or source control is needed adjacent to the historical PGE Station L and Station F/Inman-Poulson Lumber mill site.

Maps 4.2-2a–d also show outfalls upstream of the study area. Outfalls in the downtown reach have not been fully mapped, and this is an ongoing effort by the City. These

maps show outfalls that were identified by the City as of February 2010. These include municipal outfalls, including CSO outfalls, and other public and private outfalls. Table 4.5-1 lists currently available data on NPDES-permitted discharges from facilities upstream (to Willamette Falls) and downstream of the study area (Anderson 2006a,b, pers. comm.).

The list of impaired waters in Oregon prepared under Section 303(d) of the federal CWA and its amendments includes the main stem and tributaries of the Willamette River. In 2008, the 303(d) listings in the lower Willamette River (RM 0 to 24.8 as defined by DEQ)[30] included aldrin, DDT, DDE, dieldrin, iron, manganese, mercury, PCBs, PCP, PAHs, temperature, and bacteria. Johnson Creek, a tributary that enters at RM 18, is listed for toxic chemicals, including dieldrin, DDT, PAHs, and PCBs. DEQ has developed total maximum daily loads (TMDLs) for temperature, bacteria, dieldrin, and DDT in Johnson Creek to reduce these watershed contaminants.

4.5.2 Sources above Willamette Falls (Upper Willamette River)

Both point sources and nonpoint sources of contamination are present above Willamette Falls. The extent to which agriculture, forestry, urban land use, geologic features, and atmospheric deposition may have contributed to conditions in Portland Harbor is unknown.

Table 4.5-2 lists historical sources within the Willamette River basin above the falls that were present in 1967, according to OSSA. The table shows the source of waste (both industrial and municipal), the receiving stream, the Willamette river mile of the effluent discharge, the present treatment and disposal of wastes, and action needed by OSSA. Examples of the types of sources within the basin at that time included domestic sewage (with primary and/or secondary treatment), glue wastes from plywood manufacturers, pulp process wastewater, slaughterhouse wastes, kraft mill wastes, metal plating wastes, dye and wool fibers from woolen mills, sulfite mill wastes, and silage wastes.

Presently, more than 750 permitted discharges enter the Willamette River upstream of Willamette Falls, including 10 municipal sewage treatment plants and several pulp, paper, lumber, and fiberboard manufacturers. Hundreds of facilities also have general permits for discharge of noncontact cooling water and filter backwash, gravel mining waste streams, and tank cleaning fluids. Industrial stormwater discharge permits are held by facilities that handle paint, steel, metal plating, semiconductors, adhesives, and food products, as well as by landfills and transportation companies.

Most of the agricultural and forested land in the Willamette River Basin can generate nonpoint sources of pollution. The primary nonpoint source problem associated with forestry is accelerated sediment transport, but nutrients, fertilizers, and herbicides are also found in forest runoff. Erosion from agricultural lands in the Willamette Valley is

[30]For most recent listing see: http://www.deq.state.or.us/wq/assessment/rpt0406/results.asp

the most commonly cited nonpoint source of pollutants in the upper reaches of the Willamette River Basin (Tetra Tech and E&S 1993), especially fertilizers, pesticides, and herbicides. In USGS studies of pesticides in the Willamette Basin (Wentz et al. 1998), the highest concentrations of organochlorine pesticides and PCBs were reported for three mostly agricultural sites. Historical mining is also an upriver source of mercury and lead. Historical discharges of dioxins from pulp and paper mills are relevant sources of contamination as well.

Nonpoint pollutants from the upper Willamette Basin (e.g., pesticides, PAHs, metals) also enter via runoff from residential, industrial, and commercial areas that do not require stormwater permits. Municipal stormwater permits are also held by cities in the upper Willamette Basin.

A fish advisory for mercury is in effect throughout the entire main stem of the Willamette River, due in part to runoff from natural volcanic sources, past mining activities, and atmospheric deposition in the upstream reaches of the Willamette River Basin.

DEQ's 303(d) list of impaired waters above Willamette Falls includes numerous tributaries of the Willamette River. The 303(d) listings in the main stem above Willamette Falls include aldrin, arsenic, DDT, DDE, dieldrin, iron, manganese, mercury, PCBs, DO, temperature, and bacteria. Most of the 303(d) listings for the upper Willamette River tributaries are for temperature and bacteria; other listings relate to nutrients, DO, turbidity, and pH. In addition, smaller creeks in the middle and upper Willamette sub-basins are listed for dieldrin, heptachlor, dichloroethylene, tetrachloroethene, trichloroethene, arsenic, copper, iron, lead, manganese, mercury, or zinc.

Based on the 303(d) list, DEQ has developed TMDLs for 11 of the 12 Willamette River sub-basins (Table 4.5-3; DEQ 2006). TMDLs are currently being developed for the Yamhill sub-basin. Temperature, bacteria, and mercury TMDLs have been issued for all Willamette River sub-basins and the main stem. A PCDD/F TMDL was developed by USEPA in 1991 for the Willamette and Columbia rivers. Further reduction in watershed contaminants will likely occur as a result of TMDL implementation and other future watershed toxic reduction efforts.

5.0 IN-RIVER DISTRIBUTION OF CONTAMINATION

This section presents information on the distribution of contamination in the river environment based on data collected through July 19, 2010 and focuses on the in-river contaminant distribution in and immediately adjacent to the study area, as well as up- and down-river of the study area. Section 5.1 presents the criteria for selection of contaminants for discussion and use in the RI; Section 5.2 discusses the in-river distribution of contaminants in bedded sediments; Section 5.3 discusses mobile sediment (as measured in sediment traps); Section 5.4 discusses the in-river distribution of contaminants in surface water; Section 5.5 discusses the distribution of contaminants in TZW and groundwater seeps; and Section 5.6 discusses the distribution of contaminants in biota.

The discussions in the following subsections focus on distribution of contamination as orders of magnitude of detected values (e.g., <1, 1–10, 10–100, 100–1,000, etc.). Depending on the medium examined, the discussion of contaminant distribution is supported by a variety of tabular and graphical materials: 1) maps showing the extent of each contaminant's distribution, 2) summary statistics tables, 3) scatter-plot graphs depicting chemical concentrations by river mile, and 4) histogram plots for comparing values. The summary statistics tables present frequency of detection; minimum, maximum, mean, median, and 95th percentile; and the station locations of the maximum values. Summary statistics are calculated using only detected values as well as combined detect and non-detect values. These statistics have been compiled separately for the RI study area reach (RM 1.9–11.8, exclusive of the Multnomah Channel), the downtown reach (RM 11.8–15.3), the upriver reach (RM 15.3–28.4), and the downstream reach (RM 0–1.9) [refer to Map 5.0-1]. Summary statistics for sediments include both point samples and beach composite samples to provide a general understanding of contaminant concentration distributions.

Where specific sample results are cited in the text (i.e., the concentration of a sample, median and 95th percentile values), qualifiers and descriptors associated with that result are also cited, with one exception. The descriptor "T" is not cited as it generally indicates that the result was mathematically derived through summing multiple results (e.g., total PCB congeners equal the sum of the PCB congener results).[1] The "T" descriptor may also indicate that a result is an average of multiple results for a single analyte (e.g., field replicates) or that a result was selected for reporting in preference to other available results (e.g., for parameters reported by multiple methods). The descriptor "A" indicates a total value is based on an incomplete number of analytes (e.g., seven of the nine PCB Aroclors) and is cited with the results.

- Similarly, the following laboratory qualifiers are also cited with the results:

  J – The associated numerical value is an estimated quantity.

[1] The "T" qualifier appears on some maps.

N – Presumptive evidence of presence of organic compound; identification of the compound is not definitive. The N qualifier is used in combination with the J qualifier.

U – The material was analyzed for, but was not detected. The associated numerical value is the sample quantitation limit.

In certain cases, concentrations of closely-related analytes were added together to create a group sum. When calculating group concentrations for this in-river contaminant distribution evaluation, a value of zero was used for non-detected concentrations on an individual sample basis. 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) toxic equivalent concentration (TEQ) values for dioxin-like PCB congeners and PCDD/Fs were calculated using WHO 2005 toxicity equivalency factors (TEFs) for mammals[2] (Van den Berg et al. 2006). Benzo(a)pyrene (BaP) equivalent (BaPEq) values used to represent carcinogenic PAHs (cPAHs) were calculated using PEFs provided in EPA (1993b). Further information on summing methods is provided in Appendix A.

5.1 SELECTION OF INDICATOR CONTAMINANTS

COIs are contaminants expected to be present at a site based on a review of site information. Numerous chemical parameters were identified for the study area from the site assessment and were subsequently analyzed for and detected in various sampled media. Summary statistics for all COIs are presented by media for each river reach in Appendix D. Table 5.1-1 presents the COIs detected in the various media (sediment, water and biota) of the river.

Due to the large number of COIs detected at the site in various media, the RI will focus on a subset of the contaminants—designated as indicator contaminants—to facilitate a clear and practical presentation of the distribution of contamination in the study area. It should be noted that additional contaminants beyond the indicator contaminants presented in this section are present at the site at concentrations that may pose unacceptable risk to human health and the environment, and limiting the discussion of contaminants in this section in no way limits the contaminants that will be considered in the FS or cleanup decisions made by EPA.

Indicator contaminants were identified using a screening process (Table 5.1-2) that first compared the detected COIs at the site (Table 5.1-1) with those contaminants posing unacceptable risk to human health and the environment and then considered the following factors:

- Frequency of detection—Contaminants with a frequency of detection less than 20 percent were not selected.

[2] The World Health Organization (WHO) has provided a list of 12 dioxin-like congeners: PCB-77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, and 189.

- Cross media comparisons—Contaminants that would allow comparisons across media were selected.
- Collocation of contaminants—Several contaminants were selected to represent other contaminants due to collocation of the contaminants (for example, arsenic, chromium, copper, and zinc were selected to represent other metals).
- Widespread sources—Certain other contaminants with widespread sources in the harbor (e.g., metals, PAHs, and PCBs) were selected.
- Grouped contaminants—Some contaminants were grouped as one contaminant. Contaminants that were grouped include PCBs, PCDD/Fs, DDx, and PAHs.
- Low exceedance of risk—Several contaminants did not contribute significantly to risk estimates (hazard quotient [HQ] <10 or risk at 10^{-6}) and were not selected.

The first screen identified 35 contaminants in the study area. An additional screen identified a subset of 13 indicator contaminants, which are the focus of further discussion in the main text of the RI. Although not discussed further in the main RI report, summary statistic tables, maps, and figures by media are presented in Appendix D for the 21 contaminants that were not identified as indicator contaminants.

Table 5.1-2 identifies the 13 indicator contaminants selected by this process for further discussion in the RI. Contaminants that were screened due to collocation were based either on one form of a contaminant representing another or on a correlation plot of the rank and location of the data sets. The basis for each contaminant screening due to collocation is presented in Table 5.1-3 and Figures 5.1-1 through 5.1-5.

Data presentations identical to those provided in the following sections are also provided for physical parameters and other COIs in Appendix D; however, there is no discussion or interpretation of the information. Appendix D also provides discussions of patterns and trends in the constituent chemicals of grouped analytes (e.g., PCBs, PCDD/Fs, PAHs, DDx).

5.2 INDICATOR CONTAMINANTS IN BEDDED SEDIMENT

This section summarizes the surface and subsurface sediment data collected in the upriver reach, downtown reach, study area reach, and downstream reach. The locations of all surface and subsurface sediment samples in the RI data set are shown on Maps 2.1-15 and 2.1-17. The discussion of each contaminant focuses primarily on the following items:

- A description of the data set for each contaminant, including sample counts, concentration range, and frequency of detection.
- A discussion of the surface and subsurface concentration distributions in the upriver reach, downtown reach, RI study area reach, and downstream reach. The RI study area reach is organized by eastern nearshore, western nearshore,

and navigation channel subareas (Map 5.2-1) and distributions are discussed within river mile reaches and hydrodynamic reaches (see discussion in Section 3).

- A discussion of the vertical trends in sediment concentrations and the relationship of subsurface sediment to surface sediment concentrations.

The sediment chemistry distributions are depicted in three graphical formats:

1. Surface plan-view concentration maps and subsurface core concentration maps
2. Scatter-plot graphs of surface and subsurface sediment (RM 0.8-12.2)
3. Histograms comparing mean surface and subsurface concentrations by river mile (RM 0–11.8).

Core plots showing a higher level of detail have been produced for the following indicator contaminants:

- Total PCBs
- DDx
- TCDD TEQ
- Total PAHs.

Additionally, more detailed core plots were developed for total cPAHs and are presented in Appendix D1.2. More detailed core plot maps were developed for these five contaminants because they are more prevalent throughout the study area and based on their relative contribution to risk in the baseline risk evaluations (Appendices F and G).

Surface Chemistry Maps: The plan-view concentration maps present all surface sample data using color-coded dots that correspond to a concentration scale for that particular chemical. The concentration ranges (or intervals) used in color-coding the chemical data shown on the maps were based on the frequency distributions (i.e., natural breaks), or as negotiated between EPA and LWG, in the data set for these contaminants and have no environmental significance. Non-detected concentrations are differentiated from detected concentrations on the surface maps by a dot in the center of the sample symbol ○. The maps include data points from locations that were dredged or capped subsequent to the collection of the sample(s) shown by a circle centered around the sample symbol ◎.[3,4] Data from these areas are presented to show spatial

[3] For example, all data shown for locations *within the capped area* at the McCormick and Baxter site (see Maps 2.1-15i and 2.1-17i) are from surveys completed between 1999 and 2002, prior to capping. These data are shown on the surface and subsurface core plan-view maps and included in the map histograms; however, they are not included in the other sediment data presentations (i.e., scatter plots and histograms).

patterns of chemicals from a historical, pre-dredge perspective. In addition, the surface maps include histograms showing the distributions and frequencies of the detected and non-detected results. Data from all samples shown on the maps are included in the histograms.

Subsurface Core Maps: The core maps show the distribution of contaminants with depth at each of the subsurface sediment sampling stations (these maps also include the surface sample data). Inset maps for densely sampled core areas are provided in most cases. In these maps, the actual core station is marked with a triangle △. The core segment divisions displayed on the maps are scaled to the thickness of each sample interval. Note that these maps do include cores from locations that were subsequently dredged or capped, as indicated on the maps. Cores taken post-dredging are also included on the maps.

Scatter Plots: Scatter plots present the distribution of detected contaminants in surface and subsurface sediment per river mile. The data are presented in a log scale (by order of magnitude) to facilitate in the discussion on distribution and to fit all the data onto one plot due to the vast range in concentrations detected. To aid in differentiating potential concentration trends in the study area, the data in these plots are further separated into eastern nearshore, western nearshore, and navigation channel stations as defined by the federal navigation channel boundary (Map 5.2-1). Data collected in Multnomah Channel are presented with the western shore data and are identified using a different symbol. Likewise, data collected in Swan Island Lagoon are presented with the eastern shore data and identified with a unique symbol. Unlike the plan-view maps, the scatter plots do *not* include data for samples from locations that have been subsequently dredged or capped.

Histograms: The histograms compare the average surface and subsurface sediment chemical concentrations for the indicator contaminants on a subarea basis. The y-axis in the plots is centered on a value of 0, which represents the vertical horizon (i.e., 40 cm bml) between the surface and subsurface samples. Bars extending downward from the y-axis depict the subsurface mean values. Bars extending upward show the surface sediment means. Subareas included east, navigation channel, and west zones for each river mile in the study area, as well as Multnomah Channel and Swan Island Lagoon. Mean concentrations were also calculated for each zone in the entire study area (see leftmost column in each figure).

These histograms are useful in providing a visual summary of spatially averaged surface/subsurface trends throughout the study area. However, some caution is needed in interpreting the trends due to the biased nature of the RI sampling program (i.e., subsurface core samples were generally focused on known areas of contamination, whereas surface samples were distributed more widely). Further, highly contaminated

[4] Surface interval sample locations G088, G087, and G091 collected in 2004 in the International Terminals Slip were dredged subsequent to sampling. These locations were resampled in 2005 at C088, C087, and C091.

areas may not necessarily be contained within a specific river mile, but rather partially overlap two adjacent river miles. Consequently, these histograms should be examined in conjunction with the subsurface core maps in evaluating surface to subsurface trends for a specific contaminant and subarea. This is particularly true for the relatively low density PCDD/F data.

5.2.1 Sediment Data Set

The sediment RI data set is composed of all Category 1 LWG and non-LWG data (refer to Appendix D1.3, Table D1.3-1) collected within the downstream reach (RM 0 to 1.9), the RI study area reach (RM 1.9 to 11.8), the downtown reach (RM 11.8 to 15.3), and the upriver reach (RM 15.3 to 28.4), from May 1997 to July 2010. The surface sediment data set includes all samples with intervals starting at 0 cm and extending to depths ranging to 40 cm bml. The subsurface data set includes all samples collected at depths greater than 40 cm bml. The upriver reach is dynamic and the channel is coarse-grained with finer-grained sediments generally restricted to small off-channel areas (Maps 2.1-2a-b); thus, most of the main channel above RM 20 could not be sampled with a grab sampler because the river bed is cobbled or hard.

Summary statistics for indicator contaminants, percent fines, and TOC in the surface and subsurface sediment samples for the entire RI study area reach are presented in Tables 5.2-1 and 5.2-2. The data from the RI study area were segregated into the eastern nearshore, navigation channel, and western nearshore and are presented by river mile in Tables 5.2-3 and 5.2-4, Tables 5.2-5 and 5.2-6, and Tables 5.2-7 and 5.2-8, respectively. These summary statistics do *not* include results from locations that were dredged or capped subsequent to sample collection. The specific surface and subsurface samples excluded from the summary statistics are listed in Appendix D1.3, Table D1.3-32. However, post-dredged sediment samples are included in the summary statistics. Tables 5.2-9 and 5.2-10 present the study area indicator contaminant data as orders of magnitude (e.g., <1, 1–10, 10–100, 100–1,000, etc.) for only detected values and for combined detected and non-detected values, respectively. Similar summary statistics and order of magnitude data are presented for the upriver reach in Tables 5.2-11 through 5.2-14, for the downtown reach in Tables 5.2-15 through 5.2-18, and for the downstream reach in Tables 5.2-19 through 5.2-22.

5.2.2 Total PCBs in Surface and Subsurface Sediment

The distribution of total PCBs concentrations at each surface sediment sampling station throughout the study area is depicted on Map 5.2-2; concentrations with depth at subsurface stations are depicted in detail on Maps 5.2-3a–hh. If more than one sample was analyzed at the same surface sediment location, the greater of the two samples is presented on these maps; all subsurface samples are presented.

Scatter plots of the total PCBs data set for surface and subsurface sediment in the study area are presented on Figures 5.2-1 and 5.2-2, respectively. The scatter plots present the data in three panels segregated by the eastern nearshore, navigational channel, and western nearshore zones (Map 5.2-1).

Summary statistics for total PCBs in surface and subsurface sediment within the study area are shown in Tables 5.2-1 and 5.2-2. Summary statistics for surface and subsurface sediment within the eastern nearshore, navigation channel and western nearshore zones are presented in Tables 5.2-3 and 5.2-4, Tables 5.2-5 and 5.2-6, and Tables 5.2-7 and 5.2-8, respectively. Tables 5.2-9 and 5.2-10 present the total PCBs data as orders of magnitude (e.g., <1, 1–10, 10–100, 100–1,000, etc.) for only detected values and for combined detected and non-detected values. Finally, a histogram of average surface and subsurface sediment values by river mile and for the entire study area is presented in Figure 5.2-3.

Data sets for the upriver, downtown, and downstream reaches are only presented in statistical tables and order of magnitude tables. Additionally, the downtown reach surface sediment samples are presented in Map 5.2-4. Summary statistics for surface and subsurface sediment within the upriver reach are shown in Tables 5.2-11 and 5.2-12; the number of data points by order of magnitude is provided in Tables 5.2-13 (detects only) and 5.2-14 (detects and non-detects). Summary statistics for surface and subsurface sediment within the downtown reach are shown in Tables 5.2-15 and 5.2-16; the number of data points by order of magnitude is provided in Tables 5.2-17 (detects only) and 5.2-18 (detects and non-detects). Summary statistics for surface and subsurface sediment within the downstream reach are shown in Tables 5.2-19 and 5.2-20; the number of data points by order of magnitude is provided in Tables 5.2-21 (detects only) and 5.2-22 (detects and non-detects).

5.2.2.1 Total PCBs Data Set

The surface and subsurface data set includes PCBs analyzed for both Aroclors and congeners. For the purpose of sediment characterization, total PCB congener concentrations represent the sum of detected congener concentrations in a sample. In cases where no congeners were detected, the single highest detection limit of all congeners analyzed is used to represent the total value. Similarly, total PCB Aroclor values reflect the sum of detected Aroclors in a sample.

The relationship between total PCB congener and total Aroclor concentrations is discussed in detail in Appendix D1.4. The coefficient of determination between same-sample congener and Aroclor totals in surface sediment was $r^2 = 0.761$, and $r^2 = 0.476$ for subsurface sediment. Plots of these regressions are presented in Appendix D1.4. For all data (sediment, sediment trap, and biota), r^2 was 0.70. PCB totals based on congeners and Aroclors did not correspond well for 11 sediment samples; an order of magnitude difference was observed between the total congener and total Aroclor results, as described in Appendix D1.4. The evaluation indicates that total Aroclor data may over predict total PCB congeners in concentrations below ~750 µg/kg total Aroclors and may under predict above 750 µg/kg. For this reason, PCB congener data were determined to better represent total PCBs concentrations than Aroclor data, as the congener method is less affected by "weathering," non-PCB interferences, and subjective Aroclor identifications.

In this report, total PCB congener concentrations are given priority over total Aroclor concentrations when total PCB congener data exist for any given sample, based on the greater specificity and accuracy of the laboratory method for congeners. Because measured total PCBs concentrations are fairly comparable between methods in most cases, it is useful to use Aroclor concentrations when no PCB congener data exist, which represent the majority of the samples. Combining the PCB data in this way provides greater spatial and temporal coverage than using congener data alone due to the lack of congener data available.

The summary statistics values shown in Tables 5.2-1 and 5.2-2 for total Aroclors and total PCB congeners indicate overall higher sample concentrations of total PCBs when summing congeners. The higher concentrations measured by summing congeners are not a result of differences in laboratory methodology, but rather are attributable to a more targeted sample selection process, in which samples selected for PCB congener analysis frequently targeted areas known or suspected to have relatively high PCB contamination.

Consequently, the total PCBs data set consists of the result for total PCB congeners for each sample when available, and the result for total Aroclors when no total PCB congener data are available for a particular sampling location. Congener analyses for LWG sediment samples generally included all 209 congeners. [5] Total PCBs concentration data for sediment within the study area are available for 1,318 surface and 1,543 subsurface samples. Most of the total PCBs data are based on Aroclor analyses (Tables 5.2-1 and 5.2-2). Maps 5.2-5 and 5.2-6 display the locations of surface and subsurface sediment samples analyzed for PCBs and indicate whether PCB congener data, Aroclor data, or both are available.

5.2.2.2 Total PCBs in Surface Sediment

Upriver Reach (RM 15.3 to 28.4)

Total PCBs were detected in 42 of 81 surface sediment samples within the upriver reach (frequency of detection 52 percent). Detected concentrations ranged from 0.29J to 31 µg/kg (Table 5.2-11). Total PCBs (Tables 5.2-13 and 5.2-14) were at or greater than 10 µg/kg in 4 samples, between 1 and 10 µg/kg in 33 samples, and less than 1 µg/kg in 5 samples. The mean total PCBs concentration in this reach is 4.48 µg/kg.

Downtown Reach (RM 11.8 to 15.3)

Total PCBs were detected in 195 of 265 surface sediment samples within the downtown reach (frequency of detection 74 percent). Detected concentrations ranged from 0.798 J to 19,700 µg/kg (Table 5.2-15). Concentrations reported were greater than 10,000 µg/kg in 3 samples, between 1,000 and 10,000 µg/kg in 12 samples, between

[5] The exception is that total Aroclor data were selected to represent total PCBs for Round 2A beach sediment samples because the beach samples were only analyzed for coplanar PCB congeners, which constitute a small fraction of the total PCBs.

100 and 1,000 µg/kg in 51 samples, between 10 and 100 µg/kg in 81 samples, between 1 and 10 µg/kg in 47 samples, and less than 1 µg/kg in 1 sample (Tables 5.2-17 and 5.2-18).

The majority of samples with concentrations greater than 1,000 µg/kg were located along the western shoreline between RM 13.5 and 14.1, which is the location of the Zidell facility. In 2011, a remedial action was conducted at the Zidell facility under DEQ authority. Within the area addressed by the remedial action, total PCBs were detected in 111 surface sediment samples (frequency of detection of 73 percent). Concentrations reported ranged from 1.27 to 19,700 µg/kg, with a mean of 1,320 µg/kg (Table 5.2-15). When the data for the Zidell facility are removed from the downtown reach data set (Table 5.2-15), total PCBs concentrations in surface sediment ranged from 0.798 J to 4,200 µg/kg, with a mean of 108 µg/kg.

Study Area Reach (RM 1.9 to 11.8)

Total PCBs were detected in 80 percent of surface sediment samples (1,052 detections) within the study area. Concentrations reported ranged from 0.851 J to 35,400 µg/kg (Table 5.2-1), and varied throughout the study area (Figure 5.2-1). This information is presented on Map 5.2-2 (total PCBs concentrations exceeding 1,000 µg/kg are indicated in red). Several prominent concentration peaks, defined as greater than 1,000 µg/kg, are present in the eastern nearshore zone: RM 1.9–4, 6–7, Swan Island Lagoon, and RM 11–11.8 (Figure 5.2-1). Mean total PCB concentrations in these areas are: 663 µg/kg at RM 1.9–3, 369 µg/kg at RM 3–4; 223 µg/kg at RM 6–7, 373 µg/kg in Swan Island Lagoon; and 495 µg/kg at RM 11–11.8 (Table 5.2-3).

The highest total PCBs concentrations along the western side of the river are found in the western nearshore zone from RM 8–10; including the highest detected surface concentration (35,400 µg/kg) at Station G453 (RM 8.8). Mean total PCBs concentrations in this area are 978 µg/kg at RM 8–9 and 341 µg/kg at RM 9–10 (Table 5.2-7).

The highest concentrations found in the navigation channel zone are at RM 11–11.8, which appears to be an extension of the contamination noted along the eastern nearshore area (Map 5.2-2). The maximum detected concentration in this area is 5,900 µg/kg, with a mean concentration 292 µg/kg (Table 5.2-5).

Total PCBs concentrations greater than 10,000 µg/kg were found in only two locations: in the western nearshore zone, at RM 8.8 and in Swan Island Lagoon (Tables 5.2-9 and 5.2-10; Maps 5.2-3t,x). Total PCBs concentrations between 1,000 and 10,000 µg/kg were reported in 37 samples, all within the areas described above. Overall, concentrations greater than 1,000 µg/kg account for 4 percent of detected results (39 samples), 19 percent were between 100 and 1,000 µg/kg (203 samples), 59 percent (621 samples) were between 10 and 100 µg/kg, 18 percent (188 samples) were between 1 and 10 µg/kg, and 1 sample was detected at a concentration less than 1 µg/kg (Table 5.2-9).

Downstream Reach (RM 0 to 1.9)

Total PCBs were detected in 16 of 25 surface sediment samples within the downstream reach. Concentrations reported ranged from 1.03 J to 410 µg/kg (Table 5.2-19), with a single result greater than 100 µg/kg (Tables 5.2-21 and 5.2-22). Overall, concentrations between 10 and 100 µg/kg accounted for 16 percent of detected results (4 samples), and 44 percent were between 1 and 10 µg/kg (11 samples). The mean total PCBs concentration in this reach is 33.7 µg/kg.

5.2.2.3 Total PCBs in Subsurface Sediment

Upriver Reach (RM 15.3 to 28.4)

Three subsurface sediment samples were analyzed for total PCBs within the upriver reach between RM 15.4 and 16. All results were reported as non-detect, with a maximum reporting limit of 11 µg/kg (Table 5.2-12).

Downtown Reach (RM 11.8 to 15.3)

Total PCBs were detected in 59 of 110 subsurface sediment samples within the downtown reach. Concentrations reported ranged from 1.4 J to 610 µg/kg (Table 5.2-16) with a mean concentration of 92 µg/kg. Within this reach, 14 percent (15 samples) of the reported results were between 100 and 1,000 µg/kg, 44 percent (31 samples) were between 10 and 100 µg/kg, and 22 percent (13 samples) were between 1 and 10 µg/kg. All detected results were greater 1 µg/kg (Tables 5.2-17 and 5.2-18). Only two subsurface samples were collected from the vicinity of the Zidell facility, and the reported concentrations were 140 µg/kg and 190 µg/kg.

Study Area Reach (RM 1.9 to 11.8)

Total PCBs were detected in 939 subsurface samples within the study area (detection frequency of 61 percent), with detected concentrations ranging from 0.00138 J to 36,800 µg/kg (Table 5.2-2). Similar to surface sediment, total PCBs concentrations in the subsurface also varied within the study area. Several areas of higher concentrations (greater than 1,000 µg/kg) in the subsurface data are identified in the eastern nearshore zone (Figure 5.2-2, Maps 5.2-3a-hh) from RM 1.9–4, 5–6, Swan Island Lagoon, and RM 11–11.8. Mean concentrations in these areas are 521 µg/kg at RM 1.9–3; 1,530 µg/kg at RM 3–4; 369 µg/kg at RM 5–6; 560 µg/kg in Swan Island Lagoon; and 464 µg/kg at RM 11–11.8 (Table 5.2-4).

An area of high total PCBs concentrations is located in the western nearshore zone from RM 7–10. The highest subsurface concentration of 36,800 µg/kg was reported in the sample from Station C455 at 30–152 cm bml (Map 5.2-3v). Mean total PCBs concentrations in this area are 177 µg/kg at RM 7–8; 931 µg/kg at RM 8–9; and 424 µg/kg at RM 9–10 (Table 5.2-8).

The highest reported concentrations in the navigation channel are at RM 10–11.8. Mean total PCBs concentrations in this area are 443 µg/kg at RM 10–11 and 107 µg/kg at RM 11–11.8 (Table 5.2-6). The higher concentrations at RM 10–11 appear to be

associated with the western nearshore area, whereas concentrations at RM 11–11.8 appear to be associated with the eastern nearshore area (Maps 5.2-3cc-hh).

Overall, 6 samples had reported total PCBs concentrations greater than 10,000 µg/kg. These were located in the eastern nearshore zone from RM 3–4E, Swan Island Lagoon, and the western nearshore zone from RM 8–9 (Tables 5.2-9 and 5.2-10; Maps 5.2.3a-hh). An additional 40 samples had reported concentrations between 1,000 and 10,000 µg/kg; all were located within the areas described above. Total PCBs concentrations in subsurface sediment greater than 1,000 µg/kg account for 5 percent of the detected results, 34 percent (319 samples) were between 100 and 1,000 µg/kg, 50 percent were between 10 and 100 µg/kg, 9 percent (88 samples) were between 1 and 10 µg/kg, and 2 percent (20 samples) had reported concentrations less than 1 µg/kg.

Downstream Reach (RM 0 to 1.9)

Total PCBs were reported in 13 of 26 subsurface sediment samples within the downstream reach. Concentrations reported ranged from 5 to 250 µg/kg (Table 5.2-20). Three samples had reported concentrations between 100 and 1,000 µg/kg, 62 percent (8 samples) had reported at concentrations between 10 and 100 µg/kg, and two samples had reported concentrations between 1 and 10 µg/kg. The mean total PCBs concentration in this reach is 67 µg/kg (Tables 5.2-21 and 5.2-22).

5.2.2.4 Total PCBs Surface and Subsurface Sediment Relationships

The relationship between surface and subsurface sediment total PCBs concentrations were examined by comparing surface and subsurface concentrations by reach, and also by subareas within the study area.

There are insufficient data to compare surface and subsurface concentrations in the upriver reach because no attempt was made to characterize subsurface sediments in this reach. This reach is unlikely to have significant subsurface contamination due to its dynamic (i.e., non-depositional) nature. The mean surface sediment concentration in this reach is 4.48 µg/kg. Subsurface samples were non-detect for total PCBs, with a reporting limit of 11 µg/kg.

Within the downtown reach, total PCBs concentrations were higher in surface sediment than in subsurface sediment. Mean concentrations are 612 and 92 µg/kg in surface and subsurface sediment, respectively. Median concentrations are 45 and 41 µg/kg in surface and subsurface sediments, respectively.

Total PCBs concentrations are generally greater in subsurface sediments than in surface sediments within the study area. The mean surface sediment concentration in the study area is 220 µg/kg, and the mean subsurface sediment concentration is 351 µg/kg (Tables 5.2-1 and 5.2-2). Median total PCBs concentrations in surface and subsurface sediment are, respectively, 26.9 and 70.0 µg/kg. Mean concentrations are greater in the nearshore areas than in the navigation channel. Total PCBs concentrations are greater in the eastern nearshore zone than the western nearshore zone (Figure 5.2-3).

Subsurface sediment concentrations are greater than surface sediment in the eastern nearshore zone in all river miles zones except from RM 1.9–3, 6–7, 10–11, and 11–11.8. In the western nearshore zone, subsurface sediment concentrations are greater than in surface sediment in all river miles except RM 8–9. The subsurface sediment concentrations in the navigation channel are generally greater than the surface sediment concentrations, except from RM 11–11.8. Areas where subsurface sediment total PCBs concentrations exceed 1,000 µg/kg generally align with the locations where surface sediment concentrations are greater than 1,000 µg/kg (Maps 5.2-3a-hh; Figures 5.2-1, 5.2-2, and 5.2-3). Exceptions occur in the eastern nearshore zone, total PCBs concentrations greater than 1,000 µg/kg in surface sediment are found from RM 6–7 and in subsurface sediment from RM 5–6.

The subsurface sediment concentrations in the downstream reach were greater than surface concentrations. The mean total PCBs concentrations are 33.7 and 67 µg/kg in surface and subsurface sediment, respectively. The median total PCBs concentrations are 6.8 and 46 µg/kg in surface and subsurface sediment, respectively.

5.2.3 Total PCDD/Fs and TCDD TEQ in Sediment

Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are evaluated as total polychlorinated dibenzo dioxins/furans (total PCDD/Fs). The summed total value for total PCDD/Fs represents the summed value of the measured homolog concentrations. The toxicity of dioxins and furans is determined by both the number and the position of the chlorine on the molecule, and appears to be a function of the ability to bind to specific cellular receptors. Because only those congeners having a chlorine in each of the 2, 3, 7, and 8 positions exhibit a toxicological response similar to 2,3,7,8-TCDD and other 2,3,7,8 substituted isomers appear to be slightly to substantially less potent, a TEF is used to calculate a PCDD or PCDF toxicity equivalent concentration by multiplying the individual congener concentrations by its respective toxicity TEF. The TCDD TEQ represents the sum of the individual 2,3,7,8-TCDD equivalent concentrations.

The distribution of total PCDD/Fs and TCDD TEQ concentrations at each surface sampling station throughout the study area is depicted on Maps 5.2-7 and 5.2-9, respectively; concentrations with depth at subsurface stations are depicted in Maps 5.2-8a–o and in detail on Maps 5.2-10a-m, respectively.

The complete data set for total PCDD/Fs is plotted on scatter plots presented on Figures 5.2-4 and 5.2-5. Figures 5.2-7 and 5.2-8 present scatter plots of the TCDD TEQ data set for surface and subsurface sediment in the study area, respectively. The scatter plots present the data in three panels segregated by the eastern nearshore, navigation channel, and western nearshore zones (Map 5.2-1).

Summary statistics for total PCDD/Fs and TCDD TEQ in surface and subsurface sediment within the study area are shown in Tables 5.2-1 and 5.2-2. Summary statistics for surface and subsurface sediment within the eastern nearshore, navigation channel

and western nearshore zones are presented in Tables 5.2-3 and 5.2-4, Tables 5.2-5 and 5.2-6, and Tables 5.2-7 and 5.2-8, respectively. Tables 5.2-9 and 5.2-10 present the total PCDD/Fs and TCDD TEQ data as orders of magnitude (e.g., <1, 1–10, 10–100, 100–1,000, etc.) for only detected values and for combined detected and non-detected values. Finally a histogram of average surface and subsurface sediment values for total PCDD/Fs and TCDD TEQ by river mile and for the entire study area is presented in Figures 5.2-6 and 5.2-9.

Data sets for the upriver, downtown, and downstream reaches are only presented in statistical tables and order of magnitude tables. Additionally, the downtown reach surface sediment samples are presented on Maps 5.2-11 and 5.2-12. Summary statistics for surface and subsurface sediment within the upriver reach are shown in Tables 5.2-11 and 5.2-12; the number of data points by order of magnitude is provided in Tables 5.2-13 (detect only) and 5.2-14 (detect and non-detect). Summary statistics for surface and subsurface sediment within the downtown reach are shown in Tables 5.2-15 and 5.2-16; the number of data points by order of magnitude is provided in Tables 5.2-17 (detect only) and 5.2-18 (detect and non-detect). Summary statistics for surface and subsurface sediment with the downstream reach are shown in Tables 5.2-19 and 5.2-20; the number of data points by order of magnitude is provided in Tables 5.2-21 (detect only) and 5.2-22 (detect and non-detect).

5.2.3.1 Total PCDD/Fs and TCDD TEQ Data Sets

The number of sediment samples for PCDD/F analysis was based on a biased approach at locations near known or suspected sources. As a result, there are fewer data points for these analytes and the resulting TCDD TEQ data in the RI sediment database than for other chemicals (for example, the PCDD/F data set is approximately one-fifth the size of the PCB and DDx data sets). This is particularly true in areas not proximal to suspected sources, such as the navigation channel.

While the existing PCDD/F data are sufficient for RI purposes, the fewer number of data points limits the level of detail on the extent of the contaminant distribution in some areas and introduces the need for caution in interpreting the surface to subsurface trends shown by the histograms (Figures 5.2-6 and 5.2-9), and in making conclusions regarding the spatial patterns of the composition of total PCDD/Fs and TCDD TEQ in sediment (Sections 5.2.3.2 through 5.2.3.5). Total PCDD/Fs data for sediment within the study area are available for 237 surface and 327 subsurface samples; there are 238 surface and 331 subsurface samples in the study area sediment TCDD TEQ data set.

5.2.3.2 Total PCDD/Fs in Surface Sediment

Upriver Reach (RM 15.3 to 28.4)

Total PCDD/Fs were reported in 38 of 39 surface sediment samples within the upriver reach (frequency of detection 97 percent). Concentrations range from 2.39 pg/g (0.00239 µg/kg) to 733 pg/g (Table 5.2-11). Concentrations between 100 and 1,000 pg/g were reported in 12 samples (Tables 5.2-13 and 5.2-14), between 10 and

100 pg/g in 17 samples, and between 1 and 10 pg/g in 9 samples. The mean total PCDD/Fs concentration in this reach is 90 pg/g, and the median is 59 J pg/g.

Downtown Reach (RM 11.8 to 15.3)

Total PCDD/Fs were detected in 62 of 67 surface sediment samples within the downtown reach (frequency of detection of 93 percent). Detected concentrations range from 9.45 J to 15,400 J pg/g (Table 5.2-15) with a mean of 1,130 pg/g. As shown on Map 5.2-11, the highest detected concentrations are located along the eastern shoreline. Concentrations greater than 10,000 pg/g were reported in a single sample, between 1,000 and 10,000 pg/g in 17 samples, between 100 and 1,000 pg/g in 26 samples, between 10 and 100 µg/kg in 16 samples, and between 1 and 10 pg/g in 2 samples. This information is presented in Tables 5.2-17 and 5.2-18.

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-15 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. None of the total PCDD/Fs data was excluded from the downtown reach.

Study Area Reach (RM 1.9 to 11.8)

Total PCDD/Fs were detected in all 237 surface sediment samples. Reported concentrations range from 2.48 to 264,000 pg/g (Table 5.2-1); the mean is 2,410 pg/g, and the median is 412 pg/g. Detected concentrations exceeding 2,000 pg/g are indicated in red on Map 5.2-7. Total PCDD/Fs concentrations exceeding 1,000 pg/g are found in the eastern nearshore zone at RM 2–8, Swan Island Lagoon, and at RM 11 (Figure 5.2-4). Mean concentrations (see Table 5.2-3) in these areas are 1,170 pg/g at RM 3–4; 1,640 pg/g at RM 4–5; 1,300 pg/g at RM 5–6; 3,440 pg/g at RM 6–7; 1,510 pg/g at RM 7–8; 3,030 pg/g in Swan Island Lagoon; and 1,670 pg/g at RM 11–11.8E.

Concentrations exceeding 1,000 pg/g are found in the western nearshore zone at RM 6–10 and from RM 4–6. Mean concentrations (see Table 5.2-7) in these locations are 726 pg/g at RM 4–5; 830 pg/g at RM 5–6; 1,730 pg/g at RM 6–7; 15,200 pg/g at RM 7–8; 1,500 pg/g at RM 8–9; and 1,650 pg/g at RM 9–10. The highest surface sediment concentration (264,000 pg/g) in the data set was detected between RM 7–8.

The highest total PCDD/Fs concentrations in the navigation channel zone are located at RM 6–7 and RM 11–11.8. It appears that these concentrations are associated with higher concentrations found in the eastern nearshore zone (Map 5.2-7) rather than reflecting conditions in the navigation channel. The maximum detected concentrations at these locations are 2,260 pg/g at RM 6–7, and 2,020 pg/g at RM 11–11.8. Mean concentrations are 779 pg/g at RM 6–7 and 810 pg/g at RM 11–11.8 (Table 5.2-5).

Total PCDD/Fs concentrations greater than 10,000 pg/g were detected in 7 samples (Tables 5.2-9 and 5.2-10), and 63 detected values were between 1,000 and 10,000 pg/g. Overall, concentrations greater than 1,000 pg/g accounted for 30 percent of the detected

results (Map 5.2-7), 56 percent (133 samples) were between 100 and 1,000 pg/g, 13 percent (31 samples) were between 10 and 100 pg/g, and 1 percent (3 samples) were detected at concentrations between 1 and 10 pg/g.

Total PCDD/Fs concentrations greater than 2,000 pg/g (indicated in red on Map 5.2-7) were found at several locations along the eastern and western nearshore zones. Limited surface PCDD/F data are available in the navigation channel, and spatial resolution is somewhat limited. However, of the channel samples that were analyzed, most concentrations were less than 500 pg/g (except as noted above), and a pattern is evident of relatively high concentrations in nearshore areas compared with lower concentrations in the adjacent channel areas.

Downstream Reach (RM 0 to 1.9)

Total PCDD/Fs were detected in all 21 samples within the downstream reach. Concentrations reported ranged from 1.56 J to 1,780 J pg/g, with a mean concentration of 232 pg/g (Table 5.2-19). Tables 5.2-21 and 5.2-22 show that there was only 1 data point with a concentrations greater than 1,000 pg/g, 38 percent (8 samples) of the reported concentrations were between 100 and 1,000 pg/g, 52 percent (11 samples) were between 10 and 100 pg/g, and 1 sample was between 1 and 10 pg/g.

5.2.3.3 Total PCDD/Fs in Subsurface Sediment

Upriver Reach (RM 15.3 to 28.4)

Total PCDD/Fs were detected in all three subsurface sediment samples in the upriver reach; reported concentrations ranged from 3.59 to 1,090 pg/g (Table 5.2-12), with a mean concentration of 816 pg/g. One sample had a reported concentration between 1,000 and 10,000 pg/g, and the other two results were between 100 and 1,000 pg/g (Tables 5.2-13 and 5.2-14).

Downtown Reach (RM 11.8 to 15.3)

Total PCDD/Fs were detected in 39 of 44 subsurface sediment samples and samples within the downtown reach (detection frequency of 89 percent), with detected concentrations ranging from 4.74 to 4,590 J pg/g (Table 5.2-15) and a mean concentration of 1,090 pg/g. Overall, concentrations between 1,000 and 10,000 pg/g were reported in 17 samples, 11 were between 100 and 1,000 pg/g, 8 were between 10 and 100 µg/kg, and 3 were between 1 and 10 pg/g. There were no detected results less than 1 pg/g (Tables 5.2-17 and 5.2-18).

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-16 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. None of the total PCDD/Fs data was excluded from the downtown reach.

Study Area Reach (RM 1.9 to 11.8)

Total PCDD/Fs were detected in 325 of 327 subsurface sediment samples within the study area (frequency of detection 99 percent). Reported concentrations ranged from

0.0578 J to 425,000 J pg/g, with a mean concentration of 9,050 pg/g (Table 5.2-2). The distribution of reported concentrations is presented on Figure 5.2-5 and Maps 5.2-8a-o).

Total PCDD/Fs concentrations in subsurface sediment greater than 10,000 pg/g were found in the eastern nearshore zone from RM 7–8 (Figure 5.2-5). Concentrations greater than 1,000 pg/g in subsurface sediment are prevalent throughout the site, most frequently in the eastern nearshore zone from RM 2 through 8 and RM 11–11.8. Mean concentrations (see Table 5.2-4) in the eastern nearshore zone are 446 pg/g at RM 1.9–3; 638 pg/g at RM 3–4; 1,340 pg/g at RM 4–5; 561 pg/g at RM 5–6; 1,650 pg/g at RM 6–7; 19,500 pg/g at RM 7–8; 981 pg/g in Swan Island Lagoon; and 1,510 pg/g at RM 11–11.8.

Total PCDD/Fs concentrations exceed 10,000 pg/g between RM 6 and 9 in the western nearshore zone (Figure 5.2-5). Reported concentrations greater than 1,000 pg/g are located from RM 4 through 11. The highest reported concentration of 425,000 J pg/g was found in core sample WB-36 between RM 7 and 8 (Table 5.2-8). Mean concentrations in subsurface sediment in the western nearshore zone are 624 pg/g at RM 4–5; 315 pg/g at RM 5–6; 2,650 pg/g at RM 6–7; 27,300 at RM 7–8; 19,400 pg/g at RM 8–9; and 12,200 pg/g at RM 9–10.

Limited subsurface sediment data are available for the navigation channel, and most reported concentrations were less than 100 pg/g. The highest concentrations in the subsurface samples are generally found in the same areas where concentrations greater than 1,000 pg/g were reported in surface samples (Figures 5.2-5 and 5.2-6; Maps 5.2-8a–o). Reported concentration greater than 1,000 pg/g were found from RM 6 to 7 and RM 9.5 to 10.5.

Total PCDD/Fs concentrations greater than 10,000 pg/g were reported in 26 samples, 71 were between 1,000 and 10,000 pg/g (Tables 5.2-9 and 5.2-10), and overall 30 percent of the reported concentrations were greater than 1,000 pg/g. Reported concentrations between 100 and 1,000 pg/g comprise 32 percent (103 samples) of the detections, 23 percent (74 samples) were between 10 and 100 pg/g, 10 percent (31 samples) were between 1 and 10 pg/g, and 6 percent (20 samples) were less than 1 pg/g.

Downstream Reach (RM 0 to 1.9)

Total PCDD/Fs were detected in 17 of 17 samples analyzed within the downstream reach. Reported concentrations ranged from 0.093 to 967 pg/g; the mean concentration is 145 pg/g (Table 5.2-20). Overall, concentrations greater than 100 pg/g account for 29 percent (5 samples) of the detected results, 41 percent (7 samples) were between 10 and 100 pg/g, 12 percent (2 samples) were between 1 and 10 pg/g, and 18 percent (3 samples) were detected at concentrations less than 1 pg/g (Tables 5.2-21 and 5.2-22).

5.2.3.4 TCDD TEQ in Surface Sediment

Upriver Reach (RM 15.3 to 28.4)

TCDD TEQs were calculated for 48 of 49 surface sediment samples within the upriver reach. Calculated concentrations range from 0.00684 J to 2.99 pg/g (Table 5.2-11). Tables 5.2-13 and 5.2-14 show that there are three results between 1 and 10 pg/g; the majority (45 samples; 92 percent) are less than 1 pg/g. The mean TCDD TEQ concentration in this reach is 0.315 pg/g.

Downtown Reach (RM 11.8 to 15.3)

TCDD TEQs were calculated for 63 of 67 surface sediment samples within the downtown reach, with concentrations ranging from 0.011 J pg/g to 19.2 J pg/g with a mean of 2.61 pg/g (Table 5.2-15). TCDD TEQ concentrations in surface sediment in the downtown reach are shown in Map 5.2-12. Two results are between 10 and 100 pg/g, 35 detected (56 percent) are between 1 and 10 pg/g, and 26 (41 percent), are less than 1 pg/g (Tables 5.2-17 and 5.2-18).

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-15 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. None of the TCDD TEQ data was excluded from the downtown reach.

Study Area Reach (RM 1.9 to 11.8)

TCDD TEQs were calculated for 238 surface sediment samples. Calculated concentrations range from 0.008 J to 14,100 J pg/g, with a mean of 67.9 pg/g (Table 5.2-1). These results are plotted on Figure 5.2-7 and presented on Map 5.2-9, with concentrations greater than 10 pg/g indicated in red.

TCDD TEQ concentrations greater than 10 pg/g are present in the eastern nearshore from RM 3 through 8, in Swan Island Lagoon, and RM 11–11.8. Mean concentrations (see Table 5.2-3) in these areas are 2.95 pg/g at RM 3–4; 4.84 pg at RM 4–5; 4.40 pg/g at RM 5–6; 16.1 pg/g at RM 6–7; 11.9 pg/g at RM 7–8; 4.90 pg/g in Swan Island Lagoon; and 4.44 pg/g at RM 11–11.8.

TCDD TEQ concentrations greater than 10 pg/g in the western nearshore zone are present from RM 6 to 10. Mean concentrations (see Table 5.2-7) in these areas are 20.0 pg/g at RM 6–7; 78.5 pg/g at RM 7–8; 3.55 pg/g at RM 8–9; and 4.59 pg/g at RM 9–10. The highest calculated TCDD TEQ concentration in the surface sediment data set, 14,100 pg/g, is between RM 7 and 8.

There were no calculated concentrations in the navigation channel zone greater than 10 pg/g.

Only one sample has calculated TCDD TEQ greater than 10,000 pg/g, there are no results between 1,000 and 10,000 pg/g, 4 results (2 percent) are between 100 and 1,000 pg/g, 28 results (12 percent) are between 10 and 100 pg/g, 107 samples

(45 percent) are between 1 and 10 pg/g, and 98 results (41 percent) are less than 1 pg/g (Tables 5.2-9 and 5.2-10).

The spatial distribution of TCDD TEQ values in the study area is presented on Figure 5.2-7. Concentrations were higher in the western nearshore zone than in the eastern nearshore or navigation channel. The highest reported results are present in the western nearshore between RM 6.8 and 7.3, where the sample density is greater in comparison to the rest of the study area.

Limited data for TCDD TEQ are available for sediments in the navigation channel (Map 5.2-9). TCDD TEQ surface values within the channel were all less than 10 pg/g.

Downstream Reach (RM 0 to 1.9)

TCDD TEQs were analyzed and detected in all 21 samples within the downstream reach, with concentrations ranging from 0.0051 J to 2.6 J pg/g (Table 5.2-19). Tables 5.2-21 and 5.2-22 show that there are only 2 data points with concentrations ranging between 1 and 10 pg/g. The majority of the data set (19 samples; 90 percent) were detected at concentrations less than 1 pg/g. The mean TCDD TEQ concentration in this reach is 0.4 pg/g.

5.2.3.5 TCDD TEQ in Subsurface Sediment

Upriver Reach (RM 15.3 to 28.4)

TCDD TEQs were calculated in three subsurface sediment samples within the upriver reach; concentrations range from 0.656 to 2.63 pg/g (Table 5.2-12). Two results are between 1 and 10 pg/g, and the remaining result is less than 1 pg/g, with a mean concentration of 1.55 pg/g (Tables 5.2-13 and 5.2-14).

Downtown Reach (RM 11.8 to 15.3)

TCDD TEQs were calculated for 41 of 44 subsurface sediment samples within the downtown reach. Calculated concentrations range from 0.00226 J to 12.8 pg/g (Table 5.2-15), with a mean of 2.65 pg/g. There is a single result between 10 and 100 pg/g, 24 samples (59 percent) are between 1 and 10 pg/g, and 16 samples (39 percent) are less than 1 pg/g (Tables 5.2-17 and 5.2-18).

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-16 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. None of the TCDD TEQ data was excluded from the downtown reach.

Study Area Reach (RM 1.9 to 11.8)

TCDD TEQs were calculated for 313 of 331 subsurface sediment samples within the study area. Calculated concentrations range from 0.000262 J to 24,400 J pg/g, with a mean of 434 pg/g (Table 5.2-2). The distribution of TCDD TEQ concentrations in subsurface sediment in the study area is shown on Figure 5.2-8, and concentrations greater than 10 pg/g are indicated in red on Maps 5.2-8a-o and 5.2-10a-m.

Concentrations greater than 10 pg/g are present in the eastern nearshore zone from RM 1.9–3, RM 6–8, and from RM 11 to 11.8. Mean concentrations (Table 5.2-4) in these areas are 1.45 pg/g at RM 1.9–3; 5.80 pg/g at RM 6–7; 37.6 pg/g at RM 7–8; and 7.67 pg/g at RM 11–11.8.

Concentrations greater than 10 pg/g are present in the western nearshore zone from RM 4 through 9, with a prominent peak from RM 6.5 to 7.5. Mean concentrations (Table 5.2-8) in these areas are 5.27 pg/g at RM 4–5; 2.46 pg/g at RM 5–6; 20.4 pg/g at RM 6–7; 1,570 pg/g at RM 7–8; and 36.7 pg/g at RM 8–9. The highest calculated TCDD TEQ concentration of 24,400 pg/g in subsurface sediment is at Station SD092 (0–90 cm vertically composited sample) at RM 7.2W (Map 5.2-10g).

Limited subsurface TCDD TEQ data are available from the navigation channel, and the majority of calculated results are less than 10 pg/g. The highest concentrations in subsurface sediment are generally found at the same locations where TCDD TEQ are concentrations greater than 10 pg/g in surface sediment along the eastern and western nearshore zones (Maps 5.2-8a–o and 5.2-10a-m).

Tables 5.2-9 and 5.2-10 show that there are 3 data points greater than 10,000 pg/g. There are 14 detected values between 1,000 and 10,000 pg/g and 12 samples detected at concentrations between 100 and 1,000 pg/g. An additional 42 samples are detected at concentrations ranging between 10 and 100. Another 99 samples, or 32 percent, are detected at concentrations between 1 and 10 pg/g. Approximately half the detected data set (143 samples; 46 percent) is composed of sample concentrations less than 1 pg/g.

The data show that TCDD TEQ values vary spatially along the length of the study area (Figure 5.2-8). In general, values were higher in the western nearshore zone than in the eastern nearshore and navigation channel zones. The most significant peak in the data in the western nearshore occurred between approximately RM 6.8 and 7.3, where data points are relatively dense in comparison to the rest of the study area.

Limited data for TCDD TEQ are available for sediments in the navigation channel (Map 5.2-9). TCDD TEQ surface values within the channel were relatively low, with the exception of one sample with relatively elevated concentrations near the western channel boundary at RM 6.6 (33.3 J pg/g in the interval from 132 to 243 cm bml at Station C314; Figure 5.2-8).

Downstream Reach (RM 0 to 1.9)

TCDD TEQs were analyzed in 17 samples within the downstream reach and detected in 16 samples (detection frequency of 94 percent), with concentrations ranging from 0.00252 to 1.53 J pg/g (Table 5.2-20). Tables 5.2-21 and 5.2-22 show that there is only one data point with concentrations ranging between 1 and 10 pg/g. The majority of the data set (15 samples; 94 percent) were detected at concentrations less than 1 pg/g. The mean TCDD TEQ concentration in this reach is 0.260 pg/g.

5.2.3.6 Total PCDD/Fs and TCDD TEQ Surface and Subsurface Sediment Relationships

Surface and subsurface sediment relationships are examined by comparing surface and subsurface concentrations by reach and also by subareas within the study area reach. There are insufficient data to compare surface and subsurface concentrations in the upriver reach.

The surface total PCDD/Fs sediment concentrations in the downtown reach are slightly higher than the subsurface concentrations, while the TCDD TEQ concentrations are approximately the same. The mean surface total PCDD/Fs concentration is 1,130 pg/g and the subsurface concentration is 1,090 pg/g. The mean surface TCDD TEQ concentration is 2.61 pg/g and the subsurface sediment concentration is 2.66 pg/g.

Total PCDD/Fs and TCDD TEQ concentrations are generally greater in the subsurface sediments than in surface sediments within the study area as a whole. The mean total PCDD/Fs surface sediment concentration is 2,410 pg/g and the subsurface concentration is 9,050 pg/g; the mean TCDD TEQ surface sediment concentration is 68 pg/g and the subsurface concentration is 434 pg/g. Most areas throughout the study area reach lack a strong or consistent vertical concentration gradient. This pattern may be due to the lack of samples and is supported by Maps 5.2-10a-m. Some exceptions to this include the area under and just upstream of the Railroad Bridge at RM 6.9, where surface layers show higher concentrations than at depth (Map 5.2-10g), and the northwest corner of Willbridge Terminal where higher levels are evident at depth (Map 5.2-10h). This suggests a recent source or sources at the former location and a historical source or sources at the latter. Elsewhere in the study area, significant changes in the level of PCDD/F inputs over time are generally not indicated by the data collected.

The surface total PCDD/Fs sediment concentrations in the downstream reach are slightly higher than the subsurface concentrations, while the TCDD TEQ concentrations are approximately the same. The mean surface total PCDD/Fs concentration is 232 pg/g, and the subsurface concentration is 67 pg/g. The mean surface TCDD TEQ concentration is 0.401 pg/g, while the subsurface sediment concentration is 260 pg/g.

5.2.4 DDx in Sediment

DDx represents the sum of the 2,4'- and 4,4'- isomers of DDD, DDE, and DDT. The distribution of DDx concentrations at each surface sediment sampling station throughout the study area is depicted on Map 5.2-13; concentrations with depth at subsurface stations are depicted in detail on Maps 5.2-14a-hh. If more than one sample was analyzed at the same surface sediment location, the greater of the two samples is presented on these maps; all subsurface samples are presented.

Figures 5.2-10 and 5.2-11 present scatter plots of the DDx data set for surface and subsurface sediment in the study area, respectively. The scatter plots present the data in

three panels segregated by the eastern nearshore, navigational channel, and western nearshore zones (Map 5.2-1).

The summary statistics for DDx in the surface and subsurface sediment within the study area are shown in Tables 5.2-1 and 5.2-2. Summary statistics for surface and subsurface sediment within the eastern nearshore, navigational channel, and western nearshore zones are presented in Tables 5.2-3 and 5.2-4, Tables 5.2-5 and 5.2-6, and Tables 5.2-7 and 5.2-8, respectively. Tables 5.2-9 and 5.2-10 present the DDx data as orders of magnitude (e.g., <1, 1–10, 10–100, 100–1,000, etc.) for only detected values and for combined detected and non-detected values. Finally, a histogram of average surface and subsurface sediment values by river mile and for the entire study area is presented in Figure 5.2-12.

Data for the upriver, downtown, and downstream reaches are only presented in statistical tables and order of magnitude tables. Additionally, surface sediment sample locations within the downtown reach are presented in Map 5.2-15. Summary statistics for surface and subsurface sediment within the upriver reach are shown in Tables 5.2-11 and 5.2-12; the number of data points by order of magnitude is provided in Tables 5.2-13 (detect only) and 5.2-14 (detect and non-detect). Summary statistics for surface and subsurface sediment within the downtown reach are shown in Tables 5.2-15 and 5.2-16; the number of data points by order of magnitude is provided in Tables 5.2-17 (detect only) and 5.2-18 (detect and non-detect). Summary statistics for surface and subsurface sediment within the downstream reach are shown in Tables 5.2-19 and 5.2-20; the number of data points by order of magnitude is provided in Tables 5.2-21 (detect only) and 5.2-22 (detect and non-detect).

The individual total DDT, DDD, and DDE concentrations (totals of the 2,4'- and 4,4'-isomers) are depicted in similar maps, tables, and figures as DDx in Appendix D1.

5.2.4.1 DDx in Surface Sediment

Upriver Reach (RM 15.3 to 28.4)

DDx was reported in 56 of 81 surface sediment samples within the upriver reach (frequency of detection 69 percent). Concentrations reported range from 0.087 J to 14.6 J µg/kg (Table 5.2-11). Tables 5.2-13 and 5.2-14 show that 1 result was reported at a concentration greater than 10 µg/kg, 41 samples were between 1 and 10 µg/kg, 14 samples (25 percent) were reported at a concentration less than 1 µg/kg. The mean concentration in this reach is 2.01 µg/kg.

Downtown Reach (RM 11.8 to 15.3)

DDx was reported in 130 of 149 surface sediment samples within the downtown reach (frequency of detection 87 percent). Reported concentrations range from 0.047 J to 73.3 J µg/kg (Table 5.2-15), with a mean concentration of 6.6 µg/kg. The spatial distribution of DDx in surface sediment is presented on Map 5.2-15.

DDx concentrations between 10 and 100 µg/kg were reported in 25 samples, 76 results (58 percent) were between 1 and 10 µg/kg, and 29 samples were reported at concentrations less than 1 µg/kg (Tables 5.2-17 and 5.2-18).

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-15 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. None of the DDx data was excluded from the downtown reach.

Study Area Reach (RM 1.9 to 11.8)

DDx was reported in 1,130 of 1,249 surface sediment samples within the study area (frequency of detection 90 percent). Concentrations reported range from 0.051 NJ to 84,900 µg/kg (Table 5.2-1). The spatial distribution of DDx concentrations in surface sediment is presented on Figure 5.2-10 and Map 5.2-13; concentrations greater than 100 µg/kg are observed at several locations along the nearshore zones and channel margins.

DDx concentrations greater than 100 µg/kg are present in the eastern nearshore zone at RM 5–7, Swan Island Lagoon, and RM 11–11.8 (Map 5.2-13). Mean concentrations in these areas are 16.6 µg/kg at RM 5–6; 18.2 µg/kg at RM 6–7; 15.7 µg/kg in Swan Island Lagoon; and 42.0 µg/kg at RM 11–11.8 (Table 5.2-3).

DDx concentrations greater than 100 µg/kg are present in the western nearshore zone from RM 3 through 9. The most prominent areas are between RM 6.3 and 7.5, where concentrations greater than 10,000 µg/kg were found at Station OSS002 near RM 7.2 (Table 5.2-7; Map 5.2-13). DDx was reported at a concentration greater than 1,000 µg/kg in a single sample at RM 8.8. Mean DDx concentrations in these areas are 26.6 µg/kg at RM 3–4; 23.4 µg/kg at RM 4–5; 36.3 µg/kg at RM 5–6; 190 µg/kg at RM 6–7; 2,720 µg/kg at RM 7–8; and 123 µg/kg at RM 8–9 (Table 5.2-7).

Within the navigation channel, DDx concentrations greater than 100 µg/kg were reported in four samples from three areas: RM 5.6 (maximum of 148 µg/kg), RM 6.5 (maximum of 274 J µg/kg), and RM 11.3 (maximum of 140 µg/kg). These areas are collocated with contamination present in the adjacent nearshore zones. Mean concentrations in these areas are 12.6 µg/kg at RM 5–6; 29.1 µg/kg at RM 6–7; and 25.2 µg/kg at RM 11–11.8 (Table 5.2-5).

DDx concentrations greater than 10,000 µg/kg were reported in 7 samples, 22 reported values were between 1,000 and 10,000 µg/kg (also located between RM 7.2W and 7.5W, with one result being at RM 8.8), 92 results were between 100 and 1,000 µg/kg, 327 results were between 10 and 100 µg/kg, 636 results were between 1 and 10 µg/kg, and 46 results (4 percent) were reported at a concentration less than 1 µg/kg (Tables 5.2-9 and 5.2-10). In all, DDx concentrations greater than 100 µg/kg account for 11 percent of the reported results in surface sediment (Map 5.2-13).

Downstream Reach (RM 0 to 1.9)

DDx was reported in 22 of 25 surface sediment samples within the downstream reach (frequency of detection 88 percent). Concentrations reported range from 0.2 to 30 J µg/kg (Table 5.2-19). DDx was reported at concentrations greater than 10 µg/kg in 3 samples, 14 results (64 percent) were reported at concentrations between 1 and 10 µg/kg, and 5 results were reported at concentrations less than 1 µg/kg. The mean DDx concentration in this reach is 5.2 µg/kg (Tables 5.2-19, 5.2-21, and 5.2-22).

5.2.4.2 DDx in Subsurface Sediment

Upriver Reach (RM 15.3 to 28.4)

Only three subsurface sediment samples were analyzed for DDx, all between RM 15.4 and 16. DDx was reported in all three samples at concentrations from 0.99 to 9.74 µg/kg, with a mean of 5.83 µg/kg.

Downtown Reach (RM 11.8 to 15.3)

DDx was reported in 64 of 94 subsurface sediment samples within the downtown reach (frequency of detection 68 percent). Concentrations reported range from 0.052 to 301 µg/kg (Table 5.2-16), with a mean concentration of 16.3 µg/kg. One result was reported at a concentration greater than 100 µg/kg, 19 results were reported at concentrations between 10 and 100 µg/kg, 32 results were between 1 and 10 µg/kg, and 11 results were reported at concentrations less than 1 µg/kg (Tables 5.2-17 and 5.2-18). No subsurface samples were collected in the vicinity of the Zidell facility.

Study Area Reach (RM 1.9 to 11.8)

DDx was reported in 1,393 of 1,678 subsurface samples in the study area reach (frequency of detection 83 percent). Concentrations reported range from 0.0580 J to 3,640,000 µg/kg (Table 5.2-2), with a mean concentration of 11,200 µg/kg. The spatial distribution of DDx in the subsurface sediment is presented on Figure 5.2-11 and Maps 5.2-14a-hh.

Areas in the eastern nearshore zone where DDx is reported at concentrations greater than 100 µg/kg total include RM 2–3 (a single result), RM 3.5–7.5, Swan Island Lagoon, and RM 11–11.8. The extent of DDx greater than 100 µg/kg is confined to a relatively small area at RM 11, and more widely dispersed in Swan Island Lagoon (Maps 5.2-14a-hh). Mean concentrations in these areas are 14.4 µg/kg at RM 1.9–3; 87.1 µg/kg at RM 3–4; 21.7 µg/kg at RM 4–5; 56.2 µg/kg at RM 5–6; 103 µg/kg at RM 6–7; 41.4 µg/kg at RM 7–8; 65.1 µg/kg in Swan Island Lagoon; and 45.5 µg/kg at RM 11–11.8 (Figure 5.2-11, Table 5.2-4).

Areas in the western nearshore zone where DDx concentrations are greater than 100 µg/kg extend from RM 3–10, with concentrations greater than 10,000 µg/kg present between RM 7 and 7.5 (Map 5.2-13). The maximum reported subsurface concentration was found in the interval 323 to 384 cm bml at Station WB-24 at RM 7.2. DDx at concentrations greater than 1,000 µg/kg were reported from approximately RM 6. 1 to

8.8. Mean concentrations in these areas are 39.4 µg/kg at RM 3–4; 77.0 µg/kg at RM 4–5; 78.4 µg/kg at RM 5– 6; 322 µg/kg at RM 6–7; 36,900 µg/kg at RM 7–8; and 153 µg/kg at RM 8–9 (Table 5.2-8).

Areas where DDx concentrations are greater than or equal to 100 µg/kg within the navigation channel are located from RM 4.1 to 5, RM 6.4 to 7.1, and RM 9.5 to 11.5 (Figure 5.2-12), and generally correspond with contamination found in the adjacent nearshore zones. Mean concentrations in these areas are 73.9 µg/kg at RM 4–5; 19.2 µg/kg at RM 5–6; 229 µg/kg at RM 6–7; 67.1 µg/kg at RM 7–8; 8.87 µg/kg at RM 9–10; 14.6 µg/kg at RM 10–11; and 10.8 µg/kg at RM 11–11.8.

DDx concentrations greater than 10,000 µg/kg were reported in 51 results, 83 results were between 1,000 and 10,000 µg/kg, 200 results (14 percent of the detected data) were between 100 and 1,000 µg/kg, 489 results (35 percent of the detected data) were between 10 and 100 µg/kg, 425 results (31 percent) were between 1 and 10 µg/kg, and 145 results (10 percent) were reported at a concentration less than 1 µg/kg (Tables 5.2-9 and 5.2-10). DDx concentrations greater than 100 µg/kg account for 24 percent of the detected results.

Downstream Reach (RM 0 to 1.9)

DDx was reported in 17 of 26 subsurface sediment samples within the downstream reach (frequency of detection 65 percent). Concentrations reported range from 0.28NJ to 80 NJ µg/kg (Table 5.2-20). DDx concentrations between 10 and 100 µg/kg were reported in 11 results, 4 results were between 1 and 10 µg/kg, and 2 results were reported at a concentration less than 1 µg/kg. The mean concentration in this reach is 19 µg/kg (Tables 5.2-21 and 5.2-22).

5.2.4.3 DDx Surface and Subsurface Sediment Relationships

Surface and subsurface sediment relationships are examined by comparing surface and subsurface concentrations by reach and also by subareas within the study area reach. There are insufficient data to compare surface and subsurface concentrations in the upriver reach. The mean concentration in surface sediment in this reach is 2.01 µg/kg.

DDx concentrations in the downtown reach are lower in surface sediment than in subsurface sediment. Mean concentrations are 6.59 and 16.3 µg/kg in surface and subsurface sediment, respectively.

Within the study area, mean DDx concentrations in subsurface sediment are generally higher than in surface sediment (Figure 5.2-12).

Areas where DDx concentrations are greater than 100 µg/kg in subsurface sediment generally align with the locations where surface sediment concentrations are greater than 100 µg/kg (Maps 5.2-13 and 5.2-14a-hh; Figures 5.2-10, 5.2-11, and 5.2-12). Exceptions occur in the eastern nearshore zone from RM 3 to 5 and RM 7 to 8, the navigation channel from RM 7 to 11, and the western nearshore area from RM 9 to 10

where subsurface concentrations exceed 100 µg/kg, but surface sediment concentrations do not.

Within the downstream reach, DDx concentrations in subsurface sediment concentrations are greater than surface sediment concentrations. Mean concentrations are 5.2 and 19 µg/kg in surface and subsurface sediment, respectively.

5.2.5 Total PAHs in Sediment

Total PAHs is defined as the sum of the individual PAH compound concentrations. The distribution of total PAHs concentrations at each surface sediment sampling station throughout the study area is depicted on Map 5.2-16; concentrations with depth at subsurface stations are depicted in detail on Maps 5.2-17a-hh. If more than one sample was analyzed at the same surface sediment location, the greater of the two samples is presented on these maps; all subsurface samples are presented.

Figures 5.2-13 and 5.2-14 present scatter plots of the total PAHs data set for surface and subsurface sediment in the study area, respectively. The scatter plots present the data in three panels segregated by the eastern nearshore, navigational channel, and western nearshore zones (Map 5.2-1).

The summary statistics for total PAHs in the surface and subsurface sediment within the study area are shown in Tables 5.2-1 and 5.2-2. Summary statistics for surface and subsurface sediment within the eastern nearshore, navigational channel, and western nearshore zones are presented in Tables 5.2-3 and 5.2-4, Tables 5.2-5 and 5.2-6, and Tables 5.2-7 and 5.2-8, respectively. Tables 5.2-9 and 5.2-10 present the total PAHs data as orders of magnitude (e.g., <1, 1–10, 10–100, 100–1,000, etc.) for only detected values and for combined detected and non-detected values. Finally, a histogram of average surface and subsurface sediment values by river mile and for the entire study area is presented in Figure 5.2-15.

Data sets for the upriver, downtown, and downstream reaches are only presented in statistical tables and order of magnitude tables. Additionally, the downtown reach surface sediment samples are presented in Map 5.2-18. Summary statistics for surface and subsurface sediment within the upriver reach are shown in Tables 5.2-11 and 5.2-12; the number of data points by order of magnitude is provided in Tables 5.2-13 (detect only) and 5.2-14 (detect and non-detect). Summary statistics for surface and subsurface sediment within the downtown reach are shown in Tables 5.2-15 and 5.2-16; the number of data points by order of magnitude is provided in Tables 5.2-17 (detect only) and 5.2-18 (detect and non-detect). Summary statistics for surface and subsurface sediment within the downstream reach are shown in Tables 5.2-19 and 5.2-20; the number of data points by order of magnitude is provided in Tables 5.2-21 (detect only) and 5.2-22 (detect and non-detect).

5.2.5.1 Total PAHs Data Set

Frequencies of detection of PAH compounds were high, approximately 99 percent in surface samples and 95 percent in subsurface samples. The study area data set of total PAHs concentrations includes 1,661 surface samples and 1,715 subsurface samples. The upriver data set includes 78 surface samples and 3 subsurface samples. The downtown data set includes 269 surface samples and 161 subsurface samples. The downstream data set includes 25 surface samples and 26 subsurface samples.

5.2.5.2 Total PAHs in Surface Sediment

Upriver Reach (RM 15.3 to 28.4)

Total PAHs were reported in 63 of 78 surface sediment samples within the upriver reach (frequency of detection 81 percent). Concentrations reported range from 0.91 J to 1,510 µg/kg (Table 5.2-11). Tables 5.2-13 and 5.2-14 show that only 1 result was reported at a concentration greater than 1,000 µg/kg, 17 (27 percent of the detected data set) were between 100 and 1,000 µg/kg, 39 results (62 percent) were between 10 and 100 µg/kg, 5 were between 1 and 10 µg/kg, and 1 result was reported at a concentration less than 1 µg/kg. The mean total PAHs concentration in this reach is 107 µg/kg.

Downtown Reach (RM 11.8 to 15.3)

Total PAHs were reported in 248 of 269 surface sediment samples within the downtown reach (frequency of detection 92 percent). Concentrations reported range from 0.0734 to 62,500 µg/kg (Table 5.2-15), with a mean of 2,174 µg/kg. The spatial distribution of total PAHs in the downtown reach is presented on Map 5.2-18. Reported concentrations greater than 10,000 µg/kg were observed at RM 12.2W, 12.5W, between 13.5W and 14W, and at 12.3E.

Total PAHs were reported at a concentration greater than 10,000 µg/kg in 11 results, 55 were between 1,000 and 10,000 µg/kg, 121 (49 percent) were between 100 and 1,000 µg/kg, 41 (17 percent) were between 10 and 100 µg/kg, 17 were between 1 and 10 µg/kg, and 3 results were reported at a concentration less than 1 µg/kg (Tables 5.2-17 and 5.2-18). Within this reach, 27 percent of the detected results were reported at a concentration greater than 1,000 µg/kg.

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-15 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. The Zidell data set includes total PAHs from 112 surface sediment samples (frequency of detection 88 percent). Concentrations reported range from 0.0734 to 32,000 µg/kg, with a mean of 2,538 µg/kg. When the data for the Zidell facility are removed from the downtown data set (Table 5.2-15), reported total PAHs concentrations in surface sediment range from 0.57J to 62,500 µg/kg, with a mean of 1,940 µg/kg.

Study Area Reach (RM 1.9 to 11.8)

Total PAHs were reported in 1,640 of 1,661 surface sediment samples within the study area (frequency of detection 99 percent). Concentrations reported range from 3.30 J to 7,260,000 µg/kg (Table 5.2-1). The distribution of reported concentrations varies throughout the study area, and is particularly heterogeneous above RM 6.5 where sample density is greater (Figure 5.2-13).

Areas where total PAHs concentrations are generally less than 10,000 µg/kg are found in several locations within the study area, including the lower end of the study area from RM 1.9W to 3W, the upper end of the study area from RM 10 to 11.8 (except three samples in the eastern nearshore zone), and in the eastern nearshore zone between RM 6 and 10. The only area in the navigation channel with reported concentrations greater than 10,000 µg/kg is from RM 5 to 7 (Figure 5.2-13; Map 5.2-16).

Reported concentrations greater than 1,000 µg/kg are located throughout the study area; areas with concentrations greater than 20,000 µg/kg were encountered in the eastern nearshore zone from RM 4.2 to 4.8 and in the western nearshore zone from RM 5.9 to 6.8 (Figure 5.2-13; Map 5.2-16). The highest reported total PAHs concentration in surface sediment of 7,260,000 µg/kg was reported in the navigation channel at RM 5.7 (Station G225). Total PAHs concentrations greater than 20,000 µg/kg were also found adjacent to the western nearshore zone in surface sediment in the navigation channel from RM 5.2 to 6.8.

Mean total PAHs concentrations by river mile for areas in the eastern nearshore zone with reported concentrations greater than 1,000 µg/kg are 5,160 µg/kg at RM 1.9–3; 3,850 µg/kg at RM 3–4; 35,100 µg/kg at RM 4–5; 5,170 µg/kg at RM 5–6; 3,870 µg/kg at RM 6–7; 1,420 µg/kg at RM 7–8; 3,580 µg/kg in Swan Island Lagoon; 4,850 µg/kg at RM 10–11; and 3,640 µg/kg at RM 11–11.8 (Table 5.2-3).

Mean concentrations by river mile for areas in the western nearshore zone with reported concentrations greater than 1,000 µg/kg are 4,740 µg/kg at RM 3–4; 7,940 µg/kg at RM 4–5; 17,300 µg/kg at RM 5–6; 192,000 µg/kg at RM 6–7; 3,490 µg/kg at RM 7–8; 2,280 µg/kg at RM 8–9; and 2,510 µg/kg at RM 9–10 (Table 5.2-7).

Mean total PAHs concentrations by river mile in the navigation channel for areas where concentrations are greater than 1,000 µg/kg are 275,000 µg/kg at RM 5–6 and 58,600 µg/kg at RM 6–7 (Table 5.2-5).

Total PAHs concentrations greater than 10,000 µg/kg were reported in 233 results, 636 were between 1,000 and 10,000 µg/kg, 661 were between 100 and 1,000 µg/kg, 104 were between 10 and 100 µg/kg, and 6 results were reported at concentrations ranging from 1 to 10 µg/kg (Tables 5.2-9 and 5.2-10). Fifty-five percent of the results within the study area were reported at concentrations greater than 1,000 µg/kg (Map 5.2-16).

Downstream Reach (RM 0 to 1.9)

Total PAHs were reported in 25 of 25 surface sediment samples within the downstream reach. Concentrations reported range from 1.4J to 18,000J µg/kg (Table 5.2-19). One result was reported at a concentration greater than 10,000 µg/kg, 1 was between 1,000 and 10,000 µg/kg, 16 were between 100 and 1,000 µg/kg, 6 were between 10 and 100 µg/kg, and 1 result was between 1 and 10 µg/kg (Tables 5.2-21 and 5.2-22). The mean total PAHs concentration in this reach is 1,120 µg/kg.

5.2.5.3 Total PAHs in Subsurface Sediment

Upriver Reach (RM 15.3 to 28.4)

Total PAHs were reported in three of three samples collected between RM 15.4 and 16. Concentrations reported range from 253 µg/kg to 533 µg/kg, with a mean of 366 µg/kg.

Downtown Reach (RM 11.8 to 15.3)

Total PAHs were reported in 157 of 161 subsurface sediment samples within the downtown reach (frequency of detection 98 percent). Concentrations reported range from 0.25J to 4,850,000 µg/kg (Table 5.2-16), with a mean of 219,700 µg/kg. Total PAHs concentrations greater than 10,000 µg/kg were reported in 30 results, 39 results were between 1,000 and 10,000 µg/kg, 52 results were between 100 and 1,000 µg/kg, 23 results were between 10 and 100 µg/kg, 6 were between 1 and 10 µg/kg, and 7 results were reported at concentrations less than 1 µg/kg (Tables 5.2-17 and 5.2-18). Within this reach, reported concentrations greater than 1,000 µg/kg account for 44 percent of the detected results, with the highest concentrations observed in the western nearshore area at RM 12.2 (Figure 5.2-14).

Twelve of the subsurface samples were collected in the vicinity of the Zidell facility, and reported concentrations ranged from 4.8 to 451 µg/kg. With these values excluded, the mean and median total PAHs concentrations are 235,000 and 770 µg/kg, respectively.

Study Area Reach (RM 1.9 to 11.8)

Total PAHs were reported in 1,643 of 1,715 subsurface samples (frequency of detection 96 percent). Concentrations reported range from 0.150 J to 53,300,000 µg/kg (Table 5.2-2).

Areas where total PAHs concentrations exceeded 10,000 µg/kg were observed in the eastern nearshore zone between RM 3.5 and 7.5, in Swan Island Lagoon, and at RM 11.2. Mean concentrations by river mile in these areas are 22,000 µg/kg at RM 3–4; 23,500 µg/kg at RM 4–5; 11,600 µg/kg at RM 5–6; 6,560 µg/kg for RM 6–7; 3,010 µg/kg at RM 7–8; 3,400 µg/kg in Swan Island Lagoon; and 2,790 µg/kg for RM 11–11.8 (Table 5.2-4).

Locations in the western nearshore where total PAHs concentrations greater than 10,000 µg/kg are observed include RM 3 to 7.5 and at RM 9.2 (Figure 5.2-16 and Maps 5.2-17a-hh). The highest concentrations in subsurface sediment are found

between RM 6 and 6.5, and the highest reported value of 53,300,000 µg/kg was observed in this area at Station C302. Mean concentrations by river mile in these areas are 19,000 µg/kg at RM 3–4; 24,700 µg/kg at RM 4–5; 45,400 µg/kg at RM 5–6; 1,610,000 µg/kg at RM 6–7; 3,560 µg/kg at RM 7–8; and 19,200 µg/kg at RM 9–10 (Table 5.2-8).

Total PAHs concentrations greater than 10,000 µg/kg were also observed in subsurface sediment in the navigation channel from RM 4 to 6.5, adjacent to and downstream from the high concentration area in the western nearshore zone between RM 6 and 6.5, and at RM 7.9. Mean concentration by river mile in this area are 5,240 µg/kg at RM 4–5; 8,450 µg/kg at RM 5–6; 453,000 µg/kg at RM 6–7; and 1,350 µg/kg at RM 7–8 (Table 5.2-6).

Within the study area, total PAHs concentrations greater than 10,000 µg/kg were reported in 335 results, 563 were between 1,000 and 10,000 µg/kg, 484 were reported at concentrations between 100 and 1,000 µg/kg, 137 were detected at concentrations between 10 and 100 µg/kg, 87 were between 1 and 10 µg/kg, and 37 results were reported at concentrations less than 1 µg/kg. Concentrations greater than 1,000 µg/kg account for 54 percent of the reported results within the study area (Tables 5.2-9 and 5.2-10)

Downstream Reach (RM 0 to 1.9)

Total PAHs were reported in all 26 subsurface sediment samples collected within the downstream reach. Concentrations reported range from 0.49J to 23,000 µg/kg (Table 5.2-20). Tables 5.2-21 and 5.2-22 show that one result was reported at a concentration greater than 10,000 µg/kg, 4 were between 1,000 and 10,000 µg/kg, 10 were between 100 and 1,000 µg/kg, 7 results were reported at concentrations between 10 and 100 µg/kg, 2 were between 1 and 10 µg/kg, and 2 results were reported at a concentration less than 1 µg/kg. Within the downstream reach, reported concentrations greater than 1,000 µg/kg account for 19 percent of the reported results in subsurface sediment. The mean total PAHs concentration in the downstream reach is 1,339 µg/kg.

5.2.5.4 Total PAHs Surface and Subsurface Sediment Relationships

Surface and subsurface sediment relationships are examined by comparing surface and subsurface concentrations by reach and also by subareas within the study area reach.

There are insufficient data to compare surface and subsurface concentrations in the upriver reach. The mean surface sediment total PAHs concentration in this reach is 107 µg/kg.

Total PAHs concentrations within the downtown reach are greater in subsurface sediment relative to concentrations observed in surface sediment. Mean concentrations are 2,174 and 219,700 µg/kg in surface and subsurface sediment, respectively.

Within the study area, total PAHs concentrations are generally greater in subsurface than in surface sediments. Mean concentrations in surface and subsurface sediments are 27,200 and 246,000 µg/kg, respectively (Tables 5.2-1 and 5.2-2). Localized areas where concentrations are greater in surface sediment are found from RM 1.9 to 3, 4 to 5, Swan Island Lagoon, and RM 10 to 11.8 within the eastern nearshore zone; RM 8 to 9 in the western nearshore zone; and RM 5 to 6, 8 to 9, and 9 to 10 within the navigation channel.

Areas with the highest reported total PAHs concentrations in both surface and subsurface sediment generally align (Maps 5.2-17a-hh and Figures 5.2-13, 5.2-14, and 5.2-15).

Within the downstream reach, total PAHs concentrations are greater in subsurface than in surface sediment. Mean concentrations are 1,120 and 1,339 µg/kg in surface and subsurface sediment, respectively.

5.2.6 Bis(2-ethylhexyl)phthalate in Sediment

The distribution of BEHP concentrations at each surface sediment sampling station throughout the study area is depicted on Map 5.2-19; concentrations with depth at subsurface stations are depicted on Maps 5.2-20a-o. If more than one sample was analyzed at the same surface sediment location, the greater of the two samples is presented on these maps; all subsurface samples are presented.

Figures 5.2-16 and 5.2-17 present scatter plots of the BEHP data set for surface and subsurface sediment in the study area, respectively. The scatter plots present the data in three panels segregated by the eastern nearshore, navigational channel, and western nearshore zones (Map 5.2-1).

The summary statistics for BEHP in surface and subsurface sediment within the study area are shown in Tables 5.2-1 and 5.2-2. Summary statistics for surface and subsurface sediment within the eastern nearshore, navigation channel, and western nearshore zones are presented in Tables 5.2-3 and 5.2-4, Tables 5.2-5 and 5.2-6, and Tables 5.2-7 and 5.2-8, respectively. Tables 5.2-9 and 5.2-10 present BEHP data as orders of magnitude (e.g., <1, 1–10, 10–100, 100–1,000, etc.) for only detected values and for combined detected and non-detected values. Finally, a histogram of average surface and subsurface sediment values by river mile and for the entire study area is presented in Figure 5.2-18.

Data sets for the upriver, downtown, and downstream reaches are only presented in statistical tables and order of magnitude tables. Additionally, the downtown reach surface sediment samples are presented in Map 5.2-21. Summary statistics for surface and subsurface sediment within the upriver reach are shown in Tables 5.2-11 and 5.2-12; the number of data points by order of magnitude is provided in Tables 5.2-13 (detect only) and 5.2-14 (detect and non-detect). Summary statistics for surface and subsurface sediment within the downtown reach are shown in Tables 5.2-15 and 5.2-16; the

number of data points by order of magnitude is provided in Tables 5.2-17 (detect only) and 5.2-18 (detect and non-detect). Summary statistics for surface and subsurface sediment within the downstream reach are shown in Tables 5.2-19 and 5.2-20; the number of data points by order of magnitude is provided in Tables 5.2-21 (detect only) and 5.2-22 (detect and non-detect).

5.2.6.1 BEHP Data Set

The study area data set of BEHP concentrations includes 1,513 surface and 1,591 subsurface samples, the upriver data set includes 72 surface and 3 subsurface samples, the downtown data set includes 96 surface samples and 64 subsurface samples, and the downstream data set includes 21 surface and 17 subsurface samples. Because the reporting limit for several non-detect results was greater than the maximum reported values (Figures 5.2-16 and 5.2-17), the majority of this discussion will focus on detected values.

5.2.6.2 BEHP in Surface Sediment

Upriver Reach (RM 15.3 to 28.4)

BEHP was reported in 56 of 72 surface sediment samples and within the upriver reach (frequency of detection 78 percent). Concentrations reported range from 4.2 J to 2,100 µg/kg (Table 5.2-11). One result was reported at a concentration greater than 1,000 µg/kg, 9 were between 100 and 1,000 µg/kg, 40 results were between 10 and 100 µg/kg, and 6 were between 1 and 10 µg/kg (Tables 5.2-13 and 5.2-14). The mean BEHP concentration in this reach is 94 µg/kg.

Downtown Reach (RM 11.8 to 15.3)

BEHP was reported in 78 of 96 surface sediment samples within the downtown reach (frequency of detection 81 percent). Concentrations reported range from 7.6 J to 18,000 µg/kg (Table 5.2-15), with a mean of 418 µg/kg. The spatial distribution of BEHP in surface sediment is presented on Map 5.2-21.

Within the downtown reach, 1 result was reported at a concentration greater than 10,000 µg/kg, 1 result was between 1,000 and 10,000 µg/kg, 32 were between 100 and 1,000, 39 were between 10 and 100 µg/kg, and 5 results were reported at concentrations between 1 and 10 µg/kg (Tables 5.2-17 and 5.2-18).

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-15 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. None of the BEHP data was excluded from the downtown reach.

Study Area Reach (RM 1.9 to 11.8)

BEHP was reported in 932 of 1,513 surface sediment samples within the study area (frequency of detection 62 percent). Concentrations reported range from 7.00 J to 440,000J µg/kg (Table 5.2-1), with a mean of 1,050 µg/kg. The spatial distribution of BEHP in surface sediment is presented on Figure 5.2-16.

Areas where BEHP concentrations are greater than 1,000 µg/kg were observed in the eastern nearshore zone between RM 3.8 and 4.1 and in the International Terminals Slip, in Swan Island Lagoon, between RM 7 and 8 and at RM 11.2 (Figure 5.2-16, Map 5.2-19). The highest reported surface concentration in the study area of 440,000 J µg/kg was found at Station G367 at the mouth of Swan Island Lagoon. Mean BEHP concentrations by river mile in these areas are 1,310 µg/kg at RM 3–4; 792 µg/kg at RM 4–5; 573 µg/kg at RM 7–8; 6,150 µg/kg in Swan Island Lagoon; and 204 µg/kg at RM 11–11.8 (Table 5.2-3)

BEHP concentrations greater than 1,000 µg/kg were observed in the western nearshore zone from RM 6 through 10, with a prominent peak at RM 8.8 (Figure 5.2-16). Mean concentrations by river mile are 256 µg/kg at RM 6–7; 347 µg/kg at RM 7–8; 745 µg/kg at RM 8–9; and 531 µg/kg at RM 9–10 (Table 5.2-7).

The greatest concentrations observed in the navigation channel zone are located near RM 10 (Map 5.2-19). Additional elevated concentrations are located at RM 5.2, Swan Island Lagoon, and RM 10.3 near the western nearshore area (Map 5.2-19). Mean concentrations in these areas are 203 µg/kg at RM 5–6; 679 µg/kg in Swan Island Lagoon; and 446 µg/kg at RM 10–11 (Table 5.2-5).

BEHP concentrations greater than 10,000 µg/kg were reported in 9 results, 79 were between 1,000 and 10,000 µg/kg, 501 (54 percent of the detected results) were reported at concentrations between 100 and 1,000 µg/kg, 336 were between 10 to 100 µg/kg, and 7 results were reported at concentrations between 1 and 10 µg/kg (Table 5.2-9).

Downstream Reach (RM 0 to 1.9)

BEHP was reported in 10 of 21 surface sediment samples within the downstream reach (frequency of detection 48 percent). Concentrations were reported from 7.1 J to 170 µg/kg (Table 5.2-19). Two results were reported at a concentration greater than 100 µg/kg, seven were between 10 and 100 µg/kg, and one result was less than 10 µg/kg. The mean BEHP concentration in this reach is 64 µg/kg (Tables 5.2-21 and 5.2-22).

5.2.6.3 BEHP in Subsurface Sediment

Upriver Reach (RM 15.3 to 28.4)

Three subsurface sediment samples were collected and analyzed for BEHP between RM 15.4 and 16. BEHP was reported in all three samples, and concentrations reported range from 20 J to 3,800 µg/kg, with a mean of 1,300 µg/kg.

Downtown Reach (RM 11.8 to 15.3)

BEHP was reported in 36 of 64 subsurface sediment samples within the downtown reach (frequency of detection 56 percent). Concentrations reported range from 2.5 J to 815 µg/kg with a mean of 103 µg/kg (Table 5.2-16). Eight results were reported at concentrations greater than 100 µg/kg, 23 results were between 1 and 10 µg/kg, and

5 results were reported at a concentration less than 10 µg/kg (Table 5.2-17). None of the subsurface samples were collected in the vicinity of the Zidell facility.

Study Area Reach (RM 1.9 to 11.8)

Within the study area, BEHP was reported in 635 of 1,591 subsurface samples (frequency of detection 40 percent). Concentrations reported range from 2.40 J to 18,000 µg/kg (Table 5.2-2), with a mean of 345 µg/kg. The spatial distribution of BEHP concentrations in subsurface sediment is presented on Figure 5.2-17 and Maps 5.2-20a-o.

Table 5.2-9 shows that there are two data points greater than 10,000 µg/kg. There are 32 detected values between 1,000 and 10,000 µg/kg, which are primarily located within the peak areas discussed above. Subsurface sediment samples greater than 1,000 µg/kg account for 5 percent of the detected data set. An additional 257 samples, 40 percent of the detected data set, were detected at concentrations between 100 and 1,000 µg/kg. Half of the detected data set (317 samples) is between 10 and 100 µg/kg. An additional 27 samples (4 percent) are composed of concentrations ranging between 1 and 10 µg/kg, and there were no samples detected at a concentration less than 1 µg/kg.

Areas where BEHP concentrations greater than 1,000 µg/kg are observed in subsurface sediment are present in the eastern nearshore between RM 3.6 and 4.4 and in the International Terminals Slip, and in Swan Island Lagoon (Figure 5.2-17, Maps 5.2-20a-o). Mean concentrations (Table 5.2-3) in these areas are 586 µg/kg at RM 3–4; 196 µg/kg at RM 4–5; and 650 µg/kg in Swan Island Lagoon.

Areas in the western nearshore zone where BEHP concentrations are greater than 1,000 µg/kg are observed from RM 6 through 10 (Figure 5.2-17; Maps 5.2-20g,h,j,k). Mean concentrations by river mile in this area are 338 µg/kg at RM 6–7; 277 at RM 7–8; 628 µg/kg at RM 8–9; and 359 µg/kg at RM 9–10 (Table 5.2-7).

Within the navigation channel, concentrations greater than 1,000 µg/kg of BEHP are observed at RM 7.9 (which appears most likely associated the reported concentrations in Swan Island Lagoon; Map 5.2-20i), and a single result at RM 10.3 near the western nearshore area (Map 5.2-20l). Mean BEHP concentrations in these areas are 910 µg/kg for RM 7 to 8; and 502 µg/kg for RM 10 to 11 (Table 5.2-6). The maximum reported concentration of 18,000 µg/kg in subsurface sediment was from the navigation channel, from the interval of 0–195 cm bml at Station WR-VC-110 (RM 10.3).

Downstream Reach (RM 0 to 1.9)

BEHP was reported in 16 of 17 subsurface sediment samples within the downstream reach (frequency of detection 94 percent). Concentrations reported range from 3.1 J to 39 µg/kg (Table 5.2-20). Five results were reported at concentrations greater than 10 µg/kg and 11 were less than 10 µg/kg. The mean concentration in this reach is 8.2 J µg/kg (Tables 5.2-21 and 5.2-22).

5.2.6.4 BEHP Surface and Subsurface Sediment Relationships

Surface and subsurface sediment relationships are examined by comparing surface and subsurface concentrations by reach and also by subareas within the study area reach.

There are insufficient data to compare surface and subsurface concentrations in the upriver reach. The mean BEHP surface sediment concentration in this reach is 94 µg/kg.

The surface BEHP sediment concentrations in the downtown reach are greater than the subsurface concentrations, and are 418 and 103 µg/kg, respectively.

Within the study area, BEHP concentrations are generally greater in surface than in subsurface sediments; mean concentration are 1,050 and 345 µg/kg in surface and subsurface sediment, respectively (Tables 5.2-1 and 5.2-2). Exceptions to this general trend are observed in the eastern nearshore zone at RM 5–6 where mean surface and subsurface concentrations are similar, and RM 8–9 where the mean concentration in subsurface sediment is approximately twice that surface sediment (Tables 5.2-3 and 5.2-4). The maximum BEHP concentrations in surface and subsurface sediment in the eastern nearshore zone are both found in Swan Island Lagoon.

Within the western nearshore zone, localized areas where BEHP concentrations are greater in subsurface sediment include RM 5–6, where the mean subsurface concentration is an order of magnitude greater than the mean surface concentration, and RM 7–8, where mean surface and subsurface concentrations are similar. The maximum reported BEHP concentration in surface sediment in the western nearshore zone was located between RM 7 and 8, while the maximum reported concentration in subsurface sediment was located between RM 5 and 6.

Within the navigation channel, the mean BEHP concentration in subsurface sediment at RM 7 to 8 is approximately 3 times the mean surface concentration. The maximum reported surface and subsurface BEHP concentrations in the navigation channel were reported at RM 10 to 11.

Within the downstream reach, mean BEHP concentrations are greater in surface sediment (64 and 11 µg/kg in surface and subsurface sediment, respectively).

5.2.7 Total Chlordanes in Sediment

The distribution of total chlordanes concentrations at each surface sediment sampling station throughout the study area is depicted on Map 5.2-22; concentrations with depth at subsurface stations are depicted on Maps 5.2-23a-o. If more than one sample was analyzed at the same surface sediment location, the greater of the two samples is presented on these maps; all subsurface samples are presented.

Figures 5.2-19 and 5.2-20 present scatter plots of the total chlordanes data set for surface and subsurface sediment in the study area, respectively. The scatter plots

present the data in three panels segregated by the eastern nearshore, navigational channel, and western nearshore zones (Map 5.2-1).

Summary statistics for total chlordanes in surface and subsurface sediment within the study area are shown in Tables 5.2-1 and 5.2-2. Summary statistics for surface and subsurface sediment within the eastern nearshore, navigation channel, and western nearshore zones are presented in Tables 5.2-3 and 5.2-4, Tables 5.2-5 and 5.2-6, and Tables 5.2-7 and 5.2-8, respectively. Tables 5.2-9 and 5.2-10 present total chlordanes data by orders of magnitude (e.g., <1, 1–10, 10–100, 100–1,000, etc.) for detected-only values and for combined detected and non-detected values. Finally, a histogram of average surface and subsurface sediment values by river mile and for the entire study area is presented in Figure 5.2-21.

Data sets for the upriver, downtown, and downstream reaches are only presented in statistical tables and order of magnitude tables. Additionally, the downtown reach surface sediment samples are presented in Map 5.2-24. Summary statistics for surface and subsurface sediment within the upriver reach are shown in Tables 5.2-11 and 5.2-12; the number of data points by order of magnitude is provided in Tables 5.2-13 (detects only) and 5.2-14 (detects and non-detects). Summary statistics for surface and subsurface sediment within the downtown reach are shown in Tables 5.2-15 and 5.2-16; the number of data points by order of magnitude is provided in Tables 5.2-17 (detects only) and 5.2-18 (detects and non-detects). Summary statistics for surface and subsurface sediment within the downstream reach are shown in Tables 5.2-19 and 5.2-2; the number of data points by order of magnitude is provided in Tables 5.2-21 (detects only) and 5.2-22 (detects and non-detects).

5.2.7.1 Total Chlordanes Data Set

The study area data set of total chlordanes concentrations includes 1,193 surface and 1,214 subsurface samples, the upriver data set includes 77 surface and 3 subsurface samples, the downtown data set includes 145 surface and 94 subsurface samples, and the downstream data set includes 25 surface and 26 subsurface samples. Several non-detect results had reporting limits greater than the maximum reported concentrations (Figures 5.2-19 and 5.2-20); thus, the majority of this discussion will focus on the detected values only as meaningful conclusions cannot be drawn from the elevated non-detected values.

5.2.7.2 Total Chlordanes in Surface Sediment

Upriver Reach (RM 15.3 to 28.4)

Total chlordanes were detected in 38 of 77 surface sediment samples within the upriver reach (frequency of detection 49 percent). Concentrations reported range from 0.057 J to 1.53 µg/kg (Table 5.2-11). Two results were reported at a concentration greater than 1 µg/kg, and the remaining 36 detections were all reported at concentrations less than 1 µg/kg (Table 5.2-13). The mean concentration in this reach is 0.391 µg/kg.

Downtown Reach (RM 11.8 to 15.3)

Total chlordanes were reported in 110 of 145 surface sediment samples within the downtown reach (frequency of detection 76 percent). Concentrations reported range from 0.039 J to 23.2 J µg/kg (Table 5.2-15), and the mean concentration is 1.29 µg/kg. The spatial distribution of total chlordanes in surface sediment within the downtown reach is shown on Map 5.2-24.

Within the downtown reach, total chlordanes were reported at a concentration greater than 10 µg/kg in 2 results, 35 were between 1 and 10 µg/kg, and 73 results were reported at concentrations less than 1 µg/kg (Table 5.2-17).

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-15 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. None of the total chlordanes data was excluded from the downtown reach.

Study Area Reach (RM 1.9 to 11.8)

Total chlordanes were reported in 761 of 1,193 surface sediment samples within the study area (frequency of detection 64 percent). Concentrations reported range from 0.0310 J to 669 NJ µg/kg (Table 5.2-1), with a mean concentration in surface sediment of 5.03 µg/kg. The spatial distribution of reported total chlordanes concentrations in surface sediment within the study area is presented on Figure 5.2-19.

Areas in the eastern nearshore zone with reported concentrations greater than 10 µg/kg were observed at RM 2.8, 3.8, 5.5, Swan Island Lagoon, and RM 11 (Figure 5.2-19 and Map 5.2-22). The highest surface concentration detected in the eastern nearshore zone (60 µg/kg) was found at Station GCA11E at RM 11. Mean concentrations in these areas are 1.15 µg/kg at RM 2–3; 1.48 µg/kg at RM 3–4; 2.37 µg/kg at RM 5–6; 2.75 µg/kg in Swan Island Lagoon; and 11.4 µg/kg at RM 11–11.8 (Table 5.2-3).

Areas in the western nearshore zone with reported total chlordanes concentrations greater than 10 µg/kg were observed from RM 5.8 through 9 (Figure 5.2-19). The maximum reported concentration in surface sediment of 669 NJ µg/kg was at Station G355 (RM 7.3W). Mean concentrations in the western nearshore zone are 1.75 µg/kg at RM 5–6; 12.5 µg/kg at RM 6–7; 24.9 µg/kg at RM 7–8; and 28.9 µg/kg at RM 8–9. Within the navigation channel there were no reported concentrations greater than 10 µg/kg (Table 5.2-5).

Table 5.2-9 shows that there are 761detected data points in surface sediment. Total chlordanes concentrations greater than 100 µg/kg were reported in 3 results, 46 were between 10 and 100 µg/kg, 270 detected results were between 1 and 10 µg/kg, and 442 results (58 percent of detections) were reported at concentrations less than 1 µg/kg.

Downstream Reach (RM 0 to 1.9)

Total chlordanes were reported in 15 of 25 surface sediment samples within the downstream reach (frequency of detection 60 percent). Concentrations reported range from 0.067 NJ to 4.5 J µg/kg (Table 5.2-19). Three results were reported at a concentration greater than 1 µg/kg, and the remaining 12 results were all less than 1 µg/kg (Table 5.2-21), with a mean of 0.812 µg/kg.

5.2.7.3 Total Chlordanes in Subsurface Sediment

Upriver Reach (RM 15.3 to 28.4)

Only three subsurface sediment samples were analyzed for total chlordanes in the upriver reach, all collected between RM 15.4 and 16. Total chlordanes were reported in all three results, from 0.187 to 2.93 µg/kg, with a mean of 1.34 µg/kg.

Downtown Reach (RM 11.8 to 15.3)

Total chlordanes were reported in 51 of 94 subsurface sediment samples within the downtown reach (frequency of detection 54 percent). Concentrations reported range from 0.094 J to 54 J µg/kg (Table 5.2-16), with a mean concentration of 3.16 µg/kg. There are two values detected above 10 µg/kg. Total chlordanes were reported at concentrations between 1 and 10 µg/kg in 26 results, and the remaining 23 results were reported at concentrations less than 1 µg/kg (Table 5.2-17). No subsurface samples were collected from the vicinity of the Zidell facility.

Study Area Reach (RM 1.9 to 11.8)

Total chlordanes were reported in 648 of 1,214 subsurface samples (frequency of detection 53 percent) within the study area. Concentrations reported range from 0.0390 J to 2,330J µg/kg (Table 5.2-2), with a mean concentration of 19.5 µg/kg. The spatial distribution of total chlordanes in subsurface sediment is presented on Figure 5.2-20 and Maps 5.2-23a-o.

Areas in the eastern nearshore zone with total chlordanes in subsurface sediment reported at concentrations greater than 10 µg/kg were observed at RM 2.2, 3.8, 5.5, Swan Island Lagoon, and at RM 11E (Figure 5.2-20 and Maps 5.2-23a-o). The highest total chlordanes concentration of 490 µg/kg in subsurface sediment reported in the eastern nearshore zone was at Station C092 at RM 3.8. Mean total chlordanes concentrations by river mile are 2.26 µg/kg at RM 2–3; 31.2 µg/kg at RM 3–4; 4.67 µg/kg at RM 5–6; 15.5 µg/kg in Swan Island Lagoon; and 23.5 µg/kg for RM 11–11.8 (Table 5.2-3).

Total chlordanes concentrations greater than 10 µg/kg in the western nearshore zone from RM 4.5 through 9. The highest reported total chlordanes concentration of 2,330J µg/kg in subsurface sediments was reported at RM 8.8 at Station C455 in the interval of 30–152 cm bml (Figure 5.2-20). Mean concentrations by river mile are 5.79 µg/kg for RM 4–5; 17.2 µg/kg at RM 5–6; 18.9 µg/kg at RM 6–7; 68.5 µg/kg at RM 7–8; and 61.4 µg/kg at RM 8–9 (Table 5.2-8).

The highest reported concentrations of total chlordanes in subsurface sediment in the navigation channel were observed at RM 6.5, 10.3, and 11.3. Total chlordanes concentrations at RM 6.5 appear associated with observed contamination in the western nearshore zone (Map 5.2-23g). Concentrations at RM 11.3 are potentially associated the contamination noted at RM 11E (Maps 5.2-23n,o). Mean concentrations are 6.59 µg/kg at RM 6–7; 2.83 µg/kg for RM 10–11; and 7.82 at RM 11–11.8 (Table 5.2-6).

Total chlordanes were reported at a concentration greater than 1,000 µg/kg in one result, 19 were between 100 and 1,000 µg/kg, 67 results were reported at concentrations between 10 and 100 µg/kg, 316 were between 1 and 10 µg/kg, and 245 results were reported at concentrations less than 1 µg/kg (Table 5.2-9).

Downstream Reach (RM 0 to 1.9)

Total chlordanes were reported in 5 of 26 subsurface sediment samples within the downstream reach (frequency of detection 19 percent). Concentrations reported range from 0.75 NJ to 2.2 NJ µg/kg (Table 5.2-20). Four results were reported at a concentration greater than 1 µg/kg, and 1 sample was reported at less than 1 µg/kg, with a mean in of 1.5 µg/kg (Tables 5.2-21).

5.2.7.4 Total Chlordanes Surface and Subsurface Sediment Relationships

Surface and subsurface sediment relationships are examined by comparing surface and subsurface concentrations by reach and also by subareas with the study area reach. There are insufficient data to compare surface and subsurface concentrations in the upriver reach. The mean total chlordanes surface sediment concentration in this reach is 0.391 µg/kg (Table 5.2-11).

Within the downtown reach, the mean total chlordanes concentration in surface and subsurface sediments is 1.29 and 3.16 µg/kg, respectively (Tables 5.2-15a and 5.2-16a).

Within the study area, total chlordanes concentrations are greater in the subsurface sediments. The mean concentration in surface and subsurface sediments is 5.03 and 19.5 µg/kg, respectively (Tables 5.2-1 and 5.2-2). As shown on Figure 5.2-21, mean concentrations are greater in the nearshore areas than in the navigation channel, and the western nearshore zone is greater than the eastern nearshore zone.

In the eastern nearshore zone, total chlordanes concentrations are greater in subsurface than in surface sediment in all river miles except RM 10 to 11. In the western nearshore zone, subsurface sediment concentrations are greater in all river miles except RM 1.9 to 3. Within the navigation channel total chlordanes concentrations in subsurface sediment are greater than the surface sediment concentrations except from RM 1.9 to RM 4. Areas where the highest total chlordanes concentrations are observed generally align between surface and subsurface sediment.

Within the downstream reach, the mean total chlordanes concentrations are 0.812 µg/kg and 1.5 µg/kg in surface and subsurface sediment, respectively (Tables 5.2-19 and 5.2-20).

5.2.8 Aldrin and Dieldrin in Sediment

The insecticides aldrin and dieldrin, have similar chemical structures and are discussed together here because aldrin readily undergoes biotic and abiotic transformation to dieldrin. However, because aldrin is not converted to dieldrin under anaerobic conditions, it is unlikely that aldrin is converted to dieldrin in sediments, but may do so within other media that will be discussed in subsequent sections.

The distribution of aldrin and dieldrin concentrations at each surface sediment sampling station throughout the study area is depicted on Maps 5.2-25 and 5.2-27; concentrations with depth at subsurface stations are depicted on Maps 5.2-26a-o and 5.2-28a-o. If more than one sample was analyzed at the same surface sediment location, the greater of the two results is presented on these maps; all subsurface samples are presented.

Figures 5.2-22 and 5.2-23 present scatter plots of the aldrin data set for surface and subsurface sediment in the study area, respectively. Figures 5.2-25 and 5.2-26 present scatter plots of the dieldrin data set for surface and subsurface sediment in the study area, respectively. The scatter plots present the data in three panels segregated by the eastern nearshore, navigational channel, and western nearshore zones (Map 5.2-1).

The summary statistics for aldrin and dieldrin in surface and subsurface sediment within the study area are shown in Tables 5.2-1 and 5.2-2. Summary statistics for surface and subsurface sediment within the eastern nearshore, navigation channel, and western nearshore zones are presented in Tables 5.2-3 and 5.2-4, Tables 5.2-5 and 5.2-6, and Tables 5.2-7 and 5.2-8, respectively. Tables 5.2-9 and 5.2-10 present aldrin and dieldrin results as orders of magnitude (e.g., <1, 1–10, 10–100, 100–1,000, etc.) for only detected values and for combined detected and non-detected values. Finally, a histogram of average surface and subsurface sediment values by river mile and for the entire study area is presented in Figures 5.2-24 (for aldrin) and 5.2-27 (for dieldrin).

Data sets for the upriver, downtown, and downstream reaches are only presented in statistical tables and order of magnitude tables. Additionally, the downtown reach surface sediment samples are presented in Maps 5.2-29 and 5.2-30. Summary statistics for surface and subsurface sediment within the upriver reach are shown in Tables 5.2-11 and 5.2-12; the number of data points by order of magnitude is provided in Tables 5.2-13 (detects only) and 5.2-14 (detects and non-detects). Summary statistics for surface and subsurface sediment within the downtown reach are shown in Tables 5.2-15 and 5.2-16; the number of data points by order of magnitude is provided in Tables 5.2-17 (detects only) and 5.2-18 (detects and non-detects). Summary statistics for surface and subsurface sediment within the downstream reach are shown in Tables 5.2-19 and 5.2-2; the number of data points by order of magnitude is provided in Tables 5.2-21 (detects only) and 5.2-22 (detects and non-detects).

5.2.8.1 Aldrin and Dieldrin Data Sets

The data set for aldrin consists of 1,146 surface and 1,272 subsurface samples from the study area, 77 surface and 3 subsurface samples from the upriver reach, 145 surface and 94 subsurface samples from the downtown reach, and 25 surface and 26 subsurface samples from the downstream reach.

The data set for dieldrin consists of 1,190 surface and 1,208 subsurface samples from the study area, 77 surface and 3 subsurface samples from the upriver reach, 145 surface and 94 subsurface samples from the downtown reach, and 25 surface and 26 subsurface samples from the downstream reach.

There were high detection limits for several aldrin and dieldrin results within the study area (Figures 5.2-22 and 5.2-23 for aldrin, Figures 5.2-25 and 5.2-26 for dieldrin); thus, the majority of this discussion, as for other contaminants, will focus on the detected values only since meaningful conclusions cannot be drawn from the elevated non-detect values.

5.2.8.2 Aldrin and Dieldrin in Surface Sediment

Upriver Reach (RM 15.3 to 28.4)

Aldrin was reported in 7 of 77 surface sediment samples within the upriver reach (detection frequency of 9 percent). Concentrations reported range from 0.17 J to 0.55 µg/kg (Tables 5.2-11 and 5.2-13) with a mean concentration of 0.334 µg/kg.

Dieldrin was reported in 10 of 77 surface sediment samples (frequency of detection 13 percent). Concentrations reported range from 0.092 NJ to 0.4 µg/kg (Tables 5.2-11 and 5.2-13), with a mean concentration of 0.209 µg/kg.

Downtown Reach (RM 11.8 to 15.3)

Aldrin was reported in 22 of 145 surface sediment samples within the downtown reach (frequency of detection 15 percent). Concentrations reported range from 0.0735 J to 0.7 NJ µg/kg (Tables 5.2-15a and 5.2-17), with a mean concentration of 0.262 µg/kg.

Dieldrin was reported in 14 of 145 surface sediment within the downtown reach (frequency of detection 10 percent). Concentrations reported range from 0.042 J to 1.1 µg/kg (Tables 5.2-15a and 5.2-17), with a mean concentration of 0.266 µg/kg.

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-15 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. None of the aldrin or dieldrin data was excluded from the downtown reach.

Study Area Reach (RM 1.9 to 11.8)

Aldrin was reported in 268 of 1,146 surface sediment samples within the study area (frequency of detection 23 percent). Concentrations reported range from 0.00333 J to

691 J µg/kg (Table 5.2-1), with a mean concentration of 4.89 µg/kg. The spatial distribution of aldrin in surface sediment in the study area is presented on Figure 5.2-22.

Dieldrin was reported in 252 of 1,190 surface sediment samples within the study area (frequency of detection 21 percent). Concentrations reported range from 0.00834 J to 356 J µg/kg (Table 5.2-1), with a mean concentration of 2.56 µg/kg. The spatial distribution of dieldrin in surface sediment is presented on Figure 5.2-25.

Aldrin was not reported at a concentration greater than 10 µg/kg in surface sediment within the eastern nearshore zone (Figure 5.2-22). Areas with reported concentrations greater than 1 µg/kg are noted in the eastern nearshore zone from RM 2 to 4, 5.8 to 6.2, and in Swan Island Lagoon. The highest reported concentration in surface sediment of 6 µg/kg aldrin in the eastern nearshore zone was at Station PSY01 in Swan Island Lagoon. Mean aldrin concentrations (Table 5.2-3) for these areas in the eastern nearshore zone are 0.872 µg/kg at RM 1.9–3; 0.517 µg/kg at RM 3–4; 0.899 µg/kg at RM 5–6; and 1.03 µg/kg in Swan Island Lagoon.

Detected concentrations of dieldrin greater than 10 µg/kg in surface sediment were observed only in Swan Island Lagoon (Figure 5.2-25). Concentrations greater than 1 µg/kg were observed in the same pattern as aldrin, with the addition of RM 11 to 11.8 in the eastern nearshore zone. The highest reported concentration of dieldrin in surface sediment in the eastern nearshore zone (22 µg/kg) is located at Station M0201 in Swan Island Lagoon. Mean concentrations of dieldrin (Table 5.2-3) in these areas in the eastern nearshore zone are 0.826 µg/kg at RM 1.9–3; 0.205 µg/kg at RM 3–4; 1.17 µg/kg at RM 5–6; 4.35 µg/kg in Swan Island Lagoon; and 4.38 µg/kg at RM 11–11.8.

Aldrin at concentrations greater than 10 µg/kg was reported in the western nearshore zone from RM 6.8 through 7 and at RM 8.8. Reported concentrations greater than 100 µg/kg were observed at RM 7.3 and 8.8 (Figure 5.2-22). The maximum concentration of aldrin in surface sediment (691 J µg/kg) is located at Station G355 (RM 7.3W). Concentrations greater than 1 µg/kg were observed from RM 3 through 10. Mean concentrations by river mile in the western nearshore zone are 0.552 µg/kg at RM 3–4; 0.595 at RM 4–5; 1.01 µg/kg at RM 5–6; 3.41 µg/kg at RM 6–7; 40.4 µg/kg at RM 7–8; 13.5 µg/kg at RM 8–9; and 1.0 µg/kg at RM 9–10 (Table 5.2-7).

Dieldrin was reported at concentrations greater than 10 µg/kg in the western nearshore zone at RM 6.3, 7.3, and 8.3–8.8. Reported concentrations greater than 100 µg/kg were noted at RM 8.8 (Figure 5.2-25). The maximum reported concentration of dieldrin (356 J µg/kg) is located at Station G453 (RM 8.8W). Concentrations greater than 1 µg/kg were observed at RM 3.3, 5.5–9.8, and at 11.3. Mean concentrations by river mile in the western nearshore are 0.294 µg/kg at RM 3–4; 0.427 µg/kg at RM 5–6; 1.83 µg/kg at RM 6–7; 2.85 µg/kg at RM 7–8; 28.7 µg/kg at RM 8–9; and 2.50 µg/kg at RM 11–11.8 (Table 5.2-7).

Neither aldrin nor dieldrin was detected in the navigation channel at concentrations greater than 10 µg/kg (Figures 5.2-22 and 5.2-25). Concentrations of aldrin greater than 1 µg/kg were observed from RM 2 to 3, 5 to 7.5, and at 9.3. Mean concentrations (Table 5.2-5) in these areas are 0.738 µg/kg at RM 1.9–3; 1.15 µg/kg at RM 5–6. 0.806 µg/kg at RM 6–7; and 0.688 µg/kg at RM 9–10. Dieldrin was reported at concentrations greater than 1 µg/kg at RM 5.6 and RM 6.4. Mean concentrations in these areas are 0.711 at RM 5–6 and 0.494 µg/kg at RM 6–7.

Aldrin was reported at a concentration greater than 100 µg/kg in surface sediment in 2 results, 12 detected results were between 10 and 100 µg/kg, 67 results were between 1 and 10 µg/kg, and 187 (70 percent) were reported at concentrations less than 1 µg/kg (Table 5.2-9).

A single dieldrin result was reported at a concentrations greater than 100 µg/kg in surface sediment, 6 were between 10 and 100 µg/kg, 33 were reported at concentrations between 1 and 10 µg/kg, and 212 samples (84 percent) were less than 1 µg/kg (Table 5.2-9).

Downstream Reach (RM 0 to 1.9)

Aldrin was reported in 3 of 25 surface sediment samples within the downstream reach (frequency of detection 12 percent). Concentrations reported range from 0.37 J to 0.4J µg/kg (Tables 5.2-19 and 5.2-21), with a mean of 0.39 µg/kg. Dieldrin was reported in 1 of 25 surface sediment samples at a concentration of 0.069 J µg/kg.

5.2.8.3 Aldrin and Dieldrin in Subsurface Sediment

Upriver Reach (RM 15.3 to 28.4)

Aldrin and dieldrin were not detected in the three subsurface sediment samples collected in the upriver reach. Detection limits ranged up to 0.2 µg/kg for aldrin and 0.036 µg/kg for dieldrin (Table 5.2-12).

Downtown Reach (RM 11.8 to 15.3)

Aldrin was reported in 8 of 94 subsurface sediment samples within the downtown reach (frequency of detection 9 percent). Concentrations reported range from 0.079 J to 1.7 µg/kg (Table 5.2-15), with a mean concentration of 0.414 µg/kg. With the exception of the 1.7 µg/kg result, all reported values were less than 1 µg/kg (Table 5.2-17).

Dieldrin was reported in 4 of 94 subsurface sediment samples (frequency of detection 4 percent); concentrations reported range from 0.2 9J to 16 J µg/kg (Table 5.2-15, Table 5.2-17), with a mean concentration of 7.06 µg/kg.

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-15 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. None of the aldrin or dieldrin data was excluded from the downtown reach.

Study Area Reach (RM 1.9 to 11.8)

Aldrin was reported in 135 of 1,172 subsurface sediment samples within the study area (frequency of detection 12 percent). Concentrations reported range from 0.110 J µg/kg to 1,340J µg/kg (Table 5.2-1), with a mean of 23.3 µg/kg. The spatial distribution of aldrin in subsurface sediment within the study area is presented on Figure 5.2-23.

Dieldrin was reported in 77 of 1,208 subsurface sediment samples within the study area (frequency of detection 6 percent). Concentrations reported range from 0.0380 NJ to 100J µg/kg (Table 5.2-1), with a mean of 3.60 µg/kg. The spatial distribution of dieldrin in subsurface sediment also is presented on Figure 5.2-26.

The maximum reported concentration (3.81 NJ µg/kg) of aldrin in subsurface sediment in the eastern nearshore zone was at Station C019-1 at RM 2.3E. Concentrations greater than 1 µg/kg were observed from RM 1.9 to 6.7 and at RM 11.2 (Figure 5.2-23). Mean concentrations by river mile are 0.989 µg/kg at RM 1.9–3; 0.667 µg/kg at RM 3–4; 0.717 µg/kg at RM 4–5; 0.920 µg/kg at RM 5–6; 0.561 µg/kg at RM 6–7; and 1.80 µg/kg at RM 11–11.8 (Table 5.2-4).

Dieldrin was reported in subsurface sediment at a maximum concentration of 100 µg/kg in the eastern nearshore zone at RM 3.7E (Station C092; 30–152 cm bml) at the head of the International Terminals Slip (Figure 5.2-26; Table 5.2-4).

The maximum reported aldrin concentration in subsurface sediment (1,340 J µg/kg) in the western nearshore zone was observed at RM 7.4 at Station C356, 136–256 cm bml (Figure 5.2-23). Aldrin concentrations in sediment greater than 1 µg/kg were observed from RM 4.5 to 8.8, concentrations greater than 10 µg/kg were observed from RM 6.1 through 8.8, and concentrations greater than 100 µg/kg were reported at RM 6.1 and 8.8 (Figure 5.2-23). Mean concentrations in these areas are 0.851 µg/kg at RM 4–5; 1.90 µg/kg at RM 5–6; 28.9 µg/kg at RM 6–7; 72.5 µg/kg at RM 7–8; and 67.9 µg/kg at RM 8–9 (Table 5.2-8). Reported dieldrin concentrations greater than 10 µg/kg in the western nearshore zone occur between RM 6 and 8.8 (Figure 5.2-26). Mean concentrations in these areas are 4.52 µg/kg at RM 6–7; 3.95 µg/kg at RM 7–8; and 17.3 µg/kg at RM 8–9 (Table 5.2-8).

Within the navigation channel, aldrin concentrations greater than 10 µg/kg were noted at RM 6.4, and sediment concentrations greater than 1 µg/kg were detected from RM 6 to 7 and at RM 10.3 (Figure 5.2-23). The maximum reported aldrin concentration (44J µg/kg) within the navigation channel was observed at core Station C299 (RM 6.4 near the west bank). Mean concentrations in these areas are 12.9 µg/kg at RM 6–7, and 0.667 µg/kg at RM 10–11 (Table 5.2-6). Dieldrin was reported at a concentration greater than 10 µg/kg in only one sample located within the navigation channel at Station WR-CD-40 (13 µg/kg) near RM 11.3. Concentrations above 1 µg/kg were also reported in cores collected at RM 3.5, 6.1, and 11.2. Mean concentrations in these areas are 0.750 µg/kg at RM 3–4; 3.00 µg/kg at RM 6–7; and 5.55 µg/kg at RM 11–11.8 (Table 5.2-6).

Downstream Reach (RM 0 to 1.9)

Aldrin was reported in 3 of 26 subsurface sediment samples within the downstream reach (frequency of detection 12 percent). Reported concentrations range from 0.2 J to 2.8 NJ µg/kg (Table 5.2-19), with a mean of 1.2 µg/kg. Dieldrin was not reported within the downstream reach.

5.2.8.4 Aldrin and Dieldrin Surface and Subsurface Sediment Relationships

Surface and subsurface sediment relationships are examined by comparing surface and subsurface concentration by reach and also by subareas within the study area reach. There are insufficient data to compare surface and subsurface concentrations in the upriver reach. Mean concentrations in surface sediment are 0.334 and 0.209 µg/kg for aldrin and dieldrin, respectively.

Within the downtown reach, mean aldrin and dieldrin concentrations were greater in subsurface versus surface sediment. Mean surface and subsurface concentrations were 0.262 and 0.414 µg/kg for aldrin, and 0.266 and 7.06 µg/kg for dieldrin, respectively.

Within the study area, aldrin and dieldrin concentrations are also generally greater in subsurface than in surface sediments. Study area-wide, mean surface and subsurface concentrations are 4.89 and 23.3 µg/kg for aldrin and 2.56 and 3.60 µg/kg for dieldrin. Exceptions to this general trend are noted in the western nearshore zone at RM 9–10 where the mean aldrin concentration is greater in surface sediment, at RM 8–9 where the mean dieldrin concentration is greater in surface sediment, and at RM11–11.8 where both aldrin and dieldrin mean concentrations are greater in surface sediment (Figures 5.2-24 and 27).

In Swan Island Lagoon, the mean aldrin and dieldrin concentrations are greatest in surface sediment. Mean dieldrin concentrations in surface sediment are greater at RM 1.9E–3E and 5E–6E. Within the navigation channel, mean aldrin and dieldrin concentrations in surface sediment concentrations are greater than in subsurface sediment.

Insufficient data are available in the downstream reach to allow meaningful comparisons between surface and subsurface sediment concentrations.

5.2.9 Arsenic in Sediment

The distribution of arsenic concentrations at each surface sediment sampling station throughout the study area is depicted on Map 5.2-31; concentrations with depth at subsurface stations are depicted on Maps 5.2-32a-o. If more than one sample was analyzed at the same surface sediment location, the greater of the two samples is presented on these maps, all subsurface samples are presented.

Figures 5.2-28 and 5.2-29 present scatter plots of the arsenic data set for surface and subsurface sediment in the study area, respectively. The scatter plots present the data in

three panels segregated by the eastern nearshore, navigational channel, and western nearshore zones (Map 5.2-1).

Summary statistics for arsenic in surface and subsurface sediment within the study area are shown in Tables 5.2-1 and 5.2-2, respectively. Summary statistics for surface and subsurface sediment within the eastern nearshore, navigation channel, and western nearshore zones are presented in Tables 5.2-3 and 5.2-4, Tables 5.2-5 and 5.2-6, and Tables 5.2-7 and 5.2-8, respectively. Tables 5.2-9 and 5.2-10 present arsenic data as orders of magnitude (e.g., <1, 1–10, 10–100, 100–1,000, etc.) for only detected values and for combined detected and non-detected values. Finally, a histogram of average surface and subsurface sediment values by river mile and for the entire study area is presented in Figure 5.2-30.

Data sets for the upriver, downtown, and downstream reaches are only presented in statistical tables and order of magnitude tables. Additionally, the downtown reach surface sediment samples are presented in Map 5.2-33. Summary statistics for surface and subsurface sediment within the upriver reach are shown in Tables 5.2-11 and 5.2-12; the number of data points by order of magnitude is provided in Tables 5.2-13 (detects only) and 5.2-14 (detects and non-detects). Summary statistics for surface and subsurface sediment within the downtown reach are shown in Tables 5.2-15 and 5.2-16; the number of data points by order of magnitude is provided in Tables 5.2-17 (detects only) and 5.2-18 (detects and non-detects). Summary statistics for surface and subsurface sediment within the downstream reach are shown in Tables 5.2-19 and 5.2-20; the number of data points by order of magnitude is provided in Tables 5.2-21 (detects only) and 5.2-22 (detects and non-detects).

5.2.9.1 Arsenic Data Set

Arsenic results includes 1,551 surface and 1,553 subsurface samples from within the study area, 77 surface and 3 subsurface samples from the upriver reach, 233 surface and 178 subsurface samples from the downtown reach, and 25 surface and 26 subsurface samples from the downstream reach.

5.2.9.2 Arsenic in Surface Sediment

Upriver Reach (RM 15.3 to 28.4)

Arsenic was reported in 73 of 77 surface sediment samples within the upriver reach (frequency of detection 95 percent). Concentrations reported range from 1.9 J to 5.29 mg/kg (Table 5.2-11), with a mean of 2.94 mg/kg.

Downtown Reach (RM 11.8 to 15.3)

Arsenic was reported in 201 of 233 surface sediment within the downtown reach (frequency of detection 86 percent). Concentrations reported range from 1.07 to 126 mg/kg (Table 5.2-15), with a mean concentration of 6.2 mg/kg. The spatial distribution of arsenic within the downtown reach is presented on Map 5.2-33. The majority of results are less than 5 mg/kg. Localized areas with concentrations greater

than 25 mg/kg were observed at RM 13 under the Hawthorne Bridge and on the western shore between the Marquam and Ross Island bridges.

One result was reported at a concentration greater than 100 mg/kg, 17 results were between 10 and 100 mg/kg, 183 results (91 percent of the detected data set) were less than 10 mg/kg, and no detected results were reported at concentrations less than 1 mg/kg (Table 5.2-17).

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-15 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. Arsenic was reported in 74 surface sediment samples within the Zidell action area, and reported concentrations range from 1.29 to 78 J mg/kg (Table 5.2-15). The mean arsenic concentration for this area is 11.2 mg/kg. When the data for the Zidell facility is removed from the downtown data set (Table 5.2-15), the range of arsenic concentrations in surface sediment is from 1.07 to 126 mg/kg with a mean concentration of 4.71 mg/kg.

Study Area Reach (RM 1.9 to 11.8)

Arsenic was reported in 1,426 of 1,551 surface sediment samples within the study area (frequency of detection 92 percent). Concentrations reported range from 0.700 to 132 mg/kg (Table 5.2-1), with a mean of 4.86 mg/kg. The spatial distribution of arsenic concentrations within the study area is presented on Figure 5.2-28.

Within the eastern nearshore zone, sediment concentrations approaching or greater than 100 mg/kg were observed at RM 2.3, 5.6, and 7.2 (Figure 5.2-28). Areas where concentrations are greater than 10 mg/kg occur near RM 5.5, 7, and in Swan Island Lagoon (Figure 5.2-28, Map 5.2-31). The highest surface concentration detected in the eastern nearshore zone (132 mg/kg) was found at Station RB08 at RM 2.3. Mean concentrations (Table 5.2-3) for these areas are 5.76 mg/kg at RM 1.9–3; 7.05 mg/kg at RM 5–6; 7.16 mg/kg at RM 7–8; and 5.87 mg/kg in Swan Island Lagoon.

Areas in the western nearshore zone where arsenic concentrations exceed 10 mg/kg occur from RM 3.5 through 7, 8.3 to 9.2, and at 10.2. Three localized areas where reported concentrations are greater than 50 mg/kg are located at RM 6.8, 8.6 (80 mg/kg at Station A2GS10), and RM 10.2 (Figure 5.2-28). Mean concentrations in these areas in the western nearshore zone are 4.86 mg/kg at RM 3–4; 4.10 mg/kg at RM 4–5; 4.12 mg/kg at RM 5–6; 5.99 mg/kg at RM 6–7; 9.17 mg/kg at RM 8–9; 5.79 mg/kg at RM 9–10; and 9.96 mg/kg at RM 10–11 (Table 5.2-7).

There were no reported arsenic concentrations in surface sediment exceeding 10 mg/kg in the navigation channel.

Within the study area, arsenic was reported in surface sediment at a concentration greater than 100 mg/kg in 2 results, 57 were between 10 and 100 mg/kg, 1,364

(96 percent of the detected results) were reported at concentrations between 1 and 10 mg/kg, and 3 were reported at concentrations less than 1 mg/kg (Table 5.2-9).

Downstream Reach (RM 0 to 1.9)

Arsenic was reported in all 25 surface sediment samples within the downstream reach. Concentrations reported range from 0.6 J to 6.4 mg/kg (Table 5.2-19). One result was reported at a concentration less than 1 mg/kg, and the remaining 24 results were between 1 and 10 mg/kg (Table 5.2-21). The mean arsenic concentration in this reach is 3.7 mg/kg.

5.2.9.3 Arsenic in Subsurface Sediment

Upriver Reach (RM 15.3 to 28.4)

Arsenic was analyzed and reported in only three subsurface samples between RM 15.4 and 16. Concentrations reported range from 2.37 to 2.45 mg/kg.

Downtown Reach (RM 11.8 to 15.3)

Arsenic was reported in 168 of 178 subsurface sediment samples within the downtown reach (frequency of detection 94 percent). Concentrations reported from 0.57 to 7.5 mg/kg (Table 5.2-16), with a mean of 2.96 mg/kg. The majority of the results (165 samples) were reported at concentrations between 1 and 10 mg/kg, and the remaining 3 results were reported at concentrations less than 1 mg/kg (Table 5.2-17).

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-16 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. Arsenic was analyzed in 30 subsurface sediment samples within the Zidell action area. Reported concentrations range from 2 to 7.5 mg/kg, with a mean concentration in this area of 3.5 mg/kg. When the data for the Zidell facility are removed from the downtown data set (Table 5.2-16), the range of reported concentrations in subsurface sediment is 0.57 to 7.19 mg/kg, with a mean of 2.89 mg/kg.

Study Area Reach (RM 1.9 to 11.8)

Arsenic was reported in 1,489 of 1,553 subsurface samples within the study area (frequency of detection 96 percent). Concentrations reported range from 0.500 J to 51.4 mg/kg (Table 5.2-2) with a mean of 4.08 mg/kg. The spatial distribution of reported arsenic concentrations in subsurface sediment is presented on Figure 5.2-29 and Maps 5.2-32a-o).

Within the eastern nearshore zone, arsenic concentrations in subsurface sediment exhibit a different pattern than observed in surface sediment (Figure 5.2-30). Concentrations greater than 10 mg/kg occur at RM 3.6, 4.6, 5.6, 8.5, 11.3, and in Swan Island Lagoon (Figure 5.2-29 and Maps 5.2-32a-o). Single points are noted at RM 6.7 and 7.4. The highest reported subsurface concentration of 51 mg/kg was observed in the interval of 150–236 cm bml at Station C708, near the mouth of Swan Island Lagoon. Mean concentrations in these eastern nearshore areas are 3.61 mg/kg at RM 3–

4; 3.47 mg/kg at RM 4–5; 5.37 mg/kg at RM 5–6; 4.11 mg/kg at RM 6–7; 4.11 mg/kg at RM 7–8; 11.5 mg/kg at RM 8–9; 4.81 mg/kg in Swan Island Lagoon; and 4.73 mg/kg at RM 11–11.8 (Table 5.2-3).

Arsenic concentrations greater than 10 mg/kg were reported in the western nearshore zone from RM 3.6 through 9.2, most prominently between RM 8.6 and 9.2 (Figure 5.2-29). The maximum reported value in the western nearshore zone was 43.3 mg/kg at Station HA-38 at RM 9.0. Mean concentrations in this area are 6.07 mg/kg at RM 3–4; 4.04 mg/kg at RM 4–5; 4.25 mg/kg at RM 5–6; 3.61 mg/kg at RM 6–7; 4.34 mg/kg at RM 7–8; 5.67 mg/kg at RM 8–9; and 8.11 mg/kg at RM 9–10 (Table 5.2-8).

Only three results from within the navigation channel were reported at a concentration greater than 10 mg/kg, at RM 7.9, 10.3, and 11.5. Within these areas, mean arsenic concentrations were 4.18 mg/kg at RM 7–8; 4.02 mg/kg at RM 10–11; and 3.03 mg/kg at RM 11–11.8 (Table 5.2-6).

Of the reported arsenic concentrations in subsurface sediment, 45 results were greater than 10 mg/kg, 1,433 results (96 percent of the reported results) were between 1 and 10 mg/kg, and 11 were reported at concentrations less than 1 mg/kg (Table 5.2-9).

Downstream Reach (RM 0 to 1.9)

Arsenic was reported in all 26 subsurface sediment samples collected within the downstream reach, with reported concentrations ranging from 0.6 J to 13 mg/kg (Table 5.2-20). Table 5.2-21 shows that there is one sample detected at a concentration greater than 10 mg/kg. The majority of the samples (24 samples; 92 percent) were detected at concentrations between 1 and 10 mg/kg. Only one sample was detected at a concentration less than 1 mg/kg. The mean arsenic concentration in this reach is 4.06 mg/kg.

5.2.9.4 Arsenic Surface and Subsurface Sediment Relationships

Surface and subsurface sediment relationships are examined by comparing surface and subsurface concentrations by reach, and also by subareas with the study area reach. There are insufficient data to allow for a meaningful comparison of surface and subsurface concentrations in the upriver reach. The mean arsenic surface sediment concentration in this reach is 2.94 mg/kg (Table 5.2-11).

Surface sediment concentrations in the downtown reach were greater than the subsurface concentrations, suggesting that there may be ongoing sources in this reach. The mean surface concentration is 6.2 mg/kg, while the mean subsurface sediment concentration is 2.96 mg/kg (Tables 5.2-15a and 5.2-16a).

Arsenic concentrations are also generally greater in the surface sediments than in subsurface sediments within the study area as a whole. The mean surface sediment concentration is 4.86 mg/kg, and the mean subsurface sediment concentration is 4.08 mg/kg (Tables 5.2-1 and 5.2-2). Figure 5.2-30 shows that mean concentrations are

greater in the nearshore areas than in the navigation channel, and the western nearshore zone is slightly greater than the eastern nearshore zone. It also shows that concentrations are generally greater in the surface sediment than in subsurface sediment.

In the eastern nearshore zone, surface sediment concentrations are greater than subsurface sediment in all river mile zones except RM 8 to 9 and 11 to 11.8. In the western nearshore zone, subsurface sediment concentrations are greater than surface sediment in all river miles except RM 4 to 5, 6 to 7, 8 to 9, and possibly 10 to 11. The subsurface sediment concentrations in the navigation channel are generally the same as the surface sediment concentrations.

Areas where subsurface sediment concentrations are elevated do not align with the locations where surface sediment concentrations are elevated. The most prominent areas are RM 8 to 9 in the eastern nearshore zone, and RM 8 to 9 and 10 to 11 in the western nearshore zones. Additional areas where elevated concentrations do not align are RM 1.9 to 3, 5 to 6, 7 to 8, and Swan Island lagoon in the eastern nearshore zone, and RM 3 to 4, 6 to 7, and 8 to 10 in the western nearshore zone (Figure 5.2-30).

The surface sediment concentrations in the downstream reach were greater than subsurface concentrations. The mean surface concentration is 3.7 mg/kg, while the mean subsurface concentration is 4.06 mg/kg (Tables 5.2-19 and 5.2-20).

5.2.10 Chromium in Sediment

The distribution of chromium concentrations in surface sediment throughout the study area is depicted on Map 5.2-34, and subsurface results are depicted on Maps 5.2-35a-o. If more than one sample was analyzed from the same surface sediment location, the greater of the two results is presented; all subsurface samples are presented.

Scatter plots of chromium data from within the study area are presented on Figures 5.2-31 and 5.2-32, respectively, for surface and subsurface sediment segregated by the eastern nearshore, navigational channel, and western nearshore zones (Map 5.2-1).

Summary statistics for surface and subsurface sediment within the study area are shown in Tables 5.2-1 and 5.2-2. Summary statistics for surface and subsurface sediment within the eastern nearshore, navigation channel, and western nearshore zones are presented in Tables 5.2-3 and 5.2-4, Tables 5.2-5 and 5.2-6, and Tables 5.2-7 and 5.2-8, respectively. Chromium results by orders of magnitude (<1, 1–10, 10–100, 100–1,000, etc.) are presented for detected values in Table 5.2-9, and for combined detected and non-detected results in Table 5.2-10. A histogram of average surface and subsurface sediment values by river mile and for the study area is presented on Figure 5.2-33.

Results for the upriver, downtown, and downstream reaches are presented in statistical tables and order of magnitude tables. Additionally, surface sediment results for the downtown reach are presented in Map 5.2-36. Summary statistics for surface and

subsurface sediment results within the upriver reach are shown in Tables 5.2-11 and 5.2-12, respectively. Results by order of magnitude are provided in Tables 5.2-13 (detects only) and 5.2-14 (detects and non-detects). Summary statistics for surface and subsurface sediment results within the downtown reach are shown in Tables 5.2-15 and 5.2-16, respectively; the number of results by order of magnitude is provided in Tables 5.2-17 (detects only) and 5.2-18 (detects and non-detects). Summary statistics for surface and subsurface sediment within the downstream reach are shown in Tables 5.2-19 and 5.2-20, respectively; the number of results by order of magnitude is provided in Tables 5.2-21 (detects only) and 5.2-22 (detects and non-detects).

5.2.10.1 Chromium Data Set

The study area chromium data set consists of 1,536 surface and 1,530 subsurface samples. The upriver data set consists of 66 surface and 3 subsurface samples, the downtown data set consists of 265 samples and 178 subsurface samples, and the downstream data set consists of 25 surface and 26 subsurface samples.

5.2.10.2 Chromium in Surface Sediment

Upriver Reach (RM 15.3 to 28.4)

Chromium was reported in all 66 surface sediment samples within the upriver reach. Reported concentrations ranged from 11.9 J to 40.5 mg/kg (Table 5.2-11). All results were between 10 and 100 mg/kg, with a mean of 23.1 mg/kg (Table 5.2-13).

Downtown Reach (RM 11.8 to 15.3)

Chromium was reported in all 265 surface sediment samples within the downtown reach. Concentrations reported ranged from 1.24 J to 758 J mg/kg (Table 5.2-15), with a mean concentration of 34.6 mg/kg. The majority of the results are less than 50 mg/kg, with concentrations greater than 50 mg/kg present at RM 13 on the western shore downstream of the Hawthorne Bridge and on the western shore between the Marquam and Ross Island bridges (Map 5.2-36).

Within the downtown reach, 14 results (5 percent of data set) were reported at concentrations greater than 100 mg/kg, 218 results (82 percent) were between 10 and 100 mg/kg, and 33 results (12 percent) were reported at concentrations less than 10 mg/kg (Tables 5.2-17 and 5.2-18).

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-15 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. Chromium was reported in 110 surface sediment samples within the Zidell action area, and concentrations range from 1.24 J to 758 J mg/kg (Table 5.2-15), with a mean of 56.0 mg/kg. When the data for the Zidell facility are removed from the downtown data set (Table 5.2-15), the range of chromium concentrations in surface sediment is from 4.51 to 189 mg/kg, with a mean concentration of 19.4 mg/kg.

Study Area Reach (RM 1.9 to 11.8)

Chromium was reported in 1,530 of 1,536 surface sediment samples within the study area (detection frequency of 99.6 percent). Reported concentrations ranged from 4.07 J to 819 J mg/kg (Table 5.2-1), with a mean of 35.4 mg/kg.

Concentrations greater than 100 mg/kg are present in the eastern nearshore zone at RM 2.1–2.4, 3.7–4.4, 5.6–5.9, and in Swan Island Lagoon (Figure 5.2-31 and Map 5.2-34). Single results greater than 100 mg/kg are present at RM 7.2 and 11. The maximum reported concentration in the eastern nearshore zone (819 J mg/kg) was found at Station RB06 at RM 2.2. Mean concentrations (Table 5.2-3) in these areas in the eastern nearshore zone are 99.9 mg/kg at RM 1.9–3; 30.7 mg/kg at RM 3–4; 29.3 mg/kg at RM 4–5; 45.1 mg/kg at RM 5–6; 34.9 mg/kg at RM 7–8; 35.4 mg/kg in Swan Island Lagoon; and 37.7 mg/kg at RM 11–11.8.

Reported concentrations in the western nearshore zone greater than 100 mg/kg are located at RM 6–6.1, 6.8–6.9, and 8.8–9.2 (Figure 5.2-31). The maximum reported concentration of chromium in surface sediment of 774 mg/kg was found at Station 19A01 (RM 8.4W). Mean concentrations in these areas are 38.8 mg/kg at RM 6-7; 34.8 mg/kg at RM 7–8; 46.9 mg/kg at RM 8–9; and 39.1 mg/kg at RM 9–10 (Table 5.2-7). All chromium results from the navigation channel were less than 100 mg/kg.

Thirty-nine results were reported at concentrations greater than 100 mg/kg, 1,466 results (96 percent) were reported at concentrations between 10 and 100 mg/kg, and the remaining 25 results were reported at concentrations less than 10 mg/kg (Table 5.2-9).

Downstream Reach (RM 0 to 1.9)

Chromium was reported in all 25 surface sediment samples within the downstream reach. Reported concentrations range from 10.4 J to 42.2 mg/kg (Tables 5.2-19 and 5.2-21), with a mean concentration of 24.7 mg/kg.

5.2.10.3 Chromium in Subsurface Sediment

Upriver Reach (RM 15.3 to 28.4)

Chromium concentrations were analyzed in only three subsurface samples between RM 15.4 and 16. The samples were all detected at levels ranging from 19.7 to 23.4 mg/kg; the average concentration for this reach is 21.2 mg/kg.

Downtown Reach (RM 11.8 to 15.3)

Chromium was reported in 174 of 178 subsurface sediment samples within the downtown reach. Concentrations reported ranged from 4.56 to 143 mg/kg (Table 5.2-16a), with a mean of 22.2 mg/kg. Table 5.2-17 shows that only one result was reported at a concentration greater than 100 mg/kg, 161 results (93 percent of reported results) were reported at concentrations between 1 and 10 mg/kg, 12 results were reported at concentrations less than 1 mg/kg.

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-16 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. Chromium was reported in 30 subsurface sediment samples within the Zidell action area. Concentrations reported ranged from 14 to 143 mg/kg, with a mean of 36 mg/kg. When data from the Zidell facility are excluded from the downtown data set, reported chromium concentrations in subsurface sediment ranged from 4.56 to 71.7 mg/kg, with a mean of 19.4 mg/kg.

Study Area Reach (RM 1.9 to 11.8)

Chromium was reported in 1,524 of 1,530 subsurface samples. Reported concentrations ranged from 6.41 J to 464 mg/kg (Table 5.2-2), with a mean of 28.8 mg/kg. The distribution of reported chromium concentrations in subsurface sediment within the study area is shown on Figure 5.2-32.

Concentrations greater than 100 mg/kg were observed within the eastern nearshore zone at RM 2.2–2.4, 5–6, and in Swan Island Lagoon (Figure 5.2-32 and Maps 5.2-35a-o). The highest reported subsurface concentration in the eastern nearshore zone (249 mg/kg) was found at Station C207-1 near RM 5.6. Mean concentrations in these areas are 30.5 mg/kg at RM 1.9–3; 56.0 mg/kg at RM 5–6; and 31.0 mg/kg in Swan Island Lagoon (Table 5.2-3).

Reported chromium concentrations greater than 100 mg/kg are present in the western nearshore zone at RM 6.1, 7.4, and 8.8–9.2 (Figure 5.2-32). The maximum subsurface concentration (464 mg/kg) was found at Station HA-42 (46–61 cm bml) at RM 9.1. Mean concentrations in these western nearshore areas are 30.3 mg/kg at RM 6–7; 32.3 mg/kg at RM 7–8; 35.2 mg/kg for RM 8–9; and 60.5 mg/kg for RM 9–10 (Table 5.2-8).

Within the navigation channel, chromium greater than 100 mg/kg was reported at RM 6.4 and 11.3. Mean concentrations for these areas are 22.9 mg/kg at RM 6–7 and 21.5 mg/kg at RM 11–11.8 (Table 5.2-6).

Fourteen results were reported at concentrations greater than 100 mg/kg, 1,452 results were between 10 and 100 mg/kg, and 58 results are composed of concentrations less than 10 mg/kg (Table 5.2-9).

Downstream Reach (RM 0 to 1.9)

Chromium was reported in all 26 subsurface sediment samples collected within the downstream reach. Concentrations reported ranged from 6.6 to 33.8 mg/kg (Tables 5.2-20 and 5.2-21), with a mean of 23.2 mg/kg.

5.2.10.4 Chromium Surface and Subsurface Sediment Relationships

Surface and subsurface sediment relationships are examined by comparing surface and subsurface concentrations by reach and also by subareas with the study area reach.

There are insufficient data to compare surface and subsurface concentrations in the upriver reach.

Within the downtown reach, chromium concentrations are greater in surface sediment than in subsurface sediment. The mean surface concentration is 34.6 mg/kg, while the mean subsurface sediment concentration is 22.2 mg/kg (Tables 5.2-15a and 5.2-16a).

Within the study area, chromium concentrations are also generally greater in the surface sediments than in subsurface sediments as a whole. Mean concentrations are 35.4 mg/kg in surface and 28.8 mg/kg subsurface sediment (Tables 5.2-1 and 5.2-2, Figure 5.2-33). Mean concentrations are greater in the nearshore areas than in the navigation channel.

Within the eastern nearshore zone, concentrations in surface sediment are greater than in subsurface sediment in all river miles except RM 5–7 and 8–9. Within the western nearshore zone, chromium concentrations in subsurface sediment are greater than in surface sediment in all river miles except RM 9–10 and 11–11.8. Within the navigation channel, surface and subsurface sediment concentrations are generally comparable. The highest concentrations of chromium in subsurface sediment align with areas where surface sediment concentrations are greatest.

Within the downstream reach, concentrations in surface sediment are generally greater than in subsurface sediment. The mean surface concentration is 24.7 mg/kg, while the mean subsurface concentration is 23.2 mg/kg (Tables 5.2-19 and 5.2-20).

5.2.11 Copper in Sediment

The distribution of copper concentrations throughout the study area is depicted on Map 5.2-37. Reported concentrations with depth at subsurface stations are depicted on Maps 5.2-38a-o. If more than one sample was analyzed at the same surface sediment location, the greater of the two samples is presented on these maps; all subsurface samples are presented. Scatter plots of the copper data set for surface and subsurface sediment in the study area are presented on Figures 5.2-34 and 5.2-35, respectively, segregated by the eastern nearshore, navigational channel, and western nearshore zones (Map 5.2-1).

Summary statistics for copper in surface and subsurface sediment within the study area are shown in Tables 5.2-1 and 5.2-2. Summary statistics for surface and subsurface sediment within the eastern nearshore, navigation channel, and western nearshore zones are presented in Tables 5.2-3 and 5.2-4, Tables 5.2-5 and 5.2-6, and Tables 5.2-7 and 5.2-8, respectively. Copper results by orders of magnitude (e.g., <1, 1–10, 10–100, 100–1,000, etc.) are presented in Table 5.2-9 (detected results only) and Table 5.2-10 (combined detected and non-detected results). Finally, a histogram of average surface and subsurface sediment values by river mile and for the entire study area is presented in Figure 5.2-36.

Data for the upriver, downtown, and downstream reaches are only presented in statistical tables and order of magnitude tables. Additionally, surface sediment data for the downtown reach are presented in Map 5.2-39. Summary statistics for surface and subsurface sediment within the upriver reach are shown in Tables 5.2-11 and 5.2-12; the number of results by order of magnitude is provided in Tables 5.2-13 (detect only) and 5.2-14 (detect and non-detect). Summary statistics for surface and subsurface sediment within the downtown reach are shown in Tables 5.2-15 and 5.2-16; the number of data points by order of magnitude is provided in Tables 5.2-17 (detect only) and 5.2-18 (detect and non-detect). Summary statistics for surface and subsurface sediment within the downstream reach are shown in Tables 5.2-19 and 5.2-20; the number of data points by order of magnitude is provided in Tables 5.2-21 (detect only) and 5.2-22 (detect and non-detect).

5.2.11.1 Copper Data Set

Copper data for the study area data consists of 1,552 surface and 1,541 subsurface samples. The upriver data set includes 72 surface and 3 subsurface samples, the downtown data set consists of 269 surface and 178 subsurface samples, and the downstream data set consists of 25 surface samples and 26 subsurface samples.

5.2.11.2 Copper in Surface Sediment

Upriver Reach (RM 15.3 to 28.4)

Copper was reported in all 72 surface sediment samples within the upriver reach. Concentrations reported with detected concentrations ranged from 10.5 J m to 50.9 mg/kg, with a mean of 24.6 mg/kg (Table 5.2-11). All detected values were between 10 and 100 mg/kg (Table 5.2-13).

Downtown Reach (RM 11.8 to 15.3)

Copper was reported in 264 of 269 surface sediment samples within the downtown reach. Concentrations reported ranged from 5.51 to 2,150 J mg/kg, with a mean of 98.6 mg/kg (Table 5.2-15). The distribution of copper concentrations in surface sediment within the downtown reach is presented on Map 5.2-39. Reported concentrations are generally less than 30 mg/kg, although areas with concentrations greater than 60 mg/kg are noted at RM 13 on the western shore under the Hawthorne Bridge and on the western shore between the Marquam and Ross Island bridges.

Within the downtown reach, 7 results were reported at concentrations greater than 1,000 mg/kg, 29 were reported at concentrations between 100 and 1,000 mg/kg, 222 results (84 percent) were reported at concentrations between 10 and 100 mg/kg, and 6 results were reported at concentrations less than 10 mg/kg (Tables 5.2-17 and 5.2-18).

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-15 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. Copper was reported in 110 surface sediment samples within the Zidell action area. Reported concentrations ranged from 5.51 to 2,150 J mg/kg (Table 5.2-15), with a mean of 195 mg/kg. When the

data for the Zidell facility are excluded from the downtown data set, reported copper concentrations in surface sediment range from 8.39 to 366 mg/kg, with a mean of 32.6 mg/kg (Table 5.2-15).

Study Area Reach (RM 1.9 to 11.8)

Copper was reported in 1,548 of 1,552 surface sediment samples. Concentrations reported ranged from 6.19 J to 2,830 mg/kg, with a mean of 60.8 mg/kg (Table 5.2-1). The distribution of concentrations in surface sediment is presented on Figure 5.2-34.

Copper in surface sediment at concentrations greater than 100 mg/kg in the eastern nearshore zone is present at RM 2.1–2.4, 3.7–4, 5.5–6.1, Swan Island Lagoon, and RM 11.1–11.3 (Figure 5.2-34 and Map 5.2-37). Single results greater than 100 mg/kg are present at RM 6.6, 7.2, and 9.9. Mean concentrations (Table 5.2-3) in these eastern nearshore areas are 42.0 mg/kg at RM 1.9–3; 38.0 mg/kg at RM 3–4; 135 mg/kg at RM 5–6; 53.6 mg/kg at RM 6–7; 53.0 mg/kg at RM 7–8; 122 mg/kg in Swan Island Lagoon; 31.6 mg/kg at RM 9–10; and 161 mg/kg at RM 11–11.8. The highest reported concentration of 2,830 mg/kg copper was reported at RM 11.2 (Station UG01).

Areas where copper concentrations are reported greater than 100 mg/kg in the western nearshore zone are present from RM 4.3 through 10.4, and in particular at RM 4.3–4.7, 5.6–6.1, 6.8–7.4, 8.3–9.2, and 10.2–10.4 (Figure 5.2-34). The maximum reported concentration in the western nearshore zone of 1,370 mg/kg was found at Station HA-43 (RM 9.2). Mean concentrations in these areas are 39.8 mg/kg at RM 4–5; 50.7 mg/kg at RM 5–6; 46.9 mg/kg at RM 6–7; 41.4 mg/kg at RM 7–8; 102 mg/kg at RM 8–9; 110 mg/kg at RM 9–10; and 164 mg/kg at RM 10–11 (Table 5.2-7).

Within the navigation channel, the highest reported copper concentrations are located at RM 5.5, 7.9, and 10.3–10.4. Reported concentrations at RM 5.5 and 7.9 appear to be associated with results observed in the eastern nearshore area, while the results RM 10.3–10.4 appear to be associated with observed concentrations in the western nearshore area (Map 5.2-37). The mean concentrations for these areas are 30.1 mg/kg at RM 5–6; 49.3 mg/kg at RM 7–8; 62.0 mg/kg in Swan Island Lagoon; and 39.7 mg/kg at RM 10–11 (Table 5.2-5).

Within the study area, copper was reported at concentrations greater than 1,000 mg/kg in 4 results, 144 results were greater than 100 mg/kg, 1,392 results (90 percent of the detected results) were reported at concentrations between 10 and 100 mg/kg, and 8 results were reported at concentrations less than 10 mg/kg (Table 5.2-9).

Downstream Reach (RM 0 to 1.9)

Copper was reported in all 25 surface sediment samples within the downstream reach (detection frequency of 100 percent), with concentrations ranging from 8 to 45.7 mg/kg (Table 5.2-19). Table 5.2-21 shows that 23 samples are measured at concentrations between 10 and 100 mg/kg and 2 samples are measured at concentration between 1 and

10 mg/kg. There were no samples were detected at concentrations less than 1 mg/kg. The mean copper concentration in this reach is 25.5 mg/kg.

5.2.11.3 Copper in Subsurface Sediment

Upriver Reach (RM 15.3 to 28.4)

Only three subsurface sediment samples were analyzed for copper in the upriver reach, all between RM 15.4 and 16. Reported concentrations range from 26 to 33 mg/kg, with a mean of 28.6 mg/kg.

Downtown Reach (RM 11.8 to 15.3)

Copper was reported in all 178 subsurface sediment samples within the downtown reach. Concentrations reported range from 9.48 to 1,050 mg/kg, with a mean of 46.3 mg/kg (Table 5.2-16). One result was reported at a concentration greater than 1,000 mg/kg, 8 were reported at concentrations between 100 and 1,000 mg/kg, 167 results were reported at concentrations between 10 and 100 mg/kg, and 2 results were reported at concentrations less than 10 mg/kg (Table 5.2-17).

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-16 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. Copper was reported in 30 subsurface sediment samples within the Zidell action area. Concentrations reported range from 14 to 1,050 mg/kg, with a mean of 82.1 mg/kg. Excluding the data from the Zidell site, reported concentrations range from 9.48 to 457 mg/kg, with a mean of 39.0 mg/kg (Table 5.2-16).

Study Area Reach (RM 1.9 to 11.8)

Within the study area, copper was reported in all 1,541 subsurface samples. Concentrations reported range from 9.42 J to 3,290 mg/kg, with a mean of 55.2 mg/kg (Table 5.2-2). The distribution of concentrations in subsurface sediments is presented on Figure 5.2-35 and Maps 5.2-38a-o.

The subsurface sediment has elevated concentrations in generally the same areas identified in the surface sediment within the eastern nearshore zone (Figure 5.2-35). The maximum subsurface copper concentration (3,290 mg/kg) was found at Station C384 (30–128 cm bml), at the mouth of Swan Island Lagoon. Concentrations greater than 100 mg/kg are noted at RM 3.6, 4.4–4.6, 5.6, 6.1–6.7, 7.4, in Swan Island Lagoon, RM 8.4–8.8, and 11.3 (Figure 5.2-35 and Maps 5.2-38a-o). Mean copper concentrations in these areas in the eastern nearshore zone are 35.6 mg/kg at RM 3–4; 30.2 mg/kg at RM 4–5; 56.9 mg/kg at RM 5–6; 70.0 mg/kg at RM 6–7; 48.3 mg/kg at RM 7–8; 128 mg/kg at RM 8–9; and 145 mg/kg in Swan Island Lagoon (Table 5.2-4).

Within the western nearshore zone, copper concentrations exceeding 100 mg/kg are present from RM 4.1 through 9.2 (Figure 5.2-35 and Maps 5.2-38a-o). The maximum reported subsurface concentration of 1,990 mg/kg in the western nearshore zone was found at Station HA-42 (46–61 cm bml) at RM 9.1. Mean concentrations in these areas

are 48.0 mg/kg at RM 4–5; 33.9 mg/kg at RM 5–6; 39.4 mg/kg at RM 6–7; 42.6 mg/kg at RM 7–8; 59.8 mg/kg at RM 8–9; and 229 mg/kg at RM 9–10 (Table 5.2-8).

There are two areas with results greater than 100 mg/kg in the navigation channel, located at RM 7.6–8 and 10.2–10.3. The results at RM 7.6–8 may be associated with concentrations observed in the eastern nearshore zone, and the results at RM 10.2–10.3 may be collocated with elevated concentrations the western nearshore zone (Maps 5.2-38a-o). The mean concentrations for these areas are 68.7 mg/kg at RM 7–8, and 51.4 mg/kg at RM 10–11 (Table 5.2-6).

Table 5.2-9 shows that a total of 6 results in subsurface sediment were reported at concentrations greater than 1,000 mg/kg, 78 results were between 100 and 1,000 mg/kg, 1,456 results were reported at concentrations between 10 and 100 mg/kg, and 1 result was than 10 mg/kg.

Downstream Reach (RM 0 to 1.9)

Copper was reported in all 26 subsurface sediment samples within the downstream reach. Concentrations reported range from 8.9 to 43.6 mg/kg, with a mean of 25.7 mg/kg (Table 5.2-20). Table 5.2-21 shows that the majority of samples (a total of 24 of the 26 results) were reported at a concentration greater than 10 mg/kg, and 2 samples were reported at a concentration less than 10 mg/kg.

5.2.11.4 Copper Surface and Subsurface Sediment Relationships

Surface and subsurface sediment relationships are examined by comparing surface and subsurface concentrations by reach and also by subareas with the study area reach. There are insufficient data to compare surface and subsurface concentrations in the upriver reach.

The mean surface sediment concentration of 98.6 mg/kg in the downtown reach is greater than the subsurface mean of 46.3 mg/kg (Table 5.2-15a). However, when the Zidell data are excluded, the mean surface and subsurface sediment concentrations are similar at 32.6 and 39.0 mg/kg, respectively (Table 5.2-15).

Copper concentrations in the subsurface sediments are generally comparable to the concentration in the surface sediments within the study area as a whole (Figure 5.2-36). The mean surface sediment concentration is 60.8 mg/kg, and the mean subsurface sediment concentration is 55.2 mg/kg (Tables 5.2-1 and 5.2-2).

In the eastern nearshore zone, mean concentrations in surface sediment are greater than in subsurface sediment in all river mile zones except RM 6–7, 8–9, and in Swan Island Lagoon. In the western nearshore zone, mean concentrations in subsurface sediment are greater than in surface sediment in all river miles except RM 5–7 and 8–9. Within the navigation channel, mean subsurface and surface sediment concentrations are comparable, with the mean subsurface sediment concentrations slightly greater in all river miles except RM 1.9–3 and 4–7. Areas with the highest copper concentrations in

subsurface sediment generally align with the locations where surface sediment concentrations are greatest, although there are more areas with only elevated surface or elevated subsurface sediment concentrations (Figure 5.2-36). Mean surface and subsurface concentrations in the downstream reach are 25.5 and 25.7 mg/kg, respectively (Tables 5.2-19 and 5.2-20).

5.2.12 Zinc in Sediment

The distribution of zinc concentrations throughout the study area is presented on Map 5.2-40. Reported concentrations with depth are depicted on Maps 5.2-41a-o. If more than one sample was analyzed at the same surface sediment location, the greater of the two results is presented; all subsurface results are presented. Scatter plots of zinc results in the study area are presented on Figures 5.2-37 and 5.2-38 for surface and subsurface sediment, respectively, segregated by the eastern nearshore, navigational channel, and western nearshore zones (Map 5.2-1).

Summary statistics are presented in Tables 5.2-1 and 5.2-2 for surface and subsurface sediment, respectively, within the study area, and in Tables 5.2-3 and 5.2-4 for the eastern nearshore zone, Table 5.2-5 and 5.2-6 for the navigation channel, and Tables 5.2-7 and 5.2-8 for the western nearshore zone. Results by order of magnitude (e.g., <1, 1–10, 10–100, 100–1,000, etc.) are presented in Table 5.2-9 for detected results only and Table 5.2-10 for combined detected and non-detected values. Finally, a histogram of average surface and subsurface sediment values by river mile and for the entire study area is presented in Figure 5.2-39.

Data sets for the upriver, downtown, and downstream reaches are only presented in statistical tables and order of magnitude tables. The downtown reach surface sediment results are also presented in Map 5.2-42. Summary statistics for surface and subsurface sediment within the upriver reach are shown in Tables 5.2-11 and 5.2-12, respectively. The number of results by order of magnitude is provided in Tables 5.2-13 (detects only) and 5.2-14 (detects and non-detects). Summary statistics of results within the downtown reach are shown in Tables 5.2-15 and 5.2-16 for surface and subsurface sediment, respectively. The number of results by order of magnitude is provided in Tables 5.2-17 (detects only) and 5.2-18 (detects and non-detects). Summary statistics of results within the downstream reach are shown in Tables 5.2-19 and 5.2-20 for surface and subsurface sediment, respectively. The number of results by order of magnitude is provided in Tables 5.2-21 (detects only) and 5.2-22 (detects and non-detects).

5.2.12.1 Zinc Data Set

The zinc data set consists of 1,581 surface and 1,581 subsurface samples from the study area, 72 surface and 3 subsurface samples from the upriver reach, 269 surface and 178 subsurface samples from the downtown reach, and 25 surface and 26 subsurface samples downstream reach.

5.2.12.2 Zinc in Surface Sediment

Upriver Reach (RM 15.3 to 28.4)

Zinc was reported in all 72 surface sediment samples within the upriver reach. Concentrations reported range from 41.1 J to 165 mg/kg, with a mean of 75.2 mg/kg (Table 5.2-11) Four results were reported at concentrations greater than 100 mg/kg, and the remaining 68 data points were between 10 and 100 mg/kg (Table 5.2-13).

Downtown Reach (RM 11.8 to 15.3)

Zinc was reported in all 269 surface sediment samples within the Ddwntown reach. Concentrations reported range from 3.27 J to 6,480 J mg/kg, with a mean of 294 mg/kg (Table 5.2-15). The distribution of surface sediment results in the downtown reach is presented on Map 5.2-42. The majority of results are less than 300 mg/kg. Concentrations greater than 600 mg/kg were reported at RM 13 on the western shore under the Hawthorne Bridge and on the western shore between the Marquam and Ross Island bridges.

Concentrations greater than 1,000 mg/kg were reported in 15 results, 102 results were reported at concentrations between 100 to 1,000 mg/kg, 151 results were reported at concentrations between 10 and 100 mg/kg, and 1 result was reported at a concentration less than 10 mg/kg (Table 5.2-17 and 5.2-18).

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-15 presents the data statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. Zinc was reported in all 110 surface sediment samples within the Zidell action area. Concentrations reported range from 3.27 J to 6,480 J mg/kg, with a mean of 555 mg/kg (Table 5.2-15). With the Zidell facility data excluded from the downtown data set, reported zinc concentrations range from 22.8 to 1,450 mg/kg, with a mean of 113 mg/kg (Table 5.2-15).

Study Area Reach (RM 1.9 to 11.8)

Zinc was reported in all 1,581 surface sediment samples within the study area. Concentrations reported range from 3.68 J to 4,220 mg/kg, with a mean of 154 mg/kg (Table 5.2-1). The distribution of reported zinc concentrations within the study area is shown on Figure 5.2-37.

Concentrations greater than 300 mg/kg were reported in the eastern nearshore zone at RM 2.1–2.3, 3.7–4.6, 5.6–5.9, and in Swan Island Lagoon (Figure 5.2-37 and Map 5.2-40). Single exceedances greater than 300 mg/kg were reported at RM 6.7, 7.2, 9.9, and 11.3. The highest zinc concentration in the eastern nearshore zone of 2,050 mg/kg was reported at RM 4.6 (Station T4-UP13). Mean zinc concentrations in these areas in the eastern nearshore zone are 190 mg/kg at RM 1.9–3; 159 mg/kg at RM 3–4; 234 mg/kg at RM 4–5E; 192 mg/kg RM 5–6; 123 mg/kg at RM 6–7; 114 mg/kg at RM 7–8; 227 mg/kg in Swan Island Lagoon; 97.1 mg/kg at RM 9–10; and 132 mg/kg at RM 11–11.8 (Table 5.2-3).

Concentrations greater than 300 mg/kg were reported in the western nearshore zone from at RM 6.1, 6.7–6.8, 8.1–9.3, 9.6–9.7, and 10.3–10.4 (Figure 5.2-37). The maximum reported concentration of zinc in surface sediment in the study area of 4,220 mg/kg was detected at Station HA-43 at RM 9.2W. Mean concentrations for these western nearshore areas are 150 mg/kg at RM 6–7; 290 mg/kg at RM 8–9; 394 mg/kg at RM 9–10; and 212 mg/kg at RM 10–11 (Table 5.2-7). All reported concentrations of zinc in the navigation channel were less than 300 mg/kg.

Within the study area, zinc was reported at concentrations greater than 1,000 mg/kg in 15 results, 914 results were reported at concentrations greater than 100 mg/kg, 650 results were reported at concentrations between 10 and 100 mg/kg, and 2 results were reported at concentrations less than 10 mg/kg (Table 5.2-9).

Downstream Reach (RM 0 to 1.9)

Zinc was reported in all 25 surface sediment samples within the downstream reach. Concentrations reported ranged from 47.6 to 188 mg/kg, with a mean of 98.2 mg/kg (Table 5.2-19). Concentrations greater than 100 mg/kg were reported in 12 results, and 13 results were reported at concentrations between 10 and 100 mg/kg (Table 5.2-21).

5.2.12.3 Zinc in Subsurface Sediment

Upriver Reach (RM 15.3 to 28.4)

Zinc was analyzed in only three subsurface samples between RM 15.4 and 16 and reported at concentrations ranging from 65.8 to 119 mg/kg, with a mean of 87.6 mg/kg.

Downtown Reach (RM 11.8 to 15.3)

Zinc was reported in all 178 subsurface sediment samples from within the downtown reach. Concentrations reported ranged from 21.4 to 11,100 J mg/kg, with a mean of 379 mg/kg (Table 5.2-16). One result was reported at a concentration greater than 10,000 mg/kg, 9 results were reported at concentrations between 1,000 and 10,000 mg/kg, 77 results were reported at concentrations between 100 and 1,000 mg/kg, and 91 results were reported at concentrations between 10 and 100 mg/kg (Table 5.2-17).

Table 5.2-16 presents data statistics for the downtown reach with the Zidell data excluded and for the Zidell data removed from the downtown data set. Zinc was reported in 30 samples within the Zidell action area at concentrations ranging from 41 to 2,270 mg/kg, with a mean of 207 mg/kg. With the Zidell data excluded from the downtown data, reported zinc concentrations in subsurface sediment range from 21.4 to 11,100 J mg/kg, with a mean of 414 mg/kg (Table 5.2-16).

Study Area Reach (RM 1.9 to 11.8)

Zinc was analyzed and detected in 1,581 samples within the study area (100 percent detection frequency) with concentrations ranging from 24.0 to 9,000 mg/kg (Table 5.2-2) and a mean concentration of 147 mg/kg. Similar to surface sediment, zinc

concentrations in the subsurface also varied within the study area (Figure 5.2-38; Maps 5.2-41a-o).

The subsurface sediment has elevated concentrations in generally the same areas identified in the surface sediment within the eastern nearshore zone (Figure 5.2-38). Concentrations greater than 300 mg/kg are noted at RM 2.3, 3.7, 4.2–4.6, 5.6, 6.7, in Swan Island Lagoon, 8.4–8.6, and 11.1 (Figure 5.2-39 and Maps 5.2-41a-o). The maximum subsurface zinc concentration in the eastern nearshore zone (1,930 mg/kg) was found at Station C384 (30–128 cm bml), at the mouth of Swan Island Lagoon. Mean zinc concentrations (Table 5.2-3) for these areas in the eastern nearshore zone are 131 mg/kg at RM 1.9–3; 149 mg/kg at RM 3–4; 155 mg/kg at RM 4–5; 171 mg/kg at RM 5–6; 133 mg/kg at RM 6–7; 291 mg/kg at RM 8– 9; 181 mg/kg in Swan Island Lagoon; and 159 mg/kg at RM 11–11.8.

The western nearshore zone has detected zinc concentrations that exceed 300 mg/kg from RM 6.7 through 9.2 with clusters noted at RM 6.7, 7.6–7.7, and 8.3–9.2 (Figure 5.2-38 and Maps 5.2-41a-o). The maximum subsurface concentration (9,000mg/kg) was found at Station HA-42 (15–61 cm bml) at RM 9.1W. Mean concentrations (Table 5.2-8) for these areas in the western nearshore zone are 126 mg/kg at RM 6–7; 131 mg/kg at RM 7–8; 190 mg/kg at RM 8–9; and 792 mg/kg at RM 9–10.

There is one peak with samples greater than 300 mg/kg in the navigation channel zone located at RM 10.2–10.3 with two individual samples exceeding 300 mg/kg at RM 6.4 and RM 7.9. The elevated concentrations within the navigation channel are near elevated concentrations the western nearshore zone. The mean concentrations for these areas are 102 mg/kg at RM 6–7; 125 mg/kg at RM 7–8; and 127 mg/kg at RM 10–11 (Table 5.2-6).

Table 5.2-9 shows that there are 6 subsurface samples greater than 1,000 mg/kg, and 834 samples ranging between 100 and 1,000 mg/kg. Subsurface sediment values greater than 100 mg/kg account for 53 percent of the detected data set. The remainder of the detected data set (741 samples; 47 percent) is between 10 and 100 mg/kg. There were no samples detected at concentrations less than 10 mg/kg.

Downstream Reach (RM 0 to 1.9)

Zinc was analyzed and detected in 26 subsurface sediment samples within the downstream reach (detection frequency of 100 percent), with concentrations ranging from 10.8 to 244 mg/kg (Table 5.2-20). Table 5.2-21 shows that approximately half of samples (14 samples) were detected at a concentration greater than 100 mg/kg, and half the samples (12 samples) were detected at a concentration less than 100 mg/kg. There were no samples were detected at concentrations less than 10 mg/kg. The mean zinc concentration in this reach is 118 mg/kg.

5.2.12.4 Zinc Surface and Subsurface Sediment Relationships

Surface and subsurface sediment relationships are examined by comparing surface and subsurface concentrations by reach and also by subareas with the study area reach. There are insufficient data to compare surface and subsurface concentrations in the upriver reach. The mean zinc surface sediment concentration in this reach is 75 mg/kg (Table 5.2-11).

The surface sediment concentrations in the downtown reach were lower than the subsurface concentrations. The mean surface concentration is 294 mg/kg, while the mean subsurface sediment concentration is 379 mg/kg (Tables 5.2-15a and 5.2-16a).

Zinc concentrations are generally similar in the surface sediments and subsurface sediments within the study area as a whole. The mean surface sediment concentration is 154 mg/kg, and the mean subsurface sediment concentration is 147 mg/kg (Tables 5.2-1 and 5.2-2). Areas where subsurface sediment concentrations are elevated generally align with the locations where surface sediment concentrations are elevated. Figure 5.2-39 shows that mean concentrations are generally greater in the nearshore areas than in the navigation channel, and the western nearshore zone has slightly greater subsurface concentrations than the eastern nearshore zone, while the eastern nearshore zone has higher surface concentrations.

In the eastern nearshore zone, surface sediment concentrations are slightly greater than subsurface sediment in all river mile zones except RM 6–9 and 10–11.8. In the western nearshore zone, subsurface sediment concentrations are greater than surface sediment in all river miles except RM 3– 4, 6–7, and 8–9. With the exception of RM 8E–9E and 9W–10W, the subsurface concentrations are slightly greater than the surface concentrations in these areas.

The subsurface sediment concentrations in the navigation channel are generally the same as the surface sediment concentrations, although the subsurface sediment concentrations are slightly greater in all river miles except RM 5–6.

The subsurface sediment concentrations in the downstream reach were greater than surface concentrations. The mean surface concentration is 98.2 mg/kg, while the mean subsurface concentration is 118 mg/kg (Tables 5.2-19 and 5.2-20).

5.2.13 Tributyltin Ion in Sediment

Several data presentations for the surface and subsurface TBT data sets for the study area are provided for this discussion. There are maps, scatter plots, statistical summary tables, order of magnitude tables, and a histogram of mean surface and subsurface sediment concentrations by river mile. The distribution of TBT concentrations at each surface sampling station throughout the study area is depicted in Map 5.2-43, concentrations with depth at subsurface stations are depicted in Maps 5.2-44a–o.

The data for TBT in the study area are presented on scatter plots on Figures 5.2-40 and 5.2-41 for surface and subsurface sediment, respectively. These plots present the data in three panels segregated by the eastern nearshore, navigation channel, and western nearshore zones (Map 5.2-1).

Summary statistics for TBT within the study area are shown in Tables 5.2-1 and 5.2-2 for surface and subsurface sediment, respectively. Summary statistics for surface and subsurface sediment and are presented in Tables 5.2-3 and 5.2-4 within the eastern nearshore, Tables 5.2-5 and 5.2-6 in the navigation channel, and Tables 5.2-7 and 5.2-8 for the western nearshore zones. TBT data are presented as orders of magnitude (e.g., <1, 1–10, 10–100, 100–1,000, etc.) in Table 5.2-9 for detected values, and Table 5.2-10 for combined detected and non-detected values. Finally a histogram of average surface and subsurface sediment values for TBT by river mile and for the entire study area is presented in Figure 5.2-42.

Data sets for the upriver, downtown, and downstream reaches are only presented in statistical tables and order of magnitude tables. Additionally, surface sediment results for the downtown reach are presented on Map 5.2-45. Summary statistics for surface and subsurface sediment within the upriver reach are shown in Tables 5.2-11 and 5.2-12; number of results by order of magnitude is provided in Tables 5.2-13 (detects only) and 5.2-14 (detects and non-detects). Summary statistics for surface and subsurface sediment within the downtown reach are presented in Tables 5.2-15 and 5.2-16; number of results by order of magnitude is provided in Tables 5.2-17 (detects only) and 5.2-18 (detects and non-detects). Summary statistics for surface and subsurface sediment with the downstream reach are presented in Tables 5.2-19 and 5.2-20; number of results by order of magnitude is provided in Tables 5.2-21 (detects only) and 5.2-22 (detects and non-detects).

5.2.13.1 Tributyltin Ion Data Set

Sampling for TBT analysis was based on a biased approach at locations near known or suspected sources. As a result, there are relatively fewer data points for these analytes in the RI sediment database than for other chemicals. This is particularly true in areas away from suspected sources, such as the navigation channel. However, areas with known or suspected TBT sources have been sufficiently characterized and the existing TBT data are sufficient for RI purposes.

Within the study area, TBT was analyzed in 358 surface and 433 subsurface samples. The upriver data set consists of 8 surface and 3 subsurface samples. The downtown data set is 174 surface and 65 subsurface samples, and the downstream data set is 4 surface and no subsurface samples. The small number of data points for TBT limits the extent to which its distribution may be resolved (Sections 5.2.13.2 and 5.2.13.3) and introduces the need for caution in interpreting the surface to subsurface trends shown by the histograms (Figures 5.2-42).

5.2.13.2 Tributyltin Ion in Surface Sediment

Upriver Reach (RM 15.3 to 28.4)

TBT was reported in 4 of 8 surface sediment samples within the upriver reach. Concentrations reported range from 0.72 J to 2.3 µg/kg (Table 5.2-11). Three results were reported at concentrations between 1 and 10 µg/kg, and one result was reported at a concentration less than 1 µg/kg. The mean concentration in this reach is 1.31 µg/kg (Table 5.2-13).

Downtown Reach (RM 11.8 to 15.3)

TBT was reported in 62 of 174 surface sediment samples within the downtown reach (frequency of detection 36 percent). Concentrations range from 0.4 J to 1,990 µg/kg, with a mean concentration of 75.6 µg/kg (Table 5.2-15). Results with the highest concentrations are located along the western shoreline (Map 5.2-45).

Tables 5.2-17 shows that there are 2 results reported at concentrations greater than 1,000 µg/kg, 2 results between 100 and 1,000 µg/kg, 12 results were reported at concentrations between 10 and 100 µg/kg, 32 results between 1 and 10 µg/kg, and 14 results were reported at concentrations less than 1 µg/kg.

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-15 presents the statistics for the downtown reach excluding the Zidell data and for the Zidell data removed from the downtown data set. TBT was reported in 26 of 80 surface sediment samples within the Zidell action area. Concentrations reported range from 1.9 to 1,990 µg/kg, with a mean of 102 µg/kg (Table 5.2-15c). With the Zidell data excluded from the downtown data set, reported TBT concentrations range from 0.4 J to 1,700 J µg/kg, with a mean of 55 µg/kg (Table 5.2-15b).

Study Area Reach (RM 1.9 to 11.8)

TBT was reported in 333 of 358 surface sediment samples within the study area. Concentrations reported range from 0.45 J to 47,000 µg/kg, with a mean of 466 µg/kg (Table 5.2-1). The distribution of reported TBT concentrations within the study area is presented on Figure 5.2-40 and Map 5.2-43.

Concentrations greater than 1,000 µg/kg in the eastern nearshore zone were reported at RM 3.7, 7.5, and in Swan Island Lagoon. The highest reported surface sediment concentration of 47,000 µg/kg was reported at Station SD12 (RM 3.7, at the head of International Slip). A concentration of 46,000 µg/kg was reported at Station G421 in Swan Island Lagoon. Mean concentrations in these areas are 1,570 µg/kg at RM 3–4; 193 µg/kg at RM 7–8; and 2,340 µg/kg in Swan Island Lagoon (Table 5.2-3).

Within the navigation channel, TBT concentrations greater than 1,000 µg/kg were reported near Swan Island Lagoon (1,800 µg/kg at Station SD124 at RM 7.7; Figure 5.2-40). The mean concentration at RM 7–8 is 373 µg/kg (Table 5.2-5).

A single measurement greater than 1,000 µg/kg was reported at RM 8.8 in the western nearshore zone. The mean concentration at RM 8–9 is 83.8 µg/kg (Table 5.2-7).

Two results were reported at concentrations greater than 10,000 µg/kg, 12 results were between 1,000 and 10,000 µg/kg, 71 results were reported at concentrations between 100 and 1,000 µg/kg, 125 results were between 10 to 100 µg/kg, 108 results between 1 and 10 µg/kg, and 15 results were reported at concentrations less than 1 µg/kg (Tables 5.2-9, Map 5.2-43).

Downstream Reach (RM 0 to 1.9)

TBT was reported in all 4 samples within the downstream reach at concentrations between 0.37 J and 1.2 J µg/kg, with a mean of 0.85 µg/kg (Tables 5.2-19, 5.2-21, and 5.2-22).

5.2.13.3 Tributyltin Ion in Subsurface Sediment

Upriver Reach (RM 15.3 to 28.4)

TBT was analyzed in three subsurface sediment samples between RM 15.4 and 16, and was not detected at maximum detection limit of 0.094 µg/kg.

Downtown Reach (RM 11.8 to 15.3)

TBT was reported in 21 of 65 subsurface sediment samples within the downtown reach. Concentrations reported range from 0.55 J to 14,000 µg/kg (Table 5.2-15a), with a mean concentration of 1,052 µg/kg.

One result was reported at a concentration greater than 10,000 µg/kg, one each was reported between 1,000 and 10,000 µg/kg and between 100 and 1,000 µg/kg, five results were between 10 and 100 µg/kg, nine were between 1 and 10 µg/kg, and four results were reported at a concentration less than 1 µg/kg (Tables 5.2-17).

In 2011, a remedial action was taken at the Zidell facility under DEQ authority. Table 5.2-16 presents data statistics for the downtown reach with the Zidell data excluded and for the Zidell data removed from the downtown data set. TBT was reported in 13 of 23 subsurface sediment samples within the Zidell action area. Concentrations reported range to a maximum reported value of 14,000 µg/kg, with a mean of 1,697 µg/kg. When the data from the Zidell facility are excluded from the downtown data set, the range of reported concentrations ranges from 0.55 J to 23 µg/kg, with a mean of 4.48 µg/kg (Table 5.2-16).

Study Area Reach (RM 1.9 to 11.8)

TBT was detected in 223 of the 433 subsurface samples analyzed within the study area. Concentrations reported range from 0.32J to 90,000 µg/kg, with a mean of 1,410 µg/kg (Table 5.2-2). TBT concentrations in subsurface sediment within the study area are presented on Figure 5.2-41 and Maps 5.2-44a-o.

TBT concentrations reported in the eastern nearshore zone at concentrations greater than 1,000 µg/kg are present at RM 7–8 and in Swan Island Lagoon (Figure 5.2-41). A single result of 1,000 µg/kg was reported at RM 5.6. Mean concentration in these areas in are 196 µg/kg at RM 5–6; 1,250 µg/kg at RM 7–8; 13,700 µg/kg at RM 8–9; and 5,380 µg/kg in Swan Island Lagoon (Table 5.2-4).

Within the western nearshore zone there were no reported TBT concentrations greater than 1,000 µg/kg (Figure 5.2-41). Concentrations greater than 1,000 µg/kg were reported in the navigation channel at RM 7.8 and in Swan Island Lagoon (Maps 5.2-44a-o). The highest reported concentrations in subsurface sediment are generally found at the same surface locations where TBT concentrations are greater than 1,000 µg/kg along the eastern nearshore zone (Maps 5.2-44a–o).

Within the study area, 8 results were greater than 10,000 µg/kg, 14 were between 1,000 and 10,000 µg/kg, 35 results were reported at concentrations between 100 and 1,000 µg/kg, 88 results were between 10 and 100 µg/kg, 62 were between 1 and 10 µg/kg, and 16 results were reported at concentrations less than 1 µg/kg (Table 5.2-9).

Downstream Reach (RM 0 to 1.9)

TBT was not analyzed in subsurface sediment samples within the downstream reach.

5.2.13.4 Tributyltin Ion Surface and Subsurface Sediment Relationships

Surface and subsurface sediment relationships were examined by comparing surface and subsurface concentrations by reach and also by subareas within the study area. There are insufficient data to compare surface and subsurface concentrations in the upriver and downstream reaches.

Within the downtown reach, the mean TBT concentrations are 74.6 and 1,052 µg/kg in surface and subsurface sediment, respectively. With the Zidell data excluded, this relationship is reversed, and the mean concentrations in surface and subsurface sediment are 55.0 and 4.48 µg/kg, respectively.

Within the study area, TBT concentrations are generally greater in the subsurface than in surface sediments. The mean concentrations are 466 and 1,410 µg/kg in surface and subsurface sediment, respectively. Most areas throughout the study area reach lack a strong or consistent vertical concentration gradient, although the majority of the contamination appears in the shallower subsurface samples. This pattern is supported by Maps 5.2-44d-j.

5.3 INDICATOR CONTAMINANTS IN MOBILE SEDIMENT

This section discusses mobile sediment at Portland Harbor by summarizing the sediment trap data collected for this investigation. The sediment trap investigation was designed to capture anticipated spatial and temporal variability of suspended sediment mass, fill data gaps related to the nature and extent of potential sources, and support the

preparation of the BERA (Anchor 2006b). The geographic locations of all sediment trap stations are presented on Map 2.1-24.

Discussion of the indicator contaminants addressed in this section focuses primarily on the following elements:

- A description of the data set for each contaminant, including frequency of detection and concentration range
- The sampling locations and periods (sampling quarters) with elevated contaminant concentrations and any apparent spatial or temporal gradients within the data set
- An evaluation of contaminant concentrations found in the study area compared to concentrations found at locations outside of the study area.

The following subsections present tables, histograms, and other graphical summaries of the data to support discussion and evaluation of the nature and extent of the indicator contaminants in the sediment traps. Additional tabular and graphical summaries of the sediment trap data set are included in Appendix D2.

The chemistry distributions for the sediment traps are depicted graphically in histograms showing indicator contaminant concentrations for each location and grouped by sampling quarter (Figures 5.3-1a-b through 5.3-15a-b). The blank spaces in the histograms within station groups signify that the volume of material collected for the quarter was not sufficient for analysis or the sediment trap was lost. Sample analyses resulting in non-detects are flagged in the histograms to distinguish them from cases where results are not available. Scales for indicator contaminant concentrations (y-axis) were selected to emphasize higher concentrations yet visually distinguish comparatively low concentrations. In some cases, values above scale maximums are labeled with the sample concentration.

Other graphic displays used to assist with data interpretation include two scatter plots (Figures 5.3-16 and 5.3-17) with regression lines to fit the data and accompanying regression equations. Natural log-transformed PCB congener concentrations are regressed on natural log-transformed Aroclor concentrations in Figure 5.3-17 to display the relationship between PCB results obtained using different analytical methods. The relationship between sediment accumulation rates and the percentage of fines (i.e., silt and clay, particles $\leq$62 μm) is shown in a scatter plot of the un-transformed data sets (Figure 5.3-16). Plots of sample grain size distribution are shown in Figures 5.3-18a-b. Line graphs (Figures 5.3-19a-b) are used to display the Willamette River daily discharge hydrograph for the entire sediment trap sampling period, with quarterly sampling periods identified by different colors. This hydrograph also displays average historical daily discharges for a 36-year period (1972–2008). Figures 5.3-20a-b show the quarterly distribution of the daily Willamette River discharge combined with sediment accumulation rates (also depicted in Figures 5.3-21a-b), and percent fines (percent fines values are also depicted in Appendix D2.1, Figure D2.1-22a-b).

5.3.1 Mobile Sediment Data Set

This section focuses on the concentrations of indicator contaminants associated with samples from in-river sediment trap samples collected within the lower Willamette River. Sediment traps were deployed at 16 locations in the lower Willamette River from late 2006 through late 2007 (see Map 2.1-24). Twelve of the locations were within the study area between RM 1.9 and 11.5. One sediment trap was deployed just downstream of the study area at RM 1.8, two were located just upstream of Ross Island at RM 15.6 and 15.7, and one was located in Multnomah Channel. Paired sediment traps were deployed and maintained on opposite sides of the river at approximately RM 1.9, 6, 11.5, and 15.7. Samples were retrieved quarterly to obtain four quarters (1 year) of data. A total of 52 sediment trap samples were collected and analyzed per the protocols used in Rounds 2A and 2B; some samples were not obtained due to lack of material in the trap or loss of the trap.

In June 2009, seven sediment traps were deployed by the City of Portland between RM 11 and 12.1 (Map 2.1-15ff) to characterize settleable suspended sediments in this area of the river during Quarters 3 and 4 of 2009 (GSI 2010b). A total of 13 samples were collected and analyzed from this sampling event; one sediment trap (ST007) was not recovered during Quarter 4.

The samples were analyzed to measure the sediment trap mass accumulation and concentrations of sediment-bound contaminants that enter the study area from upstream sources, contaminant concentrations associated with regional sources within the study area, and concentrations of sediment-bound contaminants that migrate downstream from the study area. Additional information on the lower Willamette River hydrology, sediment accumulation, and the role of fine sediments provided to aid with interpretation of the chemical data is presented in Figures 5.3-18a-b through 5.3-21a-b. Distributions of the indicator contaminants are shown in Figures 5.3-1a-b through 5.3-15a-b and are summarized in Tables 5.3-1 through 5.3-7.

5.3.2 River Conditions During Sampling Events

Hydrologic data used to assess flow patterns during sampling were obtained from the USGS stream flow station located upstream of the Morrison Bridge (Willamette River at Portland, gage no. 14211720). The stream flows measured during the sampling events are presented in Figures 5.3-19a-b. The highest flows during sampling occurred during Quarter 1 (November and December 2006) of the 2006/2007 sampling event, with a median daily discharge of 79,000 cfs (Figure 5.3-19a). This period was characterized by variable flows, reaching twice the historical average discharge during a number of separate events. Lower than normal discharge periods (up to 60 percent of average) occurred twice during the month of December 2009, only to be followed by higher than normal flows (up to 50 percent of average) in early January 2010. The discharge record for Quarters 2 and 3 of the 2006/2007 (February through August 2007) sampling event (median discharges of 31,000 cfs and 10,000 cfs, respectively) did not demonstrate the variability that characterized Quarter 1 of the 2006/2007 sampling

event. In general, sampling during Quarters 2 and 3, and at least a portion of Quarter 4, of the 2006/2007 sampling event, and Quarter 3 of the 2009 sampling event (median discharge of 11,000 cfs), occurred during river flows that were very similar to historical averages. Discharge data from the last half of Quarter 4 of the 2006/2007 sampling event (October 2007 through mid-November 2007) are considered estimates due to uncertainty about the accuracy of the rating curve used at the Portland location for flows less than 20,000 cfs.

5.3.3 Rates of Sediment Accumulation

Net sediment accumulation rates at each station/quarter were calculated from the height of the sediment column in the traps and from the specific gravity and moisture content of the material. Sediment accumulation rates for each sediment trap are shown in Figures 5.3-21a-b. The highest rates of accumulation occurred during Quarter 1 of the 2006/2007 sampling event, with the largest accumulation in the sediment traps placed at RM 11.3 and 15.6 (Figures 5.3-21a-b); sediment accumulation rates were lower in the sediment traps placed downstream of RM 11.3. Because density measurements were only taken during the 2006/2007 sampling event, only those data were used to determine an average density of 1.22 g/cm^2/day to calculate accumulation rates for the 2009 sampling event (Figure 5.3-21b). Traps were lost at stations ST014 (RM 7.5), ST006 (Swan Island Lagoon), and ST016 (RM 9.9) during Quarter 1 of the 2006/2007 sampling event, so information regarding sediment accumulation is not available for these samples.

Medium-coarse silt made up approximately 50 percent of the trapped material during each quarter of the 2006/2007 sampling event, although the highest sediment accumulation rates generally corresponded with a comparatively low percentage of fine material in the sediment traps. Grain size data are only available for one sediment trap sample (ST001) in Quarter 3 of the 2009 sampling event and six sediment traps (ST001 through ST006) in Quarter 4. Figure 5.3-16 shows rates of accumulation as a function of percent fines. Trend lines shown for the data set as a whole ($R^2 = 0.38$), as well as for the individual quarters (R^2 ranging from 0.0063 to 0.79), suggest inverse linear relationships between accumulation rates and percent fines for this data set are weak. TOC showed relatively small differences among samples, with concentrations ranging from 1.1 to 3.5 percent. The majority of the measured TOC values, approximately 75 percent, range between 2 and 3 percent (Appendix D2.1, Figures D2.1-23a-b).

Because sediment trap samples do not constitute temporally discrete samples (i.e., they represent a continuous collection over a 3-month period), river conditions during sampling can only be discussed meaningfully in seasonal terms. Accumulation rates of trapped sediment may have been substantially affected by instantaneous events, such as high water resulting from heavy rainfall, but the impact of these isolated events cannot be quantified based on the existing data or the sampling methodology employed. Further, there were instances in which sediment traps found to contain insufficient accumulated material for analysis were redeployed with the previous quarter's deposited material. In two cases (ST001 Quarter 3, and ST013 Quarter 3), traps

retrieved in the following quarter were found to have a shorter column of sediment in them than they had when they were initially deployed (Table 5.3-1). In the case of ST013, a quarterly deposition rate of zero was used in Quarter 3 data presentations.

Figures 5.3-18a-b display the grain size distributions for all sediment trap samples analyzed. Samples from each station generally showed similar grain size distributions, except for an increase in the coarse-grained fraction (i.e., sand) during the winter quarter (Quarter 1) at stations ST008, ST009, and ST010, and during the fall quarter (Quarter 4) at ST007 during the 2006/2007 sampling event. Trends cannot be established for the trap data collected during the 2009 sampling event due to the lack of information in Quarter 3. The higher rate of sediment accumulation and the entrainment of sandy material in the sediment traps placed between RM 11.5 and 15.7 during Quarter 1 of the 2006/2007 sampling event and Quarter 4 of the 2009 sampling event may be due in part to the frequency of higher flow events that occurred during this period (Figures 5.3-20a-b). The distribution of flows shows that the highest daily flows during 2006/2007 Quarter 2 and 2009 Quarter 4 were approximately the same as median 2006/2007 Quarter 1 flows. Approximately 75 percent of the 2006/2007 Quarter 1 daily discharge levels were higher than any of those recorded during 2006/2007 Quarters 3 and 4 and 2009 Quarter 3. A lower accumulation of trapped sediments, particularly at upriver stations, occurred during 2006/2007 Quarters 3 and 4 and 2009 Quarter 3 when comparatively low-flow events were typical.

5.3.4 Total PCBs in Mobile Sediment

PCB congener analysis was conducted for all 65 sediment trap samples; 60 of these samples were also analyzed for PCB Aroclors (Tables 5.3-2 through 5.3-7). PCB congeners were detected in all 52 samples, with total PCB congener concentrations ranging from 0.925 J to 11,100 J µg/kg (Figures 5.3-1a-b). PCB Aroclors were detected in 41 of the 60 samples analyzed, with total Aroclor concentrations ranging from 3.1 U to 2,600 µg/kg (Figures 5.3-2a-b).

The relationship between total PCB congener and total PCB Aroclor concentrations is shown in Figure 5.3-17 and discussed in detail in Appendix D1.4. The sediment trap correlation between paired congener and Aroclor totals is r^2=0.7. Although the PCB concentrations in sediment trap samples correlated well for the two methods, concentrations of total PCBs measured as congeners were higher overall than total PCBs measured as Aroclors. The methods used for analysis of PCB congeners and Aroclors are fundamentally different and would be expected to yield moderate differences in total PCBs concentrations, as described in Appendix D1.4. In addition, among detected Aroclor results for the sediment trap samples about one-third of the individual concentrations (19 of 60 results) were below the method reporting limit (MRL).

5.3.4.1 Total PCBs Spatial and Temporal Evaluation in Study Area

The total PCBs concentrations varied by 3 orders of magnitude throughout the site. PCB congener concentrations were the highest in sediment traps located in the vicinity of

RM 11.3E (ST007 measured in 2006/2007 and ST003 measured in 2009) compared to other locations (Figures 5.3-1a-b). The greatest sample concentration (11,100 µg/kg) was measured in the fourth quarter of 2007. PCB congener concentrations at Station ST007 during low- and medium-flow periods (Quarters 2, 3, and 4) of the 2006/2007 sampling event were elevated 2 to 3 orders of magnitude above concentrations at other locations for the respective periods. Other significant peaks are noted in 2009 at ST001 and ST002 just downstream of ST003, and in 2007 offshore of Fireboat Cove (ST015; RM 9.7W), in Swan Island Lagoon (ST006), and in Willamette Cove (ST013; RM 6.7E). PCB Aroclors show the same notable peaks at ST013, ST006, and ST007 (2006/2007 data set) and ST003 (2009 data set) as shown in Figures 5.3-2a-b.

During the 2006/2007 sampling event, increasing concentrations generally occurred with each successive period at all stations except ST002 (RM 1.8W) and ST011 (RM 3.5 E), a trend that was clear in the PCB congener data but not apparent for Aroclors (Figures 5.3-2a-b). The lack of an apparent trend with Aroclors is possibly due to higher detection limits for Aroclors resulting in a lower number of samples with detectable Aroclor concentrations. The 2009 data show the same temporal pattern, as Quarter 3 of the 2009 data set approximately corresponds in season to Quarter 4 of the 2006/2007 data set, and Quarter 4 corresponds to Quarter 1 of the 2006/2007 data set.

Figures 5.3-1a and 5.3-2a show that concentrations in sediment traps are generally greater on the eastern shore of the river than the western shore. Concentrations also are greatest in sediment traps deployed at the upper end of the study area and show an apparent decreasing pattern in the downstream direction. There are two major exceptions to this observation at the upper end of the study area. The first is the sequence of sediment traps in the eastern nearshore area from RM 11.3, 9.9, and 6.7 (ST007, ST006, and ST013) where the concentrations go from extremely high, to extremely low and then peak again before gradually decreasing through the study area. Conversely, the sequence of sediment traps in the western nearshore area from RM 11.5, 9.7, and 7.5 (ST008, ST015, and ST014) show the concentration go from extremely low, to extremely high, and then show a decreasing pattern through the study area. Both Aroclors and PCB congeners show these patterns.

The 2009 data are limited to the eastern nearshore area from RM 11.1 to 12.2. These sediment traps show that concentrations are generally the same in the upper river traps (ST007, ST006, and ST005) and then increase in trap ST004 before spiking in trap ST003 and then decreasing in ST002 and ST001. This pattern seems to show that there is a lateral and/or a bedded sediment source of elevated PCBs in the vicinity of ST004 and ST003 that is influencing the concentration of the mobile sediments in those traps and the traps immediately downstream (ST002 and ST001). Both Aroclors and PCB congeners show this pattern.

Also, the lowest concentrations from the 2006/2007 event were observed during the higher river flows (Figures 5.3-19a-b and 5.3-20a-b) in Quarters 1 and 2; however, this period had the most accumulation in the traps (Figure 5.3-21a), suggesting that

localized suspended sediments with elevated PCB levels are diluted by inputs of cleaner suspended sediment deposited during river higher flows. During the summer period (Quarter 3), the river flows and sediment accumulation are the lowest, but the concentrations were the second highest. This observation suggests more influence of the localized elevated suspended sediment levels on the material being deposited in the traps during low flows. The highest concentrations occurred when the river flows transitioned from low flow and were beginning to increase due to increasing storm events (late summer into fall). The accumulation in the traps during this time period is still quite low, suggesting that this is the period when the highest relative percentage of the more contaminated sediment is being mobilized.

5.3.4.2 Total PCBs Relationship by River Reach

Total PCB congener concentrations in the study area samples were all higher than the average PCB concentrations from upstream locations (ST009 and ST010)—1-to-5 fold greater than upstream concentrations, in most cases. These trends were generally also reflected in the Aroclor data. The downstream total PCBs concentrations (ST001 and ST002) are generally the same as the concentrations observed in Multnomah Channel (ST003) and seem to be approaching upriver concentrations, although the total PCB congener concentrations are about 2-fold higher. The concentrations entering the site, at least in the eastern nearshore region (ST005, ST006, and ST007 of the 2009 data set) are similar in concentration to the upriver sediment traps (ST009 and ST010) indicating that for the time periods measured, the downtown reach has little to no influence on the incoming depositional sediment concentrations.

5.3.5 Total PCDD/Fs and TCDD TEQ in Mobile Sediment

Total PCDD/Fs and TCDD TEQ analysis was conducted for 60 sediment trap samples (Tables 5.3-2 through 5.3-7). Total PCDD/Fs were detected in all 60 samples, with concentrations ranging from 5.16 J to 6,100 pg/g. TCDD TEQs were also detected in all 60 samples analyzed, with concentrations ranging from 0.0529 J to 16.3 J pg/g.

5.3.5.1 Total PCDD/Fs Spatial and Temporal Evaluation in Study Area

The highest total PCDD/Fs concentration (6,100 J pg/g) occurred during Quarter 4 of the 2006/2007 sampling event at ST006 (Swan Island Lagoon) (Figures 5.3-3a-b). This sample was elevated 1 to 2 orders of magnitude above concentrations at most other locations. However, a temporal evaluation of PCDD/Fs at ST006 could not be conducted as no samples from previous quarters were analyzed for total PCDD/Fs at this location. Additional total PCDD/Fs peaks of 1,820 J and 1,250 J pg/g occurred during Quarter 3 of the 2006/2007 sampling event at ST007 (RM 11.3E) and at ST002 (RM 1.8W), respectively. Relatively high concentrations were also seen in Quarter 4 samples of the 2006/2007 sampling event in traps ST014 (RM 7.5W; 1,060 J pg/g) and ST007 (745 J pg/g), and Quarter 1 samples of the 2006/2007 sampling event in traps ST001 (RM 1.9E; 563 pg/g) and ST011 (RM 3.5E; 535 pg/g).

Total PCDD/Fs concentrations were greatest in Quarter 3 of the 2009 data set, with the highest concentration (1,640 pg/g) in sediment trap ST001 at RM 11E followed by traps ST004 (RM 11.5E; 1,280 pg/g), ST003 (RM 11.3E; 1,120 pg/g), and ST006 (RM 11.8E; 900 pg/g). Relatively high concentrations were also seen in Quarter 4 of the 2009 sampling event in trap ST005 (RM 11.8E; 879 J pg/g). The lower flow period (Quarter 3) concentrations in the 2009 data set are consistently greater than the higher flow period (Quarter 4) concentrations, suggesting that the concentration at ST005 during Quarter 3 may have had the greatest sample concentration in this area.

Samples collected in the 2006/2007 sampling event with total PCDD/Fs concentrations greater than 500 pg/g are observed in ST001 (RM 1.9E) and ST011 (RM 3.5E) during Quarter 1; ST002 (RM 1.8W) and ST007 (RM 11.3E) during Quarter 3; and ST014 (RM 7.5W), ST006 (Swan Island Lagoon), and ST007 (RM 11.3E) during Quarter 4.

There is no consistent spatial gradient or trend in total PCDD/Fs concentrations throughout the river, indicating that concentrations measured in sediment traps are more representative of localized sediments. The highest total PCDD/Fs concentrations among stations generally occurred during Quarters 4 and 3. Stations ST007 and ST009 in the eastern nearshore zone at RM 11 and 15 contained higher total PCDD/Fs than ST008 and ST010 placed at similar river miles in the western nearshore zone throughout the 2006/2007 sampling period. These results indicate that solids collected in the traps in this portion of the river in part reflect localized inputs specific to the eastern or western nearshore zones rather than being representative of river-wide mobile sediments.

5.3.5.2 TCDD TEQ Spatial and Temporal Evaluation in Study Area

The highest TCDD TEQ was found in the Quarter 4 sample of the 2006/2007 sampling event in trap ST006 (Swan Island Lagoon) (Figures 5.3-4a-b). As with total PCDD/Fs, Quarter 4 was the only time TCDD TEQs were analyzed at this location so it is difficult to gauge the occurrence of similar TCDD TEQ concentrations during other periods. TCDD TEQs greater than 1 pg/g were measured during the 2006/2007 sampling event at ST001 (RM 1.9E), ST011 (RM 3.5E), and ST005 (RM 6.0W) during Quarter 1; ST002 (RM 6.0W) during Quarter 2; ST002 (RM 1.8W) and ST007 (RM 11.3E) during Quarter 3; and ST014 (RM 7.5W), ST006 (Swan Island Lagoon), ST007 (RM 11.3E) during Quarter 4. During Quarter 3 of the 2009 sampling event, TCDD TEQ values greater than 1 pg/g occurred in all sediment traps except ST002 and were not analyzed in ST005. TCDD TEQ values greater than 1 pg/g were also present in Quarter 4 of the 2009 sampling event in traps ST004 and ST0005. TCDD TEQ spatial and temporal patterns were similar to total PCDD/Fs patterns.

5.3.5.3 Total PCDD/Fs and TCDD TEQ Relationship by River Reach

Study area locations generally had total PCDD/Fs and TCDD TEQ concentrations higher than concentrations from the upstream locations. However, total PCDD/Fs and TCDD TEQ concentrations from the two upstream locations were not similar to each other, with concentrations from ST009 (RM 15.7E) averaging more than 6 times those

from ST010 (RM 15.6W). Some ST009 samples had comparatively higher total PCDD/Fs and TCDD TEQ concentrations than concurrently sampled study area locations during the same quarters (Figures 5.3-3a and 5.3-4a).

Total PCDD/Fs and TCDD TEQ concentrations in the downstream reach were elevated above the upriver sediment traps (ST009 and ST010) at ST001 (RM 1.9E) and ST002 (RM 1.8W). Total PCDD/Fs and TCDD TEQ in the study area reach were also elevated above the upriver traps at traps ST011 (RM 3.5E), ST014 (RM 7.5W), ST006 (Swan Island Lagoon), and ST007 (RM 11.3E). Total PCDD/Fs in the study area were also elevated above the upriver traps at ST005 (RM 6.0W).

Total PCDD/Fs concentrations downstream of the study area were greater in Multnomah Channel (ST003) during Quarter 4 of the 2006/2007 sampling event than in the lower study area (RM 3.5 to 7.5). TCDD TEQ concentrations were also elevated in this sample. Mobile sediments were also greater downstream at ST002 (RM 1.8W) during Quarter 3 of the 2006/2007 sampling event than anywhere else below RM 11.3E (ST007) in the main channel, and at ST001 (RM 1.9E) during Quarter 1 of the 2006/2007 sampling event than anywhere in the main channel of the study area.

5.3.6 DDx in Mobile Sediment

DDx analysis was conducted for 63 sediment trap samples (Tables 5.3-2 through 5.3-7). DDx compounds were detected in all but two sediment trap samples. Concentrations of DDx ranged from 0.69 to 150 µg/kg in samples with detectable concentrations.

5.3.6.1 DDx Spatial and Temporal Evaluation in Study Area

The highest DDx concentration (150 µg/kg) occurred during Quarter 4 of the 2006/2007 sampling event at ST007 (RM 11.3E) and was approximately 5 times higher than the next highest sample. DDx concentrations greater than 10 µg/kg are observed in sediment traps ST007 (RM 11.3E), ST006 (Swan Island Lagoon), ST011 (RM 3.5E), and ST014 (RM 7.5W) during Quarter 3 of the 2006/2007 sampling event. During Quarter 4 of the 2006/2007 sampling event, peak DDx concentrations are observed in traps ST007 (RM 11.3E), ST006 (Swan Island Lagoon), ST004 (RM 6.0E), ST015 (RM 9.7W), ST014 (RM 7.5W), ST005 (RM 6.0W), and ST012 (RM 4.5W). DDx concentrations greater than 10 µg/kg occurred in the 2009 sampling event in trap ST001 (RM 11E) during Quarter 3 and trap ST003 (RM 11.3E) during Quarters 3 and 4.

At most locations in 2006/2007, DDx concentrations were highest during Quarter 4 from mid-August to mid-November. In 2009, DDx concentrations were also highest during Quarter 4, although the time frame was mid-September to mid-January for that sampling event (Figures 5.3-5a-b). However, both Quarter 4 sampling events caught the rising limb of the hydrograph (Figures 5.3-19a-b), suggesting elevated levels of DDx on suspended sediments enter the river system during periods of increasing precipitation. The spatial patterns of sediment trap data from the study area indicate inputs of elevated DDx sediment at RM 11.3E and at RM 6E, which may also be the downstream deposition of sediments from RM 11.3. Elevated levels of DDx in

suspended sediments are also observed in Swan Island Lagoon. In the western nearshore zone, elevated concentrations are evident at RM 6.0W and 7.5W. Less prominent elevated concentrations are observed at RM 9.7W and 4.5W.

Patterns of relative concentrations of DDx constituents among samples are somewhat confounded by elevated detection limits and interferences. Detection limits were elevated in 18 percent of the samples, and another 4 percent were classified as non-detects due to contamination in the associated laboratory or field blanks (Anchor and Integral 2008c). The elevated detection limits could obscure low concentrations of DDx. In addition, 37 percent of the results were qualified as tentatively identified and estimated (NJ) during data validation due to poor confirmation, and another 49 percent were estimated (J) as a result of the confirmation data.

5.3.6.2 DDx Relationship by River Reach

DDx concentrations in study area samples were generally higher than those from upstream locations. Overall, 24 of the 63 (38 percent) study area samples had higher DDx concentrations than the maximum concentration from upstream samples. Differences between study area and upstream samples were most pronounced during Quarters 3 and 4 of both the 2006/2007 and 2009 sampling events. By contrast, study area samples from the first two quarters had DDx concentrations that are only nominally higher than the concentrations observed in the upstream samples.

Concentrations of DDx in the downstream reach at ST001 (RM 1.9E) were elevated above the upriver sediment traps (ST009 and ST010); however, ST002 (RM 1.8W) concentrations seemed consistent with the upriver concentrations. DDx in all the study area reach traps were also elevated above the upriver traps except traps ST016 (RM 9.9E) and ST013 (RM 6.7E).

DDx concentrations in Multnomah Channel (ST003) during the 2006/2007 sampling event were lower than or about the same as in the study area. Mobile sediments were also lower downstream at ST002 (RM 1.8W) than at ST001 (RM 1.9E) or ST003 (Multnomah Channel).

5.3.7 Total PAHs in Mobile Sediment

Total PAHs analysis was conducted for 62 sediment trap samples (Tables 5.3-2 through 5.3-7). PAHs were detected in all samples analyzed, with concentrations of total PAHs ranging from 77 J to 11,000 µg/kg.

5.3.7.1 Total PAHs Spatial and Temporal Evaluation in Study Area

Total PAHs concentrations varied by over 2 orders of magnitude throughout the site. Concentrations were the highest in sediment traps located in the vicinity of RM 6.0W (ST005 measured in 2006/2007) compared to other locations (Figures 5.3-6a-b). The highest concentration (11,000 µg/kg) was measured in the fourth quarter of 2007. Other elevated levels (greater than or equal to 1,000 µg/kg) are noted in 2007 at ST006 (Swan Island Lagoon), ST014 (RM 7.5W), ST004 (RM 6.0E), ST011 (RM 3.5E), ST014

(RM 7.5W), ST012 (RM 4.5W), and in 2009 at ST001 and ST003 within RM 11E and 11.3E.

During the 2006/2007 sampling event, the highest total PAHs concentrations within stations tended to occur during Quarters 3 and 4, but additional seasonal differences among stations were not apparent. The lack of an apparent trend is possibly due to the lack of samples collected for every quarter at all stations. The 2009 data set also shows the lack of a trend where some samples are greater in Quarter 3 while others are greater in Quarter 4.

Figure 5.3-6a shows that concentrations in sediment traps are generally greater on the western shore of the river than the eastern shore. Concentrations also are greatest in sediment traps deployed at the middle of the study area and are generally higher downstream of this area compared with upstream.

The 2009 data are limited to the eastern nearshore area from RM 11.1 to 12.2. These sediment traps show that concentrations vary throughout the area. This pattern seems to show that there may be localized sediment contamination that is influencing the concentration of the mobile sediments in this area.

Also, the lowest concentrations were observed during the higher river flows (Figures 5.3-19a-b and 5.3-20a-b) in Quarters 1 and 2 of the 2006/2007 sampling event; however, this period had the most accumulation in the traps (Figure 5.3-21a), suggesting that localized inputs are diluted by the larger volume of cleaner material being transported and deposited during higher river flows. During the summer period (Quarter 3), the river flows and sediment accumulation are the lowest, but the concentrations were the second highest. This pattern suggests that there is more localized influence on the material being deposited during low flow periods. The highest concentrations occurred when the river flows transitioned from low flow and were beginning to increase due to increasing storm events (late summer into fall). However, the accumulation in the traps during this time period is still quite low, suggesting that this is the period when more contaminated sediments are being mobilized in (resuspended bed material) and adjacent (e.g., stormwater discharge) to the site.

5.3.7.2 Total PAHs Relationship by River Reach

Total PAHs concentrations were greater upriver in ST010 (RM 15.6W) during Quarter 1 of the 2006/2007 sampling event than all other samples, except ST005 (RM 6.0W). Overall, 32 of the 34 (94 percent) study area samples had total PAHs concentrations higher than concurrent samples from upstream locations, with the exception of Quarter 1, where the total PAHs concentration of upstream sample ST010 (1,300 µg/kg) was higher than all but one study area sample (ST005). Generally, concentrations in the study area were within an order of magnitude of the upriver concentrations, with the exception of samples collected at ST005 (RM 6.0W) where concentrations were up to 40 times the upriver concentrations.

Samples in the upper reaches (RM 8 to 11.8) of the study area are consistent with samples collected upriver, although the 2009 data indicate that there are relatively high total PAHs levels in the vicinity of RM 11E. The 2009 data also show that there is variability in localized areas of the site (Figure 5.3-6b), with concentrations ranging by a factor of 5 within the river mile. The downstream total PAHs concentrations (ST001 and ST002) range from about 2 to 4 fold higher than the upriver concentrations. In general, total PAHs concentrations were higher at locations between RM 3 and 6, including Multnomah Channel (ST003), which had a relatively high Quarter 4 level (2,300 J µg/kg), than in other sampled locations (Figure 5.3-6a).

5.3.8 Bis(2-ethylhexyl)phthalate in Mobile Sediment

BEHP analysis was conducted for 61 sediment trap samples (Tables 5.3-2 through 5.3-7). BEHP was detected in all samples analyzed at concentrations ranging from 35 to 1,600 µg/kg.

5.3.8.1 BEHP Spatial and Temporal Evaluation in Study Area

BEHP concentrations varied by 2 orders of magnitude throughout the site. BEHP concentrations were greatest during Quarters 3 and 4 of the 2006/2007 sampling event (1,600 and 710 µg/kg) at ST006 (Swan Island Lagoon), although samples were not analyzed at ST006 during Quarters 1 and 2 (Figure 5.3-7a). High concentrations were also noted at ST007 (RM 11.3E) during Quarters 2, 3, and 4, and ST015 (RM 9.7W) during Quarter 4. Concentrations throughout the site were generally less than 250 µg/kg, except as noted above, and varied most during Quarter 4 of the 2006/2007 sampling event, with values ranging by a factor of 4 (excluding the high concentrations noted above). There is no observable spatial or temporal trend in the concentrations of BEHP throughout the site.

Concentrations measured in the 2009 sampling event (Tables 5.3-6 and 5.3-7; Figure 5.3-7b) reveal that concentrations in localized areas of the site vary widely. Concentrations in Quarter 3 varied by a factor of 5, while concentrations in Quarter 4 varied by a factor of 3. Relatively high concentrations (greater than 250 µg/kg) are noted in ST002, ST006, and ST007 during Quarter 3, and ST001, ST002, ST003, ST005, and ST006 during Quarter 4.

5.3.8.2 BEHP Relationship by River Reach

Upstream BEHP concentrations at ST009 (RM 15.7E) and ST010 (RM 15.6W) were generally lower than study area locations during concurrent sampling. During Quarter 4, however, the BEHP concentration at ST010 (480 J µg/kg) was higher than at all study area locations except ST006 (Figure 5.3-7a). Quarter 3 also showed a higher upriver concentration in ST009 (210 µg/kg) than at ST004 (81 µg/kg) and ST012 (150 µg/kg).

Concentrations in the downstream traps (ST001 and ST002) and in Multnomah Channel (ST003) were lower than concurrent study area traps. In Quarters 1 and 2, the downstream traps show that mobile concentrations were at or approaching upriver

concentrations. During Quarters 3 and 4, the downstream traps had lower concentrations than the upriver traps.

5.3.9 Total Chlordanes in Mobile Sediment

One or more chlordanes were detected in 37 of the 63 samples analyzed (Tables 5.3-2 through 5.3-7). Detectable concentrations of total chlordanes ranged from 0.22 J to 3.7 NJ µg/kg. Extremely high reporting limits for non-detects are noted in trap ST007 during Quarters 3 and 4 of the 2006/2007 sampling event (98 and 460 µg/kg, respectively) and in trap ST003 during Quarter 4 of the 2009 sampling event (86 µg/kg). Detection limits were also notably high in traps ST001 and ST003 during Quarter 3 of the 2009 sampling event (3.2 and 4.3 µg/kg, respectively). These elevated non-detects appear to be due to matrix interferences. These samples all had relatively high PCB levels, which may have interfered with the pesticide quantification.

5.3.9.1 Total Chlordanes Spatial and Temporal Evaluation in Study Area

The highest detected total chlordanes concentration was found at ST008 (RM 11.5W) during Quarter 1 (Figures 5.3-8a-b). Other comparatively high detected concentrations (>3 µg/kg) were found during Quarter 4 at ST011 (RM 3.5E) and during Quarter 3 at ST006 (Swan Island Lagoon). Total chlordanes concentrations were highly variable within and among locations and within and among seasons. Higher concentrations were noted in Quarters 1, 3, and 4 of the 2006/2007 sampling event than in Quarter 2. Although west-side samples had higher levels during Quarter 1 than east-side sediment traps, variations in data were difficult to assess due to the number of non-detects and the vast range of reporting limits. Therefore, spatial and seasonal gradients or trends were not apparent.

5.3.9.2 Total Chlordanes Relationship by River Reach

Overall, study area total chlordanes concentrations were higher than upstream concentrations. The maximum total chlordanes concentration in upstream samples was 1 NJ µg/kg, whereas 9 of the 14 study area stations had at least 1 sample with greater than 1 µg/kg total chlordanes. Only one downstream sample in ST002 had a concentration greater than 1 µg/kg.

5.3.10 Aldrin and Dieldrin in Mobile Sediment

Aldrin and dieldrin, two closely related organochlorine pesticides, were analyzed in 63 samples. Aldrin was detected in seven samples and dieldrin was detected in six samples (Tables 5.3-2 through 5.3-7). Only one of the samples analyzed contained detectable levels of both aldrin and dieldrin for the same sample (the 2009 Quarter 4 sample at ST004, RM 11.5E). Extremely high reporting limits for non-detects are noted for the 2006/2007 sampling event in trap ST008 during Quarter 1 for both aldrin and dieldrin (1.6 and 3 µg/kg, respectively), traps ST004 and ST007 during Quarter 3 for dieldrin (1.1 and 13 µg/kg), and in trap ST006 during Quarter 4 for aldrin (1.2 µg/kg). All other non-detected values were less than 1 µg/kg.

The detected concentrations of aldrin ranged from 0.11 J to 1.1 NJ µg/kg (Figures 5.3-9a-b), with the highest concentration found at Station ST005 (RM 6W). Two of the detected aldrin samples were at downstream locations ST001 (RM 1.9E) and ST003 (Multnomah Channel). Detected dieldrin concentrations were more variable (Figures 5.3-10a-b), with concentrations ranging from 0.15 NJ µg/kg to a maximum of 4.9 µg/kg at ST006 (Swan Island Lagoon). Two of the six dieldrin detections were at the upstream location ST009 (RM 15.7E) and one was downstream at ST003 (in Multnomah Channel).

5.3.10.1 Aldrin and Dieldrin Spatial and Temporal Evaluation in Study Area

There were five detected values for aldrin within the study area. Two aldrin detections occurred during Quarter 1 of the 2006/2007 sampling event at ST005 (RM 6.0W) and ST012 (RM 4.5W), one detection occurred during Quarter 4 of the 2006/2007 sampling event at ST014 (RM 7.5W), and two detections occurred during Quarter 4 of the 2009 sampling event at ST002 (RM 11.1E) and ST004 (RM 11.5E).

There were three detectable dieldrin concentrations within the study area. Two were measured during Quarter 3 of the 2006/2007 sampling event at ST006 (Swan Island Lagoon) and ST011 (RM 3.5E), and one was measured in Quarter 4 of 2009 at ST004 (RM 11.5E).

The infrequency of detections did not allow for assessment of a possible geographical concentration gradient or trend. However, detected aldrin concentrations occurred primarily at or below RM 7.5 in the western nearshore zone, while dieldrin was detected primarily in the eastern nearshore zone.

5.3.10.2 Aldrin and Dieldrin Relationship by River Reach

Aldrin was not detected in upriver samples, but was detected in two downstream samples, ST001 (RM 1.9E) and ST003 (Multnomah Channel) during Quarter 1 of the 2006/2007 sampling event. Dieldrin was detected upriver at ST009 (RM 15.7E) during both Quarters 3 and 4 of the 2006/2007 sampling event, but was only detected downstream at ST003 (Multnomah Channel) during Quarter 4. There were not enough data to determine any relationship for aldrin and dieldrin between river reaches.

5.3.11 Arsenic in Mobile Sediment

Arsenic was detected in all 62 samples analyzed at concentrations ranging from 1.48 J to 7.01 mg/kg (Tables 5.3-2 through 5.3-7).

5.3.11.1 Arsenic Spatial and Temporal Evaluation in Study Area

There was relatively little variation in concentrations among samples within the study area, with values ranging between 2.75 and 7.01 mg/kg (Figures 5.3-11a-b). The highest arsenic concentration was found at Station ST011 (RM 3.5E) during Quarter 4 of the 2006/2007 sampling event. The highest levels were generally found during Quarter 4, particularly downstream of RM 9, although Quarter 2 showed equally high levels in the upper study area (RM 9.7–11.5).

5.3.11.2 Arsenic Relationship by River Reach

Most concentrations of arsenic from study area stations were similar to or slightly above arsenic concentrations in upriver locations. Arsenic levels in study area samples rarely varied from the arsenic levels at upstream stations by more than a factor of 2. Downstream samples had similar concentrations to those in the study area, and were also generally greater than the upriver samples by a factor of 2.

5.3.12 Chromium in Mobile Sediment

Chromium was detected in all 62 samples analyzed at concentrations ranging from 10.8 J to 59.5 mg/kg (Tables 5.3-2 through 5.3-7).

5.3.12.1 Chromium Spatial and Temporal Evaluation in Study Area

There was relatively little variation in concentrations among samples within the study area, with values ranging between 16.8 and 47.1 mg/kg (Figures 5.3-12a-b). The highest chromium concentration in the study area was found during Quarter 1 of the 2006/2007 sampling event at Station ST013 (RM 6.7E). The highest concentrations within stations also tended to occur during Quarter 1. The only other sample collected within the study area greater than 40 mg/kg was at ST006 (Swan Island Lagoon) during Quarter 3 of the 2006/2007 sampling event. The majority of the 2009 data set had concentrations less than 30 mg/kg. There were no locations with levels of chromium consistently higher than all others, and there was little variability between samples collected on either shore of the river.

5.3.12.2 Chromium Relationship by River Reach

Although the highest chromium concentration was found in ST009 (RM 15.7E) in the upriver reach during Quarter 3 of the 2006/2007 sampling event, the majority of samples in this reach range between 30 and 40 mg/kg. Likewise, most chromium concentrations from study area stations were within the range of samples typically found in the upriver reach. Downstream samples ranged from 16.8 J to 40.4 mg/kg with the majority of values also typically within the 30–40 mg/kg range.

5.3.13 Copper in Mobile Sediment

Copper was detected in all 62 samples analyzed at concentrations ranging from 15.2 to 93.6 mg/kg (Tables 5.3-2 through 5.3-7). There was relatively little variation in concentrations among samples, with the majority of the values within a factor of 3.

5.3.13.1 Copper Spatial and Temporal Evaluation in Study Area

The highest copper concentration was found at Station ST006 (Swan Island Lagoon) during Quarter 3 of the 2006/2007 sampling event (Figures 5.3-13a-b). The highest concentrations among sampling periods per station often occurred during Quarter 4 of the 2006/2007 sampling event, particularly at stations from RM 3.5 through 6.7. The majority of samples collected in Quarter 4 were greater than 50 mg/kg, while the majority of samples collected in other quarters were generally between 30 and 50 mg/kg. All samples collected during the 2009 sampling event were less than

43 mg/kg. Samples greater than 50 mg/kg are noted from the 2006/2007 sampling event during Quarter 1 at ST013 (RM 6.7E), during Quarter 2 at ST004 (RM 6.0E) and ST013 (RM 6.7E), during Quarter 3 at ST006 (Swan Island Lagoon) and ST011 (RM 3.5E), and during Quarter 4 at ST004 (RM 6.0E), ST005 (RM 6.0W), ST006 (Swan Island Lagoon), ST007 (RM 11.3E), ST011 (RM 3.5E), ST012 (RM 4.5W), and ST013 (RM 6.7E).

5.3.13.2 Copper Relationship by River Reach

Although the second highest copper concentration was found in a sample from one of the upstream locations (ST009) during Quarter 3 of the 2006/2007 sampling event, the majority of samples in this reach are less than 43 mg/kg. Most copper concentrations from study area stations were slightly above upriver copper concentrations collected during the same time period, except during Quarter 3, as mentioned above. Copper levels in study area samples rarely varied from the copper levels at upstream stations by more than a factor of 2. Downstream samples ranged from 25.1 to 52.4 mg/kg, which is similar to the majority of samples measured in the study area.

5.3.14 Zinc in Mobile Sediment

Zinc was detected in all 62 samples analyzed at concentrations ranging from 71.5 to 319 mg/kg (Tables 5.3-2 through 5.3-7). There was relatively little variation in concentrations among samples, with concentrations being within a factor of 3.

5.3.14.1 Zinc Spatial and Temporal Evaluation in Study Area

The highest zinc concentration was found during Quarter 3 of the 2006/2007 sampling event at Station ST006 (Swan Island Lagoon). ST006 was the only station that appeared to contain comparatively high localized concentrations, although only data from two quarters were available from this location. Among sampling periods (Figures 5.3-14a-b), the highest zinc concentrations per station most often occurred during Quarter 4 of the 2006/2007 sampling event. Quarter 4 of the 2009 sampling event generally had the lowest zinc levels among sampling periods. The majority of samples collected were less than 140 mg/kg. Samples greater than 140 mg/kg are noted from the 2006/2007 sampling event during Quarter 2 at ST015 (RM 9.7W), during Quarter 3 at ST006 (Swan Island Lagoon) and ST011 (RM 3.5E), and during Quarter 4 at ST004 (RM 6.0E), ST005 (RM 6.0W), ST006 (Swan Island Lagoon), ST007 (RM 11.3E), ST011 (RM 3.5E), ST012 (RM 4.5W), ST013 (RM 6.7E), ST015 (RM 9.7W) and ST016 (RM 9.9E).

5.3.14.2 Zinc Relationship by River Reach

Most concentrations of zinc from study area stations were slightly above zinc concentrations in upriver locations, except during Quarter 3 of the 2006/2007 sampling event. Zinc levels in study area samples rarely varied from the zinc levels at upstream stations by more than a factor of 2 during the same sampling period. Downstream samples ranged from 101 to 160 mg/kg, with higher concentrations in downstream stations ST001 and ST002 during Quarter 4 of the 2006/2007 sampling event. Samples

collected downstream during Quarters 1, 2, and 3 and those collected in Multnomah Channel are similar to the majority of samples measured in the study area, but slightly higher than upriver samples.

5.3.15 Tributyltin Ion in Mobile Sediment

TBT analysis was conducted for 60 sediment trap samples (Tables 5.3-2 through 5.3-7). TBT was detected in 46 of the samples analyzed with detectable concentrations of TBT ranging from 0.48 J to 81 µg/kg.

5.3.15.1 TBT Spatial and Temporal Evaluation in Study Area

TBT concentrations at ST006 (Swan Island Lagoon) during Quarters 3 and 4 of the 2006/2007 sampling event, the only two quarters that data were available for that station, and at ST001 during Quarter 3 of the 2009 event were elevated an order of magnitude above other locations (Figures 5.3-15a-b). Concentrations within locations were generally highest during Quarter 4, and concentrations during all sampling periods were generally highest downstream of Swan Island Lagoon. The majority of samples collected were less than 5 mg/kg. Samples greater than 5 mg/kg are noted from the 2006/2007 sampling event during Quarter 3 at ST004 (RM 6.0E), ST006 (Swan Island Lagoon), and ST014 (RM 7.5W, and during Quarter 4 at ST005 (RM 6.0W), ST006 (Swan Island Lagoon), ST007 (RM 11.3E), ST011 (RM 3.5E), and ST014 (RM 7.5W). The only sample greater than 5 mg/kg during the 2009 sampling event was during Quarter 3 at ST001 (RM 11E).

5.3.15.2 TBT Relationship by River Reach

There was only one sample out of six in the upriver reach that was detected; the detected concentration was 1.9 mg/kg. All non-detect values in the upriver reach were below this value. In general, TBT levels in the study area were higher than TBT level detected in the upriver reach. However, since only one of six samples from the upriver stations had a detectable TBT concentration, the degree of elevation over upstream concentrations cannot be meaningfully quantified. Concentrations of TBT in the downstream reach were generally less than 4.3 mg/kg, with only one sample greater than 5 mg/kg noted during Quarter 3 at ST002 (RM 1.8W). Downstream TBT samples are notably less than the study area, but greater than the upriver reach.

5.4 INDICATOR CONTAMINANTS IN SURFACE WATER

This section summarizes the surface water data collected during the RI investigation. These data include those collected between November 2004 and March 2007. The surface water study was designed to characterize surface water contaminant concentrations and flow conditions of the river during three different flow regimes: low river flow (low flow; <50,000 cfs), high river flow (high flow; >50,000 cfs), and stormwater-influenced flow (low-flow conditions with active runoff in the study area). The threshold discharge rate of 50,000 cfs was selected because it is the river discharge at which significant transport of streambed sediment begins (Willamette Basin Task Force 1969). The geographic locations of all surface water sampling locations are presented on Map 2.1-18.

The discussion of indicator contaminants addressed in this section focuses primarily on the following elements:

- A description of the data set for each contaminant
- The relationship of contaminant concentration with respect to flow rate
- The sampling locations and event types with elevated contaminant concentrations compared to ambient water quality criteria (AWQC)
- Locations with the highest contaminant concentrations.

The following subsections present tables and other graphical formats to support discussion and evaluation of the in-river distribution of the 14 indicator contaminants discussed in the RI main report. Additional tabular and graphical summaries of 21 contaminants in surface water are included in Appendix D3.

The final subsection in this discussion presents a site-specific evaluation of hydrophobic contaminants using four contaminants: total PCBs, dioxin/furans, total PAHs, and DDx. This discussion presents the relationship of contaminant concentration with respect to dissolved and particulate fractions and relationship with suspended solids and associated organic carbon.

The surface water chemistry distributions and supporting information are depicted in several graphical formats: hydrographs and hyetographs of sampling events, discharge rates, and precipitation events; histograms of sample concentrations for all sampling events for the indicator contaminants; and line plots, stacked bar charts, and scatter plots for the indicator contaminants.

Hydrographs and Hyetographs: The hydrographs show the measured discharge rates during each surface water sampling event, and the hyetographs show precipitation events and amounts to provide perspective on the timing of the sampling events and the specific conditions prior to, during, and after each event. These are provided as Figures 5.4-1 through 5.4-4.

Histograms: Two types of histograms are presented for each contaminant. The first histogram provides a graphical summary of contaminant concentrations by river mile for each flow event type (high flow, low flow, and stormwater-influenced flow). These histograms present XAD dissolved (blue bars), XAD particulate (red bars), and peristaltic total (green bars) concentrations averaged for each river mile. For each analyte, data are sorted by flow event type and by location in the river channel (west and east channel and transect locations). The number above each column indicates the number of samples averaged for each river mile. Concentrations below detection limits were included in averages at the full detection limit. The second type of histogram presents particulate and dissolved concentrations measured at each surface water station as stacked bars, with particulate concentrations shown in blue and dissolved concentrations shown in red. Total concentrations are presented as purple bars. Concentrations below detection limits are shows as hollow bars at the full detection limit. For some analytes, a pair of histograms is presented to show the full y-axis concentration scale, as well as a zoom on the y-axis to show lower concentrations.

Line Plots: The line plots present the concentrations of the indicator contaminants for each flow type (high flow, low flow, stormwater-influenced flow) at the transect stations for all surface water sampling events. The squares, diamonds, and triangles represent the data points. Prior to generating the plots, data were averaged so that only one value per transect per sampling event is shown. NB/NS total (dissolved plus particulate) concentrations were averaged for samples from stations W027 (Multnomah Channel), W005 (RM 4), W011 (RM 6.3), and W024 (RM 16), and east, west, and mid-channel total concentrations were averaged for stations W025 (RM 2) and W023 (RM 11), where applicable. The data for the 2007 high-flow event is displayed in two colors because this event was completed in two phases with a stand-down period between high-flow conditions.

Scatter Plots: Scatter-plot presentations of the detected surface water data show concentrations of the indicator contaminants by river mile. The symbols on the scatter plots distinguish between flow types (high flow, low flow, stormwater-influenced flow) and single-point and transect samples. The evaluation of hydrophobic indicator contaminants presents indicator contaminants relationships with flow, TSS, and organic carbon. Particulate versus dissolved concentrations are also presented for detailed evaluation of the results. The symbols on the scatter plots distinguish between flow types (high flow, low flow, stormwater-influenced flow) and point and transect samples.

5.4.1 Surface Water Data Set

The Round 2A and 3A surface water sampling programs consisted of seven field collection events that occurred between November 2004 and March 2007. The seven events are listed below:

- November 2004 (Round 2A, low flow)
- March 2005 (Round 2A, low flow)

- July 2005 (Round 2A, low flow)
- January 2006 (Round 3A, high flow)
- September 2006 (Round 3A, low flow)
- November 2006 (Round 3A, stormwater-influenced flow)
- January–March 2007 (Round 3A, high flow[6]).

Other studies included in this evaluation are as follows:

- Siltronic—May and June 2005 (MFA 2005b, low flow)
- NW Natural—October 2007(Anchor 2008d, low flow)
- City of Portland—February 5, 1992 (low flow) and March 15, 2006 (low flow) (Sanders 2006, TSS only).

Peristaltic and XAD (column and filter) samples were collected during all sampling events, but not at all sampling locations. Table 5.4-1 summarizes the sampling methods at each sampling station for each sampling event.

Surface water samples were collected at 23 target locations from RM 2 to 11 in the lower Willamette River during three Round 2A sampling events in 2004 and 2005. A peristaltic pump was used to collect samples at all single-point locations. Additional samples were collected by employing a peristaltic pump and the high-volume XAD sampling method at 7 of the 23 locations, including 3 cross-sectional river transects and 4 single-point locations. During the Round 3A sampling events, surface water was collected at 18 target locations from RM 2 to 16 in 2006 and 2007. A transect station located at the upper end of Multnomah Channel (RM 2.9) was added to the program to provide a better understanding of the flux of chemicals exiting the study area via Multnomah Channel; and a transect station at RM 16 was added to assist with the analysis of upstream sources and loading into the study area. Peristaltic and high-volume samples were collected from 18 stations, including 6 transects and 12 single-point locations. Table 5.4-1 summarizes sampling methods at each station for all Round 2A and 3A sampling events. Peristaltic surface water samples were analyzed for conventional analytes, metals, and organic compounds (PCB Aroclors, organochlorine pesticides, and SVOCs). High-volume samples were analyzed by high-resolution gas chromatography/high-resolution mass spectrometry (HRGC/HRMS) for PCB congeners, PCDD/Fs, organochlorine pesticides, phthalate esters, and PAHs.

For comparison of peristaltic and XAD data on the same basis, a summed XAD concentration was calculated from the XAD column and XAD filter concentrations. In

[6] The January 2007 high-flow event was cancelled after two days of sampling due to unexpected change in flow conditions. Sampling recommenced on February 21, 2007 once high-flow conditions (>50,000 cfs) were once again observed and continued through March 10, 2007.

this sum, non-detects were set to zero. If both XAD fractions were non-detect, the summed detection limit was set to the sum of the individual detection limits.

A total of six transect locations located at RM 2, mouth of Multnomah Channel, RM 3.9, 6.3, 11, and 16 were sampled; due to flow conditions and sample event objectives, not all transects were sampled during all sampling events. Transects were sampled in three ways: as a vertically integrated equal discharge increment transect [T-EDI-VI]; as a near-surface equal discharge increment transect and near-bottom equal discharge increment transect pair [T-EDI-NS/NB]; and as a vertically integrated, three segment (east, mid-channel, west) transect [T-VI (E, M, W)][7]. At three locations (W010, W014, and W020) single point vertically integrated (SP-VI) samples were collected during Round 2A low-flow conditions to support the BHHRA. The remaining Round 2A single-point samples were collected in support of the BERA as near-bottom samples. Round 3A single-point samples were collected as near-surface and near-bottom pairs. Siltronic collected peristaltic single point samples, and NW Natural and the City of Portland collected surface water grab samples. Not all samples were analyzed for every analyte. Each subsection that follows discusses which samples were analyzed for each indicator contaminants.

A total of 16 peristaltic sample locations and 7 peristaltic and XAD stations were sampled during the Round 2A low-flow conditions, and 6 peristaltic and XAD stations were sampled during the Round 3A low-flow conditions (Table 5.4-2). Sixteen single-point peristaltic stations (W001–W004, W006–W010, W012, W014, W017, and W019–W022) and four single-point peristaltic and XAD stations were sampled (W013, W015, W016, W018) during each of the three Round 2A sampling events (Table 5.4-1). Both peristaltic and XAD samples were collected for all the low-flow transect samples in Round 2A. Three Round 2A transect locations (W005, W011, and W023) were collected during low-flow conditions as T-EDI-VI. Four Round 3A transect locations (W005, W011, W024, and W027) were collected as T-EDI-NS/NB and the other two Round 3A transect locations (W023 and W025) were collected as T-VI (E, M, W). Replicates were collected based on a 5 percent target frequency at the following single-point stations: W013 (peristaltic and XAD) and W016 (peristaltic only) during November 2004; W013 (peristaltic and XAD), W002 (peristaltic only), W004 (peristaltic only), and W016 (peristaltic only) during March 2005; and W002 (peristaltic only), W016 (peristaltic only), and W013 (peristaltic and XAD) during July 2005. A total of 92 peristaltic samples and 38 XAD samples were collected to represent the low-flow conditions of the river (Table 5.4-3). As summarized in Table 5.4-4, samples collected during this flow regime include the following:

- 61 peristaltic and 15 XAD single-point, near-bottom (SP-NB) samples
- 8 peristaltic SP-VI samples
- 9 peristaltic and 9 XAD transect, T-EDI-VI samples

[7] A single vertically integrated sample was collected from the mid-point of each transect segment.

- 2 peristaltic and 2 XAD east-channel vertically integrated transect samples, 2 peristaltic and 2 XAD mid-channel vertically integrated transect samples, and 2 peristaltic and 2 XAD west-channel vertically integrated transect samples
- 4 peristaltic and 4 XAD transect, T-EDI-NS samples
- 4 peristaltic and 4 XAD transect, T-EDI-NB samples.

Stormwater-influenced flow conditions were only sampled once during Round 3A (November 2006). Both peristaltic and XAD samples were collected at all six transect locations (W005, W011, W023, W024, W025, and W027) and 12 single-point stations (W026 and W028–W038) during this sampling event (Table 5.4-1). Four of the transect locations (W005, W011, W024, and W027) were sampled as T-EDI-NS/NB. The other two transect locations (W023 and W025) were sampled as T-VI (E, M, W). All the single-point samples were collected as SP-NS/NB pairs. Replicates were collected at single-point stations W033 (peristaltic and XAD) and W036 (peristaltic only). A total of 42 peristaltic samples and 40 XAD samples were collected to represent the stormwater-influenced flow conditions of the river (Table 5.4-3). As summarized in Table 5.4-4, samples collected during this flow regime include the following:

- 14 peristaltic and 13 XAD single-point, near-surface (SP-NS) samples
- 14 peristaltic and 13 XAD SP-NB samples
- 2 peristaltic and 2 XAD east-channel vertically integrated transect samples, 2 peristaltic and 2 XAD mid-channel vertically integrated transect samples, and 2 peristaltic and 2 XAD west-channel vertically integrated transect samples
- 4 peristaltic and 4 XAD transect, T-EDI-NS samples
- 4 peristaltic and 4 XAD transect, T-EDI-NB samples.

High-flow conditions were sampled twice during Round 3A (January 2006 and January-March 2007). In January 2006, peristaltic and XAD samples were collected at three transects (W005, W023, and W024). Due to safety concerns and sampling challenges associated with the extreme high-flow conditions, the January 2006 samples were collected mid-channel at a single fixed depth for each of the three transect stations that were sampled. No vertical integration was performed. One replicate was collected at W023 for the peristaltic sample only. Both peristaltic and XAD samples were collected at all 6 transects and 12 single-point stations (W026 and W028–W038) during the January–March 2007 sampling event. Four of the transect locations (W005, W011, W024, and W027) were sampled as T-EDI-NS/NB. The other two transect locations (W023 and W025) were sampled as T-VI (E, M, W). Stations W023-M and W025-M were first sampled in January 2007, and then reoccupied in March 2007 (W023-M2, W025-M2) due to changing flow conditions. All the single-point samples were collected as SP-NS/NB pairs. SP-NS/NB replicates were collected at single-point station W033 (peristaltic only) during the January–March 2007 event. A total of 46 peristaltic samples and 43 XAD samples were collected to represent the high-flow

conditions of the river (Table 5.4-3). As summarized in Table 5.4-4, samples collected during this flow regime include the following:

- 13 peristaltic and 12 XAD SP-NS samples
- 13 peristaltic and 12 XAD SP-NB samples
- 2 peristaltic and 2 XAD east-channel vertically integrated transect samples, 4 peristaltic and 2 XAD mid-channel vertically integrated transect samples, and 2 peristaltic and 2 XAD west-channel vertically integrated transect samples
- 4 peristaltic and 4 XAD transect, T-EDI-NS samples
- 4 peristaltic and 4 XAD transect, T-EDI-NB samples.

Uncertainty associated with the surface water data is related primarily to the representativeness of the analytical data set. The surface water sampling program was designed to capture representative flow conditions and locations over time. However, only a limited number of surface water samples during a limited number of conditions could be collected over time. In addition, sampling protocols evolved over time based on the assessment of previous efforts as well changing river flow conditions. This evolution included some changes in both sample locations and sampling methods. While these changes were intended to more fully characterize the site, they also make the compilation and combination of these data more complex. For example, single-point stations occupied in Round 2 were sampled on multiple occasions. However, during Round 3, the stations were shifted into deeper water to accommodate the Round 3 modification to collect both near-bottom and near-surface samples simultaneously or were relocated at EPA's request. Also, while the six transects were sampled in almost all the sampling events, sampling methods were modified over the course of the sampling program. While the data evaluation compares concentrations at the river transects, there is uncertainty associated with the changes in sampling methods as well as the unavoidable flow condition differences between specific sampling events.

This complexity prohibits a quantitative statistical evaluation of temporal and flow variability in surface water. Further, the limited number of stations and samples preclude definition of the magnitude and extent of the surface water contamination in all localized areas. Such locations may need to be addressed further in remedial design. Nonetheless, the data collected and presented here met the objectives of the sampling program and are sufficient for the purposes of the site-wide RI.

5.4.2 River Conditions during Round 2A and 3A Sample Collection

A summary of the sampling events, including dates of collection, flow rates, and relative flow conditions, are presented in Table 5.4-5. Average discharge rates (recorded as cfs) for each event are based on measurements collected by the USGS at the stream flow station located upstream of the Morrison Bridge at RM 12.8 (station 14211720). Flow measurements from the USGS gauge at this station are collected every 30 minutes and were used to calculate flow rates for each of the seven sampling

events. It should be noted that discharge rates below 20,000 cfs measured at this station are considered to be unreliable by the USGS. Therefore, the average discharge rates calculated for the low-flow events should be considered estimates.

The surface water sampling events and their corresponding flow rates are presented against the backdrop of the average year (1972–2008) hydrograph measured at Morrison Bridge on Figure 5.4-1. Overall, the sampling events were well distributed over the average water year, capturing the range of flow conditions, including base flow, rising limb, peak flow, and falling limb conditions. Additionally, the November 2006 sampling captured a stormwater-influenced flow event at the onset of the transition from a low-flow period to a high-flow period. Figures 5.4-2a-d present the actual annual hydrograph measured at Morrison Bridge (RM 12.8) and hyetograph during each year of sampling (2004–2007), including daily average and historical average (1978–2008) discharge rates and daily precipitation levels, as well as the sampling events collected during each year. Several rainfall events occurred during the November 2004 sampling event, and one day of measurable rainfall occurred during each of the March and July 2005 sampling events.

The seasonal cycle of water discharge in the Willamette River is also apparent on Figure 5.4-1. Annual low water levels occur during the summertime regional dry season, and flows increase during the wetter winter months (November to March). Furthermore, a distinct and persistent period of relatively high water levels occurs from late May through June when Willamette River flow into the Columbia is slowed by high-water stage/flow in the Columbia River during the spring freshet in the much larger Columbia River Basin. The flow regime can influence the concentration of contaminants in the water column.

Flow measurements were not collected at the lower end of the study area where the river flows either into the Columbia River or into Multnomah Channel. To better understand the flow dynamics at the lower end of the study area, a hydrodynamic model (discussed in Section 6) was used to estimate these flows. The model shows that the relative stages of the Columbia and Willamette rivers determine the fraction of the Willamette River flow which flows down Multnomah Channel (WEST 2006a). Figure 5.4-3 presents the average annual hydrograph, based on modeled discharge rates for 2003 through 2007, for RM 4, 2, and Multnomah Channel. The Morrison Bridge (RM 12.8) 25-yr average hydrograph is also shown for comparison.

Figure 5.4-4 presents the modeled daily average flows for 2003 through 2007 and highlights the time periods when surface water samples were collected at RM 4, 2, and Multnomah Channel. A few key observations are apparent in Figures 5.4-3 and 5.4-4. First, for a significant portion of each year, generally May through September, Multnomah Channel flow increases above the flow at both RM 2 and 4. During these periods, the relatively higher Columbia River stage drives a reversal in flow direction at RM 2, so that Multnomah Channel flow includes the entire Willamette River flow plus some flow from the Columbia River. Second, Figure 5.4-4 shows that surface water

sampling events at the RM 2 and Multnomah Channel sample transects did not occur during these flow reversal periods; rather, sampling was conducted when the Willamette River flow was in the downstream direction, and flows split between Multnomah Channel and the main stem. This indicates that surface water samples collected at RM 2 and Multnomah Channel are representative of Willamette River water and are not strongly influenced by mixing with Columbia River water.

Tidal action also compounds the hydrology and interplay of the two rivers, and affects the Willamette River upstream as far as Portland Harbor and beyond. The high (i.e., flood) tide can influence Willamette River levels by up to 3 ft in Portland Harbor when the river is at a low stage. These tidal fluctuations can result in short-term flow reversals (i.e., upstream flow) in Portland Harbor during times of low river stage combined with large flood tides. Tidal changes were observed at multiple stations during the surface water sampling events. At this time, there is not adequate high-resolution discharge information to determine the potential influence of tidal fluctuations and water mixing on surface water sampling results; however, the overall tidal impact is not expected to be significant.

5.4.3 Suspended Solids

Suspended sediment loads are potentially an important component of the lower Willamette River physical system. TSS data have been collected as part of the surface water data collection effort to understand distributions and patterns of contaminant concentrations. As stated in Section 3, evaluations overall indicate that a positive correlation exists between TSS concentrations and flow rate in the lower Willamette River.

Organic carbon is present in both suspended sediment and the dissolved phase. This organic carbon comes from a range of natural sources including watershed inputs, such as the dissolution and decay of plant material and soil organic matter, and in-river sources such as phytoplankton. In some locations anthropogenic sources such as petroleum may be significant. Hydrophobic compounds, for example persistent organic pollutants, such as PCBs, dioxin/furans, and chlorinated pesticides, tend to accumulate in the organic fraction ($f_{oc)}$ of sediments and soils, although they can be present in aqueous solution due to the dissolved organic carbon (DOC) and the presence of colloids[8] in the water column. Organic carbon in the suspended sediment is a strong determinant in the adsorption of organic contaminants (i.e., persistent organic pollutants) with low aqueous solubilities. DOC is important in the transport of metals in the aquatic systems. Metals can be strongly complexed by DOC, enhancing metal solubility while also reducing metal bioavailability.

[8]Colloids are the smallest particles, having dimensions between 1 nm and 100 µm; they are composed of humic substances, Fe and Mn oxides and soil-derived materials, and are ubiquitous in natural waters (Stumm and Morgan 1996). A fraction of colloids is small enough to pass through 0.45-µm filter materials; as such, compounds sorbed to, or comprising, colloids are operationally part of the "dissolved" fraction.

Figures 5.4-5 and 5.4-6 present the f_{oc} on the TSS in each surface water sample as a function of flow rate and river mile, respectively. The surface water transect particulate and DOC data are presented by event on Figures 5.4-7 and 5.4-8. The f_{oc} values on the TSS range from 0 to 20 percent in the low-flow samples and 0 to 50 percent in the stormwater-influenced flow samples. Conversely, the f_{oc} on the TSS in high-flow samples is distinctly lower, ranging from 0 to less than 4 percent, suggesting the introduction of suspended particles with low organic carbon content during high-flow events. Generally low f_{oc} values may be a function of larger particles (lower surface area per volume and therefore fewer organic carbon binding sites) introduced during high-flow conditions.

Figure 5.4-9 presents a scatter plot of f_{oc} and TSS that summarizes the overall trend of solids concentrations and f_{oc} in the data set. High-flow samples tend to exhibit lower f_{oc} associated with TSS. The shape of the curve is largely driven by the fact that f_{oc} is a function of TSS. The suspended solids associated with the stormwater-influenced flow samples appear to have the highest levels of organic carbon content. The TSS concentrations and corresponding f_{oc} values vary somewhat between flow types, and the low-flow samples appear to fall between the high-flow and stormwater-influenced flow samples based on the level of organic carbon. There is the possibility that there may be local nearshore effects at the point of discharge that were not captured in the surface water sampling data set.

5.4.4 Total PCBs in Surface Water

Total PCB data are summarized in Tables 5.4-6 through 5.4-11. Transect samples are summarized by flow event in Tables 5.4-6, 5.4-8, and 5.4-10. Single-point samples are summarized by flow event in Tables 5.4-7a-d, 5.4-9a-d, and 5.4-11a-d. All PCB surface water sample results are presented in Table 5.4-12 by sample event and sample location.

Dissolved and particulate PCB congener concentrations in surface water XAD columns and filters and PCB Aroclor concentrations from the peristaltic pumps are presented in bar graphs by flow event and by river mile/channel position on Figures 5.4-10 and 5.4-11a-b.

Total PCB concentrations at the transect locations as a function of flow rate are presented on Figure 5.4-12. The data points presented in this figure are averages of all data points collected at a particular transect for each measured flow event.

Figures 5.4-13a-b present scatter plots of all detected total PCB congener surface water data. Note the symbols and colors indicate the sample type—point vs. transect—and the general flow conditions of the sampling event—low flow, stormwater-influenced flow, or high flow.

5.4.4.1 Total PCBs Data

Total PCBs were analyzed as PCB Aroclors by USEPA Method 8081 in 53 of the total 180 peristaltic samples collected: 42 SP-NB samples, 8 SP-VI samples, and 3 T-EDI-VI

samples. High-volume surface water samples (XAD samples) were analyzed as PCB congeners by HRGC/HRMS in 121[9] of the total 121 XAD samples collected: 25 SP-NS samples, 40 SP-NB samples, 9 T-EDI-VI samples, 23 T-VI (E, M, W) samples, 12 T-EDI-NS samples, and 12 T-EDI-NB samples.

PCB Aroclors were not detected in the majority of the peristaltic samples (47 of 53 non-detect samples) with detection limits ranging from 0.0025 to 0.0027 µg/L, which is 3 orders of magnitude greater than the Oregon water quality criterion (WQC) for human health (6.4×10^{-6} µg/L), although below the chronic Oregon WQC for aquatic life (0.014 µg/L) and USEPA's maximum contaminant level (MCL)[10] (0.5 µg/L) for drinking water.

Detections of PCB Aroclors were limited to six single-point samples collected during the Round 2A low-flow event at the following stations:

- W001 (RM 2.0E)
- W004 (RM 3.7E–head of International Slip)
- W014 (RM 6.7E)
- W022 (RM 9.7W).

Detected PCB Aroclor concentrations for SP-NB samples range from 0.00467 J to 0.0136 J µg/L; only one SP-VI sample (W014) was detected at 0.0154 µg/L.

Total PCB congener concentrations, calculated as the sum of the dissolved (XAD column) and particulate (XAD filter) concentrations, were detected in all samples. The following discussion is based on the total PCB congener data.

5.4.4.2 Total PCBs Relationships to River Flow Conditions

Total PCBs concentrations in samples collected during low-flow conditions ranged as follows (sample types not sampled are also listed):

- SP-NS: Not sampled
- SP-NB: 3.75×10^{-4} J to 0.0136 J µg/L (station W013 at RM 6.9E)
- SP-VI: One sample was detected at 0.0154 µg/L (station W014 at RM 6.7E)
- T-VI (E, M, W): 2.75×10^{-4} J to 9.50×10^{-4} J µg/L (station W023-E at RM 11)

[9] Only the column of the XAD sample collected during July 2005 low-flow event was analyzed for total PCBs; the filter was not analyzed.

[10] Under Oregon State Administrative Rules, OAR 340-041-0340, Table 340A, the designated beneficial use of the lower Willamette River includes private and public domestic water supply after adequate pretreatment to meet drinking water standards. There are no known current or anticipated future uses of the lower Willamette River within Portland Harbor as a private or public domestic water supply. As such, their use in this section is solely as values for comparison.

- T-EDI-NS: 1.59×10^{-4} J to 6.73×10^{-4} J µg/L (station W011 at RM 6.3)
- T-EDI-NB: 1.74×10^{-4} J to 9.50×10^{-4} J µg/L (station W005 at RM 3.9)
- T-EDI-VI: 1.71×10^{-4} J to 6.08×10^{-4} J µg/L (station W023 at RM 11).

Total PCBs concentrations in samples collected during stormwater-influenced flow conditions ranged as follows:

- SP-NS: 1.82×10^{-4} J to 0.00259 J µg/L (station W030 at RM 5.5E)
- SP-NB: 1.12×10^{-4} J to 8.97×10^{-4} J µg/L (station W026 at RM 2.1E)
- SP-VI: Not sampled
- T-VI (E, M, W): 1.21×10^{-4} J to 0.00129 J µg/L (station W025-E at RM 2)
- T-EDI-NS: 1.49×10^{-4} J to 4.58×10^{-4} J µg/L (station W005 at RM 3.9)
- T-EDI-NB: 2.05×10^{-4} J to 4.40×10^{-4} J µg/L (station W005 at RM 3.9)
- T-EDI-VI: Not sampled.

Total PCBs concentrations in samples collected during high-flow conditions ranged as follows:

- SP-NS: 1.11×10^{-4} J to 7.49×10^{-4} J µg/L (station W035 in Swan Island Lagoon)
- SP-NB: 1.49×10^{-4} J to 7.03×10^{-4} J µg/L (station W035 in Swan Island Lagoon)
- SP-VI: Not sampled
- T-VI (E, M, W): 4.19×10^{-5} J to 2.09×10^{-4} J µg/L (station W023-M at RM 11)
- T-EDI-NS: 7.83×10^{-5} J to 2.50×10^{-4} J µg/L (station W027 in Multnomah Channel)
- T-EDI-NB: 7.05×10^{-4} J to 3.91×10^{-4} J µg/L (station W005 at RM 3.9)
- T-EDI-VI: Not sampled.

Total PCBs concentrations were consistently lower in high-flow samples compared to the low-flow and stormwater-influenced flow samples (Figure 5.4-12), suggesting dilution at high-flow rates overwhelms local effects and PCBs concentrations. All sample events show the concentrations at the RM 11 transect are consistently greater than at the RM 16 transect (Figure 5.4-12), indicating there are inputs of PCBs to the system in this reach. During three of the four low-flow sampling events (March 2005, July 2005, and September 2006), concentrations increase between RM 11 and 6. However, the November 2004 low-flow event did not show this same trend. Two of the low-flow events (July 2005 and September 2006) show sustained elevated concentrations between RM 6 and 4.

The February 2007 high-flow sampling event shows increasing concentrations between RM 6 and 4; this trend is also apparent in the November 2006 stormwater-influenced

flow event. Only the stormwater-influenced flow event shows increasing concentrations between RM 4 and 2.Two of the three highest total PCBs concentrations at RM 11 were from the sampling stations on the east side of the channel (Figure 5.4-11a-b). The second highest result at RM 11 was from a Round 2A vertically and horizontally integrated transect, and the field crew noted stormwater runoff entering the east side of the channel during collection of this sample (Jones 2007, pers. comm.).

5.4.4.3 Spatial Distribution of Total PCBs

None of the sample results exceeds USEPA's MCL for PCBs (0.5 µg/L) for drinking water. Total PCBs results from two sample stations exceeded the chronic DEQ WQC for aquatic life (0.014 µg/L): stations W004 (RM 3.7 at the head of International Slip) and W014 (RM 6.9E in Willamette Cove). All sample results exceed the DEQ WQC for human health (6.4×10^{-6} µg/L) by 1 to 4 orders of magnitude. The majority of the highest total PCB concentrations (>0.001 µg/L) were associated with single-point samples collected during low-flow conditions.

The highest detected concentrations (>0.01 µg/L) were collected at the following stations during low-flow conditions:

- W004 (RM 3.7E at the head of International Slip)
- W013 and W014 (RM 6.9E in Willamette Cove).

The next highest detected concentrations (between 0.01 and 0.001 µg/L) were collected at the following stations during low-flow conditions:

- W001 (RM 2.0E)
- W015 (RM 6.9W)
- W016 (RM 7.2W)
- W018 (in Swan Island Lagoon)
- W022 (RM 9.7W).

Concentrations between 0.01 and 0.001 µg/L were also detected during the stormwater-influenced flow event at the following stations:

- W025-E (RM 2.0)
- W028 (RM 3.6E)
- W030 (RM 5.5E).

These data suggest that local PCB sources may exist in these regions of the study area. The range of total PCBs concentrations within the complete data set across the study area was fairly consistent between RM 11 and 2 (Figure 5.4-13a-b), excluding the highest single-point concentrations, and elevated concentrations near the east side of the river at RM 6.7. Within the study area, total PCBs concentrations continued to increase

between RM 11 and 4 in six of seven transect-based sampling events (the sole exception is the November 2004 low-flow sampling event). Total PCBs concentrations at both RM 2 and Multnomah Channel transects generally decreased from those at RM 4 but remained higher than those at RM 16. An exception to this was the RM 2 total PCBs concentration from the November 2006 stormwater-influenced flow event, which was higher than other transect concentrations measured in that event.

5.4.5 Total PCDD/Fs and TCDD TEQ in Surface Water

Total PCDD/Fs and TCDD TEQ data are summarized in Tables 5.4-6 through 5.4-11. Transect samples are summarized by flow event in Tables 5.4-6, 5.4-8, and 5.4-10. Single-point samples are summarized by flow event in Tables 5.4-7a-d, 5.4-9a-d, and 5.4-11a-d. All PCDD/F and TCDD TEQ surface water sample results are presented in Tables 5.4-13 and 5.4-14, respectively, by sample event and sample location.

Dissolved and particulate PCDD/F congener concentrations in surface water XAD columns and filters and concentrations from the peristaltic pump samples are presented in bar graphs by flow event and by river mile/channel position on Figures 5.4-14 and 5.4-15. Dissolved and particulate TCDD TEQ concentrations in surface water are presented similarly on Figures 5.4-18 and 5.4-19a-b.

Total PCDD/Fs concentrations at the transect locations as a function of flow rate is presented on Figure 5.4-16. The data points presented in this figure are averages of all data points collected at a particular transect for each measured flow event.

Figure 5.4-17 presents a scatter plot of all detected total PCDD/Fs surface water data. Note the symbols and colors indicate the sample type—point vs. transect—and the general flow conditions of the sampling event—low flow, stormwater-influenced flow, or high flow.

5.4.5.1 Total PCDD/Fs and TCDD TEQ Data

Total PCDD/Fs were analyzed as PCDD/F congeners in high-volume surface water samples by HRGC/HRMS in 79 of the total 121 XAD samples collected, including 7 SP-NS samples, 16 SP-NB samples, 9 T-EDI-VI samples, 23 T-VI (E, M, W) samples, 12 T-EDI-NS samples, and 12 T-EDI-NB samples. Total PCDD/F congener concentrations, calculated as the sum of the dissolved (XAD column) and particulate (XAD filter) concentrations, were detected in all samples.

TCDD TEQs were calculated in 121 of the total 121 XAD samples collected, including 25 SP-NS samples, 40 SP-NB samples, 9 T-EDI-VI samples, 23 T-VI (E, M, W) samples, 12 T-EDI-NS samples, and 12 T-EDI-NB samples. Stacked bar graphs depicting TCDD TEQ concentrations in the surface water dissolved (XAD column) and particulate (XAD filter) samples by flow condition and river mile are presented on Figures 5.4-18 and 5.4-19. TCDD TEQ concentrations, calculated as the sum of the dissolved (XAD column) and particulate (XAD filter) TCDD toxicity equivalent concentrations of each dioxin/furan congener, were detected in all samples.

5.4.5.2 Total PCDD/Fs and TCDD TEQ Relationships to River Flow Conditions

Concentrations of total PCDD/Fs and TCDD TEQ during low-flow, stormwater-influenced flow, and high-flow conditions are summarized in this section.

5.4.5.2.1 Total PCDD/Fs Relationship to River Flow Conditions

Total PCDD/Fs concentrations in samples collected during low-flow conditions ranged as follows:

- SP-NS: Not sampled
- SP-NB: 3.07×10^{-5} to 1.62×10^{-4} µg/L (station W013 at RM 6.9E)
- SP-VI: Not sampled
- T-VI (E, M, W): 6.0×10^{-6} J to 2.7×10^{-5} J µg/L (station W023-E at RM 11)
- T-EDI-NS: 8.49×10^{-6} J to 2.58×10^{-5} J µg/L (station W027 in Multnomah Channel)
- T-EDI-NB: 9.31×10^{-6} J to 5.16×10^{-5} J µg/L (station W005 at RM 3.9)
- T-EDI-VI: 1.68×10^{-5} J to 5.05×10^{-5} J µg/L (station W005 at RM 3.9).

Total PCDD/Fs concentrations in samples collected during stormwater-influenced flow conditions ranged as follows:

- SP-NS: 3.60×10^{-5} J µg/L to 5.38×10^{-5} J µg/L (station W035 in Swan Island Lagoon)
- SP-NB: 3.90×10^{-5} µg/L to 5.52×10^{-5} J µg/L (station W032 at RM 6.9E)
- SP-VI: Not sampled
- T-VI (E, M, W): 5.51×10^{-6} J µg/L to 1.18×10^{-4} µg/L (station W023-E at RM 11)
- T-EDI-NS: 1.99×10^{-5} J µg/L to 5.22×10^{-5} µg/L (station W011 at RM 6.3)
- T-EDI-NB: 2.57×10^{-5} µg/L to 5.01×10^{-5} µg/L (station W005 at RM 3.9)
- T-EDI-VI: Not sampled.

Total PCDD/Fs concentrations in samples collected during high-flow conditions ranged as follows:

- SP-NS: 2.47×10^{-5} to 7.44×10^{-5} µg/L (station W035 in Swan Island Lagoon)
- SP-NB: 2.67×10^{-5} J to 7.49×10^{-5} µg/L (station W035 in Swan Island Lagoon)
- SP-VI: Not sampled
- T-VI (E, M, W): 5.36×10^{-6} J to 4.40×10^{-5} J µg/L (station W005 at RM 3.9)

- T-EDI-NS: 9.73×10^{-6} J to 3.00×10^{-5} J µg/L (station W027 in Multnomah Channel)
- T-EDI-NB: 8.14×10^{-6} J µg/L to 2.89×10^{-5} µg/L (station W027 in Multnomah Channel)
- T-EDI-VI: Not sampled.

Figure 5.4-16 shows that there does not appear to be an overall trend between total PCDD/Fs values and flow conditions. All sample events show concentrations at the RM 11 transect are consistently greater than concentrations at the RM 16 transect (Figure 5.4-16), indicating there are inputs of total PCDD/Fs to the system in this reach. During three of the four low-flow sampling events (March 2005, July 2005, and September 2006), concentrations of PCDD/Fs increase between RM 11 and 6.3. The July 2005 low-flow event shows increasing concentrations between RM 6.3 and 3.9. The stormwater-influenced flow event shows concentration peaks at RM 11 and 2; the February 2007 high-flow event shows a similar pattern. Concentrations of total PCDD/Fs leaving the study area in Multnomah Channel were consistently higher than at RM 16 upstream of the study area, while concentrations at RM 2 were consistently lower than RM 16 and Multnomah Channel.

5.4.5.2.2 TCDD TEQ Relationship to River Flow Conditions

TCDD TEQ concentrations in samples collected during low-flow conditions ranged as follows:

- SP-NS: Not sampled
- SP-NB: 1.10×10^{-7} J to 9.17×10^{-7} J µg/L (station W013 at RM 6.9E)
- SP-VI: Not sampled
- T-VI (E, M, W): 1.81×10^{-8} J to 6.43×10^{-8} J µg/L (station W023E at RM 11)
- T-EDI-NS: 2.69×10^{-8} J to 9.17×10^{-8} J µg/L (station W027 in Multnomah Channel)
- T-EDI-NB: 3.14×10^{-8} J to 1.97×10^{-7} J µg/L (station W005 at RM 3.9)
- T-EDI-VI: 4.30×10^{-8} J to 3.27×10^{-7} J µg/L (station W005 at RM 3.9).

TCDD TEQ concentrations in samples collected during stormwater-influenced flow conditions ranged as follows:

- SP-NS: 7.77×10^{-8} J to 1.36×10^{-7} J µg/L (station W035 in Swan Island Lagoon)
- SP-NB: 1.01×10^{-7} J to 2.12×10^{-7} J µg/L (station W033 at RM 7W)
- SP-VI: Not sampled
- T-VI (E, M, W): 1.33×10^{-8} J to 2.78×10^{-7} J µg/L (station W023E at RM 11)

- T-EDI-NS: 3.73×10^{-8} J to 1.38×10^{-7} J µg/L (station W027 in Multnomah Channel)
- T-EDI-NB: 7.77×10^{-8} J to 1.09×10^{-7} J µg/L (station W027 in Multnomah Channel)
- T-EDI-VI: Not sampled.

TCDD TEQ concentrations in samples collected during high-flow conditions, ranged as follows:

- SP-NS: 5.09×10^{-8} J to 1.68×10^{-7} J µg/L (station W035 in Swan Island Lagoon)
- SP-NB: 4.91×10^{-8} J to 1.49×10^{-7} J µg/L (station W035 in Swan Island Lagoon)
- SP-VI: Not sampled
- T-VI (E, M, W): 1.13×10^{-8} J to 9.12×10^{-8} J µg/L (station W023-M at RM 11)
- T-EDI-NS: 2.38×10^{-8} J to 6.73×10^{-8} J µg/L (station W027 in Multnomah Channel)
- T-EDI-NB: 1.65×10^{-8} J to 6.82×10^{-8} J µg/L (station W005 at RM 3.9)
- T-EDI-VI: Not sampled.

5.4.5.3 Spatial Distribution of Total PCDD/Fs and TCDD TEQ

There are no DEQ WQC for total PCDD/Fs. None of the sample results exceed the MCL for TCDD TEQ (3.0×10^{-5} µg/L) or the DEQ chronic AWQC for aquatic life (3.8×10^{-5} µg/L). All the sample results exceed the DEQ TCDD WQC for human health (5.1×10^{-10} µg/L) by 1 to 3 orders of magnitude. However, this value is significantly lower than analytical detection limits. The majority of the highest total concentrations ($>1.0\times10^{-7}$ µg/L) were associated with both transect and single-point samples collected predominantly during low-flow and stormwater-induced flow conditions.

The highest TCDD TEQ concentrations ($>1.0\times10^{-7}$ µg/L) were detected at the following stations during low-flow events:

- W005 (transect at RM 3.9)
- W011 (transect at RM 6.3)
- W013 (RM 6.7E)
- W015 (RM 6.9W).

The highest TCDD TEQ concentrations ($>1.0\times10^{-7}$ µg/L) during the stormwater-influenced flow event were detected at the following stations:

- W005 (transect at RM 3.9)
- W023 (RM 11E)

- W027 (transect in Multnomah Channel)
- W032 (RM 6.7E)
- W033 (RM 7W)
- W035 (Swan Island Lagoon).

The only samples with relatively high TCDD TEQ concentrations were collected during high-flow events in Swan Island Lagoon (SP-NS, 1.7×10^{-7} and SP-NB, 1.5×10^{-7} µg/L).

5.4.6 DDx in Surface Water

DDx data are summarized in Tables 5.4-6 through 5.4-11. Transect samples are summarized by flow event in Tables 5.4-6, 5.4-8, and 5.4-10. Single-point samples are summarized by flow event in Tables 5.4-7a-d, 5.4-9a-d, and 5.4-11a-d. All DDx surface water sample results are presented in Table 5.4-15 by sample event and sample location.

Dissolved and particulate DDx concentrations in surface water XAD columns and filters and DDx concentrations from the peristaltic pumps are presented in bar graphs by flow event on Figure 5.4-20 and by river mile/channel position on Figure 5.4-21a-b.

DDx concentrations at the transect locations as a function of flow rate are presented on Figure 5.4-22. The data points presented in this figure are averages of all data points collected at a particular transect for each measured flow event.

Figures 5.4-23a-b present a scatter plot of all detected DDx surface water data. Note the symbols and colors indicate the sample type—point vs. transect—and the general flow conditions of the sampling event—low flow, stormwater-influenced flow, or high flow.

5.4.6.1 DDx Data

DDx contaminants were analyzed by USEPA Method 8081A in 84 of the total 180 peristaltic samples collected, including 59 SP-NB samples, 16 SP-NS samples, 8 SP-VI samples, and 1 T-EDI-NS sample. High-volume surface water samples (XAD samples) were analyzed for DDx contaminants by AXYS Method MLA-028 (Rev 1 or 2) in 93 of the total 121 XAD samples collected, including 26 SP-NB samples, 11 SP-NS samples, 12 T-EDI-NB samples, 12 T-EDI-NS samples, 9 T-EDI-VI samples, and 23 T-VI (E, M, W) samples.

DDx contaminants were not detected in the majority of the peristaltic samples (55 of 84 non-detect samples) with detection limits ranging from 4.72×10^{-4} to 0.0016 µg/L. Most of the detection limits are less than the chronic Oregon WQC for aquatic life (0.001 µg/L for 4,4'-DDT); only four of the non-detect samples exceed 0.001 µg/L.

DDx contaminants were detected in all but one (LW3-W3023-M-F) of the XAD samples (mid channel, filter sample).

5.4.6.2 DDx Relationships to River Flow Conditions

DDx concentrations are subsequently listed as measured in the peristaltic samples or calculated as the sum of the dissolved (XAD column) and particulate (XAD filter) concentrations. DDx concentrations in samples collected during low-flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB:4.92×10^{-5} J to 0.0187 J µg/L (station W001 at RM 2E)
- SP-NS: Not sampled
- SP-VI: All non-detected peristaltic samples
- T-EDI-NB: 6.87×10^{-5} J to 5.46×10^{-4} J µg/L (station W005 at RM 3.9)
- T-EDI-NS: 6.03×10^{-5} J to 5.00×10^{-4} J µg/L (station W027 at Multnomah Channel)
- T-VI (E, M, W): 8.91×10^{-5} J to 3.22×10^{-4} J µg/L (station W025-W at RM 2)
- T-EDI-VI: 4.28×10^{-5} J to 2.37×10^{-4} J µg/L (station W011 at RM 6.3).

DDx concentrations in samples collected during stormwater-influenced flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB: 1.01×10^{-4} J to 0.0047 J µg/L (station W037 at RM 9.6W)
- SP-NS: 7.67×10^{-5} J to 0.0029 J µg/L (station W031 at RM 6.1W)
- SP-VI: Not sampled
- T-EDI-NB: 9.11×10^{-5} J to 2.01×10^{-4} J µg/L (station W011 at RM 6.3)
- T-EDI-NS: 5.8×10^{-5} J to 0.0019 µg/L (station W027 in Multnomah Channel)
- T-VI (E, M, W): 3.32×10^{-5} J µg/L to 1.84×10^{-4} J µg/L (station W025-W at RM 2)
- T-EDI-VI: Not sampled.

DDx concentrations in samples collected during high-flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB: 1.80×10^{-4} J to 0.00205 J µg/L (station W037 at RM 9.6W)
- SP-NS: 1.70×10^{-4} J to 9.60×10^{-4} J µg/L (station W029 at RM 4.4W)
- SP-VI: Not sampled
- T-EDI-NB: 3.75×10^{-4} J to 5.78×10^{-4} J µg/L (station W005 at RM 3.9)
- T-EDI-NS: 3.46×10^{-4} J to 5.35×10^{-4} J µg/L (station W005 at RM 3.9)
- T-VI (E, M, W): 1.62×10^{-4} J to 6.18×10^{-4} J µg/L (station W023-E at RM 11)
- T-EDI-VI: Not sampled.

With the exception of the highest DDx concentrations that were measured at RM 6.9 and 7.2 and a single high concentration measured at RM 2 (March 2005), the range of DDx concentrations detected was fairly consistent. DDx concentrations in surface water transect stations (Figures 5.4-23a-b) were generally higher in high-flow samples than in those associated with the low-flow and stormwater-influenced flow samples.

5.4.6.3 DDx Spatial Distribution

Results from 20 sample stations exceeded the chronic Oregon WQC for aquatic life (0.001 µg/L for 4,4'-DDT) by a factor of 1 to 19.

The highest concentrations (>0.003 µg/L) were detected at the following stations during low-flow events:

- W001 (RM 2E)
- W015 (RM 6.9W) on three dates
- W016 (RM 7.2W).

The highest concentrations (>0.003 µg/L) were detected at the following stations during the stormwater-influenced flow event:

- W030 (RM 5.5E)
- W037 (RM 9.6W).

The highest XAD concentrations were measured in single-point samples collected during low-flow conditions near the middle of the study srea at RM 6.9W (station W015; 0.00767 µg/L) and RM 7.2W (station W016; 0.00976 µg/L). Excluding these higher concentrations, the overall range of observed concentrations across the study area and upstream to RM 16 was fairly consistent. High-flow transect samples showed upstream concentrations that were greater than low-flow and stormwater–influenced flow concentrations in the study area (Figure 5.4-22). The stormwater-influenced flow and low-flow samples increased between RM 11 and 6; and decreased downstream.

5.4.7 Total PAHs in Surface Water

Total PAHs data are summarized in Tables 5.4-6 through 5.4-11. Transect samples are summarized by flow event in Tables 5.4-6, 5.4-8, and 5.4-10. Single point samples are summarized by flow event in Tables 5.4-7a-d, 5.4-9a-d, and 5.4-11a-d. All PAH surface water samples are presented in Table 5.4-16 by sample event and sample location.

Dissolved and particulate total PAHs concentrations in surface water XAD columns and filters and total PAHs concentrations from the peristaltic pump samples are presented in bar graphs by flow event in Figure 5.4-24 and by river mile/channel position in Figure 5.4-25a-b.

Total PAHs concentrations at the transect locations as a function of flow rate are presented in Figure 5.4-26. The values presented in this figure are averages of all measurements collected at a particular transect for each measured flow event.

Figure 5.4-27 presents a scatter plot of all detected total PAHs surface water data. Note the symbols and colors indicate the sample type—point vs. transect—and the general flow conditions of the sampling event—low flow, stormwater-influenced flow, or high flow.

5.4.7.1 Total PAHs Data

Total PAHs were analyzed by HRGC/LRMS in 174 of the 180 peristaltic samples[11], including 83 SP-NB, 26 SP-NS, 8 SP-VI, 12 T-EDI-NB, 12 T-EDI-NS, 9 T-EDI-VI samples and 24 T-VI (E, M, W) samples. High-volume surface water samples (XAD samples) were analyzed by HRGC/HRMS in 85 of the total 121 XAD samples, including 22 SP-NB, 7 SP-NS, 12 T-EDI-NB, 12 T-EDI-NS, and 9 T-EDI-VI, and 23 T-VI (E, M, W) samples.

Total PAHs were detected in over half of the peristaltic samples (101 of 174 samples) with detection limits for the non-detects ranging from 0.0065 to 0.043 µg/L. Total PAHs were detected in all the XAD samples (column sample or filter sample or both). The detection limits in non-detect peristaltic samples were well below the MCL for benzo(a)pyrene (0.2 µg/L). The highest detected PAH value of 7.4 µg/L (station W031 at RM 6.1) is well below the Oregon-specific water quality guidance for freshwater aquatic life for the only two PAHs for which there is any such guidance (acenaphthene: 520 µg/L; and naphthalene: 620 µg/L).

Detected total PAHs concentrations are subsequently listed as measured in the peristaltic samples or calculated as the sum of the dissolved (XAD column) and particulate (XAD filter) concentrations.

5.4.7.2 Total PAHs Relationships to River Flow Conditions

Detected PAHs concentrations in samples collected during low-flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB: 0.0026 J to 2.5 J µg/L (station W012 at RM 6.3W)
- SP-NS: Not sampled
- SP-VI: 0.0049 J to 0.0413 J µg/L (station W020 at RM 9.1 in Swan Island Lagoon)
- T-EDI-NB: 0.0045 J to 0.066 J µg/L (station W027 at Multnomah Channel)

[11] Sample events could involve replicate samples, and for XAD sampling, the column and filter samples together are counted as one sample. These counts are strictly of sample events, and the values listed here are with replicates averaged together.

- T-EDI-NS: 0.0061 J to 0.048 J µg/L (station W027 at Multnomah Channel)
- T-VI (E, M, W): 0.0039 J to 0.037 J µg/L (station W025-E at RM 2)
- T-EDI-VI: 0.0061 J to 0.066 J µg/L (station W023 at RM 11).

PAHs concentrations in samples collected during stormwater-influenced flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB: 0.005 J to 0.12 J µg/L (station W033 at RM 7W)
- SP-NS: 0.0060 J to 0.051 J µg/L (station W033 at RM 7W)
- SP-VI: Not sampled
- T-EDI-NB: 0.0041 J to 0.068 J µg/L (station W027 at RM 2.9W)
- T-EDI-NS: 0.0087 J to 0.039 J µg/L (station W005 at RM 3.9)
- T-VI (E, M, W): 0.00279 J µg/L to 0.023 J µg/L (Station W025-E at RM 2)
- T-EDI-VI: Not sampled.

PAHs concentrations in samples collected during high-flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB: 0.010 J to 7.4 J µg/L (station W031 at RM 6.1W)
- SP-NS: 0.0047 J to 0.27 J µg/L (station W036 at RM 8.6W)
- SP-VI: Not sampled
- T-EDI-NB: 0.0087 J to 0.023 µg/L (station W005 at RM 3.9)
- T-EDI-NS: 0.0064 J to 0.021 J µg/L (station W005at RM 3.9)
- T-VI (E, M, W): 0.0026 J to 0.059 J µg/L (station W005 at RM 3.9)
- T-EDI-VI: Not sampled.

PAHs concentrations were generally higher in low-flow samples as compared to the high-flow and stormwater-influenced flow samples, suggesting that inflow concentrations at high flow rates overwhelm local effects and dilute the PAHs concentrations (Figure 5.4-24). For all but stormwater-influenced flow events, the transect samples (Figure 5.4-26) show slightly increased concentrations between the RM 16 and 11 transects, indicating there may be inputs of PAHs to the system in this reach. Some events—three of the four low-flow sampling events (November 2004, July 2005, and September 2006), one high-flow event (January 2006), and the stormwater-influenced flow event (November 2006)—show increases in concentrations between RM 11 and 6. However, the March 2005 low-flow event did not show this same trend. Two of the low-flow events (July 2005 and September 2006), the stormwater-influenced flow events (November 2006), and one of the high-flow events (February 2007) show increasing concentrations between RM 6 and 4.

5.4.7.3 Spatial Distribution of Total PAHs

Elevated sample concentrations for total PAHs were recorded at the following stations:

- W031 (RM 6.1W) 7.4 µg/L (February 2007, high flow)
- W012 (RM 6.3W) 2.5 µg/L (July 2005, low flow)
- W012 (RM 6.3W) 1.3 µg/L (November 2004, low flow)
- W021 (RM 8.7 in Swan Island Lagoon) 0.29 µg/L (July 2005, low flow)
- W036 (RM 8.6W) 0.27 µg/L (February 2007, high flow)
- W015 (RM 6.9W) 0.23 µg/L (July 2005, low flow).

All but the last of these were measured in peristaltic samples. The first three appear to be outliers on the distribution of peristaltic samples. All measured concentrations are below the two DEQ guidance values for freshwater aquatic life (acenaphthene: 520 µg/L; and naphthalene: 620 µg/L).

5.4.8 BEHP in Surface Water

BEHP data are summarized in Tables 5.4-6 through 5.4-11. Transect samples are summarized by flow event in Tables 5.4-6, 5.4-8, and 5.4-10. Single-point samples are summarized by flow event in Tables 5.4-7a-d, 5.4-9a-d, and 5.4-11a-d. All BEHP surface water sample results are presented in Table 5.4-17 by sample event and sample location.

Dissolved and particulate BEHP concentrations in surface water XAD columns and filters and BEHP concentrations from the peristaltic pumps are presented in bar graphs by flow event and by river mile/channel position on Figures 5.4-28 and 5.4-29a-b, respectively.

BEHP concentrations at the transect locations as a function of flow rate are presented on Figure 5.4-30. The data points presented in this figure are averages of all data points collected at a particular transect for each measured flow event.

Figure 5.4-31 presents a scatter plot of all detected BEHP surface water data. Note the symbols and colors indicate the sample type—point vs. transect—and the general flow conditions of the sampling event—low flow, stormwater-influenced flow, or high flow.

5.4.8.1 BEHP Data

BEHP was analyzed by USEPA Methods 8270C or 525.2 in 173 of the total 180 peristaltic samples collected, including 82 SP-NB samples, 26 SP-NS samples, 8 SP-VI samples, 12 T-EDI-NB samples, 12 T-EDI-NS samples, 9 T-EDI-VI samples and 24 T-VI (E, M, W) samples. BEHP was analyzed in high-volume surface water samples (XAD samples) by AXYS Method MLA-027 Rev 01 in 24 of the total 121 XAD samples collected, including 15 SP-NB samples and 9 T-VI (E, M, W) samples.

BEHP was not detected in the majority of the peristaltic samples (157 of 173 samples) with detection limits ranging from 0.098 to 4.1 µg/L.

Detections of BEHP were limited to 15 samples collected during the Round 3A sampling event at the following stations:

- W005 (T-EDI-NS and T-EDI-NB; RM 3.9)
- W011 (T-EDI-NB; RM 6.3)
- W023 (T-VI; RM 11 M)
- W024 (T-EDI-NB; RM 16)
- W025 (T-VI; RM 2E and W)
- W027 (T-EDI-NB; Multnomah Channel)
- W029 (SP-NB; RM 4.4W)
- W032 (SP-NB; RM 6.7E)
- W033 (SP-NS; RM 7W)
- W036 (SP-NS; RM 8.6W).

Detected BEHP concentrations in peristaltic samples ranged from 0.7 to 6.8 J µg/L. During low-flow conditions, BEHP was detected in four samples at concentrations ranging from 0.7 to 1.5 µg/L (T-VI (E, M, W) sample; station W025E at RM 2). During stormwater-influenced flow conditions, BEHP was detected in one T-EDI-NB sample at a concentration of 6.8 J µg/L (station W005 at RM 3.9). During high-flow conditions, BEHP was detected in 11 samples at concentrations ranging from 0.98 J to 3.5 J µg/L (SP-NB sample; station W032 at RM 6.7E).

BEHP concentrations, calculated as the sum of the dissolved (XAD column) and particulate (XAD filter) concentrations, were detected in 9 of 24 samples, all collected during low-flow conditions. BEHP concentrations in these samples ranged as follows:

- SP-NB: 0.0078 J to 0.033 µg/L (station W015 at RM 6.9W)
- T-EDI-VI: 0.0091 J to 0.023 J µg/L (station W023 at RM 11)
- SP-NS, SP-VI, T-EDI-NS, T-EDI-NB: Not sampled with XAD.

5.4.8.2 BEHP Relationship to River Flow Conditions

Detected BEHP concentrations and frequencies were relatively consistent regardless of flow rate. The frequency of detection was 5 percent for low-flow event peristaltic sampling results; 24 percent for high-flow event peristaltic sampling results; 3 percent for stormwater-influenced flow peristaltic sampling events; and 38 percent for low-flow event XAD sampling results.

Detected BEHP concentrations in low-flow peristaltic samples ranged from 0.7 to 1.5 µg/L (station W025E at RM 2) in September 2006. Detected BEHP concentrations in high-flow peristaltic samples ranged from 0.98 J to 3.5 J µg/L (station W032 at RM 6.9E) in February 2007. BEHP was detected in only 1 of 37 stormwater-influenced flow samples at a concentration of 6.8 J µg/L (station W005 at RM 3.9) in November 2006.

Detected BEHP concentrations in low-flow XAD samples ranged from 0.0078 J to 0.033 µg/L (station W015 at RM 6.9W).

5.4.8.3 Spatial Distribution of BEHP

One sample result exceeded the MCL for BEHP (6.0 µg/L). All the detected peristaltic and three detected XAD samples exceeded the DEQ human health criteria of 0.2 µg/L. The highest concentrations (>3.0 µg/L) were detected at the following stations:

- W005 (RM 3.9)
- W032 (RM 6.9E).

The next highest concentrations (>1.5 µg/L but <3 µg/L) were detected at the following stations during high-flow conditions:

- W011 (RM 6.3)
- W024 (RM 16)
- W025 (RM 2E)
- W029 (RM 4.4W)
- W036 (RM 8.6W).

5.4.9 Total Chlordanes in Surface Water

Total chlordanes data are summarized in Tables 5.4-6 through 5.4-11. Transect samples are summarized by flow event in Tables 5.4-6, 5.4-8, and 5.4-10. Single-point samples are summarized by flow event in Tables 5.4-7a-d, 5.4-9a-d, and 5.4-11a-d. All total chlordanes surface water sample results are presented in Table 5.4-18 by sample event and sample location.

Total chlordanes concentrations in surface water XAD columns and filters as well as concentrations from the peristaltic pumps are presented in bar graphs by low-flow, stormwater-influenced flow, or high-flow events and by river mile/channel position on Figures 5.4-32 and 5.4-33a-b, respectively.

Total chlordanes concentrations at the transect locations as a function of flow rate are presented on Figure 5.4-34. The data points presented in this figure are averages of all data points collected at a particular transect for each measured flow event.

Figure 5.4-35 presents a scatter plot of detected total chlordanes surface water data. Note the symbols and colors indicate the sample type—point vs. transect—and the general flow conditions of the sampling event—low flow, stormwater-influenced flow, or high flow.

5.4.9.1 Total Chlordanes Data

Total chlordanes were analyzed by USEPA Method 8081A for 84 of 180 peristaltic samples collected. High-volume surface water samples (XAD samples) were analyzed for total chlordanes by the AXYS method for pesticides for 93 of 121 XAD samples collected.

Total chlordanes were not detected in the majority of the peristaltic samples (78 non-detects of 84 samples) with detected total chlordanes concentrations ranging from 2.90×10^{-4} to 0.0021 µg/L and detection limits for not detected results ranging from 4.72×10^{-4} to 0.0024 µg/L. Total chlordanes were detected in all 93 XAD column (dissolved) samples, with detected concentrations ranging from 6.72×10^{-6} to 5.57×10^{-5} µg/L. Total chlordanes were detected in XAD (column + filter) samples at concentrations ranging from 7.32×10^{-6} to 2.41×10^{-4} µg/L. All of these detected and not detected results are below the acute (2.4 µg/L) and chronic (0.0043 µg/L) Oregon WQC for aquatic life as well as the MCL (2 µg/L). All of the peristaltic detected and not detected results are greater than the Oregon WQC for human health (8.10×10^{-5} µg/L) that is protective of drinking water plus the consumption of organisms. The majority of the XAD samples, calculated as the sum of the XAD column and XAD filter, are less than this criterion; only six sample results exceeded the criterion, with concentrations ranging from 8.34×10^{-5} to 2.41×10^{-4} µg/L. These results suggest that the XAD samples analyzed using the AXYS method for pesticides achieved sufficiently low detection limits to determine that total chlordanes are below applicable human health and ecological criteria in the majority of samples.

5.4.9.2 Total Chlordanes Relationship to River Flow Conditions

Detected total chlordanes concentrations were relatively consistent, with concentrations slightly higher during high flow conditions. A total of 12 samples (6 peristaltic, 6 XAD) exceed the DEQ human health criterion of 8.1×10^{-5} µg/L. Of the samples that exceed the criterion, 8 are from the high-flow events conducted in February and March 2007, and there are 2 each from low-flow and stormwater–influenced flow events.

Detected total chlordanes concentrations in samples collected during low-flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB: 1.73×10^{-5} J to 0.0021 µg/L (station W002, RM 2W)
- SP-NS: Not sampled
- SP-VI: Not detected
- T-EDI-NB: 2.23×10^{-5} J to 5.88×10^{-5} J µg/L (station W005, RM 3.9)

- T-EDI-NS: 2.27×10^{-5} J to 4.48×10^{-5} J µg/L (station W027i, RM 2.9W)
- T-VI (E, M, W): 2.98×10^{-5} J to 3.33×10^{-5} J µg/L (station W023-E, RM 11)
- T-EDI-VI: 1.34×10^{-5} to 3.70×10^{-5} µg/L (station W011, RM 6.3).

Detected total chlordanes concentrations in samples collected during high-flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB: 4.66×10^{-5} to 6.0×10^{-4} µg/L(station W030, RM 5.5E)
- SP-NS: 4.77×10^{-5} to 5.1×10^{-4} µg/L (station W030, RM 5.5E)
- SP-VI: Not sampled
- T-EDI-NB: 4.83×10^{-5} to 9.43×10^{-5} µg/L (station W005, RM 3.9)
- T-EDI-NS: 3.84×10^{-5} to 9.07×10^{-5} µg/L (station W005, RM 3.9)
- T-VI (E, M, W): 3.36×10^{-5} to 9.11×10^{-5} µg/L (station W023-E, RM 11)
- T-EDI-VI: Not sampled.

Detected total chlordanes concentrations in samples collected during stormwater–influenced flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB: 1.06×10^{-5} to 3.61×10^{-5} µg/L (station W033, RM 7W)
- SP-NS: 7.32×10^{-6} to 0.0016 µg/L (station W036, RM 8.6W)
- SP-VI: Not sampled
- T-EDI-NB: 2.12×10^{-5} to 3.66×10^{-5} µg/L (station W027 in Multnomah Channel)
- T-EDI-NS: 1.66×10^{-5} to 3.76×10^{-5} µg/L (station W027 in Multnomah Channel)
- T-VI (E, M, W): 1.34×10^{-5} to 2.14×10^{-5} µg/L (station W023-E at RM 11)
- T-EDI-VI: Not sampled.

5.4.9.3 Spatial Distribution of Total Chlordanes

None of the sample results exceed the 2 µg/L drinking water MCL for total chlordanes, or the DEQ ecological acute (2.4 µg/L) or chronic (0.0043 µg/L) criteria for the protection of aquatic life. Each of the four detected concentrations from peristaltic samples exceed the DEQ WQC for human health (8.10×10^{-5} µg/L). Detection limits were higher for the peristaltic samples than the XAD samples. The samples with concentrations greater than the human health criterion were collected at the following stations:

- W002 (RM 2.2W)
- W029 (RM 4.4W)
- W030 (RM 5.5E, NS and NB)

- W036 (RM 8.6W)
- W038 (RM 9.9E).

The sample from station W002 was collected during the low-flow event conducted in July 2005, and the samples from stations W029 and W030 were collected during the high-flow event conducted in March 2007. The samples from stations W036 andW038 were collected during the stormwater-influenced flow event conducted on November 2006.

Lower detection limits were achieved for the XAD samples. Total chlordanes were detected in each of the 93 XAD samples with concentrations in 6 samples slightly exceeding the AWQC for human health (8.10×10^{-5} µg/L). The samples were collected at the following stations:

- W005 (RM 3.9) (two samples)
- W015 (RM 6.9W)
- W023-E (RM 11E)
- W031 (RM 6.1W)
- W033 (RM 7W).

The sample from station W015 was collected during low-flow conditions in November 2004. The samples from stations W005 and W023 were collected during high-flow conditions in March 2007. The samples from stations W031 and W033 were collected during high-flow conditions in February 2007. The low detection limits for the XAD samples and the low frequency of exceedance of the human health AWQC criterion suggest that specific inputs of total chlordanes do not exist in the study area.

5.4.10 Aldrin in Surface Water

Aldrin data are summarized in Tables 5.4-6 through 5.4-11. Transect samples are summarized by flow event in Tables 5.4-6, 5.4-8, and 5.4-10. Single point samples are summarized by flow event in Tables 5.4-7a-d, 5.4-9a-d, and 5.4-11a-d. All aldrin surface water sample results are presented in Table 5.4-19 by sample event and sample location.

Dissolved and particulate aldrin concentrations in surface water XAD columns and filters and aldrin concentrations from the peristaltic pumps are presented in bar graphs by flow event type on Figure 5.4-36 and by river mile/channel position on Figures 5.4-37a-b.

Aldrin concentrations at the transect locations as a function of flow rate are presented on Figures 5.4-38. The data points presented in this figure are averages of all data points collected at a particular transect for each measured flow event.

Figure 5.4-39 presents a scatter plot of all detected aldrin surface water data. Note the symbols and colors indicate the sample type—point vs. transect—and the general flow conditions of the sampling event—low flow, stormwater-influenced flow, or high flow.

5.4.10.1 Aldrin Data

Aldrin was measured by USEPA Method 8081A in 84 of the total 180 peristaltic sample events, including 59 SP-NB, 16 SP-NS, 8 SP-VI, 0 T-EDI-NB, and 1 T-EDI-NS samples. High-volume surface water samples (XAD samples) were analyzed by HRGC/HRMS in 93 of the total 121 XAD samples collected, including 26 SP-NB, 11 SP-NS, 12 T-EDI-NB, 12 T-EDI-NS, 9 T-EDI-VI, and 23 T-VI (E, M, W) samples.

With one exception, Aldrin was not detected in any of the peristaltic samples, with detection limits ranging from 5.7×10^{-5} to 0.0058 µg/L; all but 3 of these detection limits were less than 0.001 µg/L. The single detected sample was a SP-NB measurement of 0.0052 µg/L at W030 (RM 5.5E) during high flow. This value was 319 times higher than the highest detected sample in the XAD data, and the non-detect SP-NS sample at the same location and time had the (higher) detection limit of 0.0058 µg/L. For comparison, the DEQ WQC for human health is 5.0×10^{-6} µg/L.

Aldrin concentrations, calculated as the sum of the dissolved (XAD column) and particulate (XAD filter) concentrations, were detected in 81 of the 93 samples, with detection limits in the non-detects ranging from 6.13×10^{-7} to 6.2×10^{-6} µg/L.

5.4.10.2 Aldrin Relationship to River Flow Conditions

Detected aldrin concentrations in samples collected during low-flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB: 3.1×10^{-7} J to 1.63×10^{-5} J µg/L (station W013 at RM 6.7E)
- SP-NS: Not sampled
- SP-VI: Not sampled
- T-EDI-NB: 4.39×10^{-6} J to 6.62×10^{-6} J µg/L (station W005 at RM 3.9)
- T-EDI-NS: 1.79×10^{-6} J to 4.6×10^{-6} J µg/L (station W027 at Multnomah Channel)
- T-EDI-VI: 2.96×10^{-7} J to 2.74×10^{-6} J µg/L (station W011-E at RM 6.3)
- T-VI (E, M, W): 1.86×10^{-6} J to 4.09×10^{-6} J µg/L (station W025E at RM 2).

Detected aldrin concentrations in samples collected during stormwater-influenced flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB: 1.41×10^{-6} J to 3.67×10^{-6} J µg/L (station W033 at RM 7W)
- SP-NS: 6.35×10^{-7} J to 4.84×10^{-6} J µg/L (station W033 at RM 7W)
- SP-VI: Not sampled

- T-EDI-NB: 2.01×10^{-6} J to 5.75×10^{-6} J µg/L (station W027 at Multnomah Channel)
- T-EDI-NS: 2.04×10^{-6} J to 2.63×10^{-6} J µg/L (station W027 at Multnomah Channel)
- T-EDI-VI: Not sampled
- T-VI (E, M, W): 1.1×10^{-6} J to 3.26×10^{-6} J µg/L (station W025-W at RM 2).

Detected aldrin concentrations in samples collected during high-flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB:5.14×10^{-7} J to 0.0052 µg/L (station W030 at RM 5.5E)
- SP-NS: 2.16×10^{-6} J to 3.52×10^{-6} J µg/L (station W035 at RM 8.5 in Swan Island Lagoon)
- SP-VI: Not sampled
- T-EDI-NB: 2.81×10^{-6} J to 4.75×10^{-6} J µg/L (station W027 at Multnomah Channel)
- T-EDI-NS: 2.57×10^{-6} J to 4.0×10^{-6} J µg/L (station W005 at RM 3.9)
- T-EDI-VI: Not sampled
- T-VI (E, M, W): 1.24×10^{-6} J to 5.99×10^{-6} J µg/L (station W025-M at RM 2).

Aldrin concentrations were slightly lower in the low flow than in the high-flow XAD samples. Comparison with stormwater–influenced flow samples is difficult due to the high frequency of non-detects.

Concentration trends along the river were examined by using T-VI (E, M, W) XAD samples, either single samples (November 2004, March 2005, July 2005, January 2006, January 2007, March 2007) or averages of east, west, and middle samples (September 2006, November 2006). Low-flow samples are consistent in showing a decreasing concentration trend between RM 6 and 1 in the three events with suitable samples (November 2004, March 2005, July 2005), consistent with no sources in this range. The high-flow event of January 2006 and the stormwater-influenced flow event of November 2006 indicate an increasing concentration between RM 3 and 1. One low-flow event (September 2006) and one high-flow event (January 2007) showed an increase in concentration between RM 11 and 2, suggesting sources within that range, while a second high-flow event (March 2007) showed a decrease in concentration.

5.4.10.3 Spatial Distribution of Aldrin

Five detected XAD samples exceeded the DEQ criterion for human health (water + organisms) of 5.0×10^{-6} µg/L:

- W011 (RM 6.3 T-EDI-NB)

- W027 (Multnomah Channel T-EDI-NB)
- W025 (RM 2M T-VI)
- W005 (RM 3.9 T-EDI-NB)
- W015 (RM 6.9W SP-NB).

The highest XAD concentration measurement of 1.63×10^{-5} µg/L was in a SP-NB measurement at W015 (RM 6.9W) but the nearest available measurements in W032 and W033 and downriver in W011 do not suggest an area of elevated concentrations.

5.4.11 Dieldrin in Surface Water

Dieldrin data are summarized in Tables 5.4-6 through 5.4-11. Transect samples are summarized by flow event in Tables 5.4-6, 5.4-8, and 5.4-11. Single-point samples are summarized by flow event in Tables 5.4-7a-d, 5.4-9a-d, and 5.4-11a-d. All dieldrin surface water sample results are presented in Table 5.4-20 by sample event and sample location.

Dieldrin concentrations in surface water XAD columns and filters and dieldrin concentrations from the peristaltic pumps are presented in bar graphs by flow event and by river mile/channel position on Figures 5.4-40 and 5.4-41a-b, respectively.

Dieldrin concentrations at the transect locations as a function of flow rate are presented on Figure 5.4-42. The data points presented in this figure are averages of all data points collected at a particular transect for each measured flow event.

Figure 5.4-43 presents a scatter plot of all detected dieldrin surface water data. Note the symbols and colors indicate the sample type—point vs. transect—and the general flow conditions of the sampling event—low flow, stormwater-influenced flow, or high flow.

5.4.11.1 Dieldrin Data

Dieldrin was measured by USEPA Method 8081A in 84 of the total 180 peristaltic samples, including 59 SP-NB, 16 SP-NS, 8 SP-VI, 0 T-EDI-NB, and 1 T-EDI-NS samples. High-volume surface water samples (XAD samples) were analyzed by HRGC/HRMS in 93 of the total 121 XAD samples collected, including 26 SP-NB, 11 SP-NS, 12 T-EDI-NB, 12 T-EDI-NS, 9 T-EDI-VI and 23 T-VI (E, M, W) samples.

The range of detected concentrations in the three SP-NB peristaltic samples in which dieldrin was detected was 0.0010 to 0.0012 µg/L (maximum value during high flow at both W036, RM 8.6 and W028, RM 3.6E, January 2007).

Dieldrin concentrations, calculated as the sum of the XAD column and XAD filter concentrations, ranged from 1.67×10^{-5} to 3.84×10^{-4} µg/L.

5.4.11.2 Dieldrin Relationships to River Flow Conditions

Where detected, dieldrin concentrations were relatively consistent in both low-flow and high-flow samples, and were also relatively similar across sample types. The range of dieldrin concentrations by sample type are presented below.

Dieldrin concentrations in samples collected during low-flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB: 2.27×10^{-5} to 6.25×10^{-5}µg/L (station W015 at RM 6.9W)
- SP-NS: Not sampled
- SP-VI: Not sampled.
- T-EDI-NB: 3.48×10^{-5} J to 4.87×10^{-5} J µg/L (station W005 at RM 3.5)
- T-EDI-NS: 3.53×10^{-5} J to 4.70×10^{-5} J µg/L (station W005 at RM 3.5)
- T-EDI-VI:1.67×10^{-5} J to 4.34×10^{-5} J µg/L (station W011 at RM 6.3)
- T-VI (E, M, W): 3.77×10^{-5} J to 4.62×10^{-5} J µg/L (station W023-W at RM 11).

Dieldrin concentrations in samples collected during high-flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB: 1.10×10^{-4} J to 0.0012 J µg/L (station W028 at RM 3.6E)
- SP-NS: 1.08×10^{-4} J to 1.80×10^{-4} J µg/L (station W033 at RM 7W)
- SP-VI: Not sampled
- T-EDI-NB: 9.93×10^{-5} to 1.58×10^{-4} µg/L (station W027 at Multnomah Channel)
- T-EDI-NS: 7.05×10^{-5} to 1.59×10^{-4} J µg/L (station W005 at RM 3.9)
- T-VI (E, M, W): 8.49×10^{-5} to 3.84×10^{-4} µg/L (station W005 at RM 3.9)
- T-EDI-VI: Not sampled.

Dieldrin concentrations in samples collected during stormwater–influenced flow conditions ranged as follows (the station listed is for the maximum):

- SP-NB: 3.62×10^{-5} J to 5.01×10^{-5} J µg/L (station W031 at RM 6.1W)
- SP-NS: 3.19×10^{-5} J to 4.98×10^{-5} J µg/L (station W031 at RM 6.1)
- SP-VI: Not sampled.
- T-EDI-NB: 3.06×10^{-5} J to 4.82×10^{-5} J µg/L (station W024 at RM 16)
- T-EDI-NS: 3.22×10^{-5} J to 5.37×10^{-5} J µg/L (station W024 at RM 16)
- T-VI (E, M, W): 2.51×10^{-5} J to 3.87×10^{-5} J µg/L (station W023-E at RM 11)
- T-EDI-VI: Not sampled.

5.4.11.3 Spatial Distribution of Dieldrin

All of the surface water samples analyzed for dieldrin exceeded the human health DEQ value developed to be protective of drinking water and consumption of organisms (5.3×10^{-6} µg/L). No sample result exceeded the DEQ dieldrin chronic value for protection of aquatic life (0.056 µg/L).

5.4.12 Arsenic in Surface Water

Arsenic data are summarized in Tables 5.4-6 through 5.4-11. Transect samples are summarized by flow event in Tables 5.4-6, 5.4-8, and 5.4-10. Single-point samples are summarized by flow event in Tables 5.4-7a-d, 5.4-9a-d, and 5.4-11a-d. All total and dissolved arsenic surface water sample results are presented in Tables 5.4-21a-b by sample event and sample location. Dissolved and particulate arsenic concentrations in surface water collected from peristaltic pumps are presented in bar graphs by flow event on Figure 5.4-44 and by river mile/channel position on Figure 5.4-45.

Arsenic concentrations at the transect locations as a function of flow rate are presented on Figure 5.4-46. The data points presented in this figure are averages of all data points collected at a particular transect for each measured flow event.

Figure 5.4-47 presents a scatter plot of all detected arsenic surface water data. Note the symbols and colors indicate the sample type—point vs. transect—and the general flow conditions of the sampling event—low flow, stormwater-influenced flow, or high flow.

5.4.12.1 Arsenic Data

Peristaltic samples were collected and analyzed by USEPA Method 6020 for total and dissolved arsenic during Rounds 2A and 3A. Dissolved arsenic was detected in 136 (78 percent) of the 174 samples and 157 (90 percent) of 174 total arsenic samples during the Round 2A and 3A sampling events.

Total arsenic concentrations were generally consistent across the entire study area during the Round 2A and 3A sampling events. The overall range of detected concentrations for all total arsenic samples was narrow, ranging from 0.254 to 0.745 µg/L, suggesting that there are no specific areas with elevated arsenic concentrations.

5.4.12.2 Arsenic Relationship to River Flow Conditions

Detected arsenic concentrations were relatively consistent regardless of flow rate; however, frequency of detection was significantly reduced during stormwater-influenced flow events. The frequency of detection was 100 percent for total arsenic and 98 percent for dissolved arsenic for all combined low-flow and high-flow sampling event sample results. The frequency of detection was 58 percent for total arsenic and 13 percent for dissolved arsenic for the stormwater-influenced flow samples.

While total arsenic concentrations were relatively consistent, in general, they were slightly higher in low-flow sampling events, with concentrations ranging from 0.33 to

0.75 µg/L compared to high-flow sampling events with concentrations ranging from 0.25 to 0.63 µg/L. Twenty-three stormwater-influenced flow samples displayed a narrow range of detected concentrations between 0.43 to 0.53 µg/L. Dissolved and particulate arsenic concentrations in surface water are depicted in histograms by flow event type on Figure 5.4-44 for high-flow, low-flow, and stormwater-influenced flow events.

Arsenic concentrations in samples collected during low-flow conditions ranged as follows (the station listed is for the maximum):

- Total arsenic, single point: 0.33 to 0.75 µg/L at station W001 (RM 2E)
- Dissolved arsenic, single point: 0.25 to 0.64 µg/L at station W001 (RM 2E)
- Total arsenic, transect: 0.35 to 0.64 µg/L at station W025-E (RM 2).
- Dissolved arsenic, transect: 0.19 to 0.60 µg/L at station W025-M (RM 2).

Arsenic concentrations in samples collected during high-flow conditions ranged as follows (the station listed is for the maximum):

- Total arsenic, single point: 0.30 to 0.63 J µg/L at station W034 (NS; RM 7.5)
- Dissolved arsenic, single point: 0.19 J to 0.34 J µg/L at station W034 (NS; RM 7.5)
- Total arsenic, transect: 0.25 to 0.54 µg/L at station W005 (RM 4) and station W023 (RM 6.3)
- Dissolved arsenic, transect: 0.18 to 0.28 µg/L at station W027 (NB; Multnomah Channel).

Arsenic concentrations in samples collected during stormwater–influenced flow conditions ranged as follows (the station listed is for the maximum):

- Total arsenic, single point 0.43 J to 0.53 J µg/L at station W038 (NB; RM 11)
- Dissolved arsenic, single point: 0.38 J to 0.48 µg/L at station W038 (NB; RM 11E)
- Total arsenic, transect: 0.44 to 0.48 J µg/L at station W005 (NB; RM 4)
- Dissolved arsenic, transect: Not detected.

5.4.12.3 Spatial Distribution of Arsenic

All of the total and dissolved arsenic surface water results were less than the drinking water MCL of 10 µg/L, the DEQ human health criterion of 2.1 µg/L, and the DEQ chronic value of 150 µg/L for the protection of aquatic life.

5.4.13 Chromium in Surface Water

Data for chromium in surface water are summarized in Tables 5.4-6 through 5.4-11. Transect samples are summarized by flow event in Tables 5.4-6, 5.4-8, and 5.4-10. Single-point samples are summarized by flow event in Tables 5.4-7a-d, 5.4-9a-d, and 5.4-11a-d. All total and dissolved chromium surface water sample results are presented in Tables 5.4-22a-b by sample event and sample location.

Dissolved and particulate chromium concentrations in surface water collected from peristaltic pumps are presented in bar graphs by flow event on Figure 5.4-48 and by river mile/channel position on Figure 5.4-49.

Figure 5.4-50 is a line plot of transect chromium concentrations in surface water by river mile (RM 2–16). The data points presented in this figure are averages of all data points collected at a particular transect for each measured flow event.

Figure 5.4-51 is a scatter plot of detected chromium concentrations in surface water by river mile (RM 2–16). The symbols and colors indicate the sample type—point vs. transect—and the general flow conditions of the sampling event—low flow, stormwater-influenced flow, or high flow.

5.4.13.1 Chromium Data

Peristaltic samples were collected and analyzed by USEPA Method 6020 for total and dissolved chromium during Rounds 2A and 3A. Dissolved chromium was detected in 58 of 174 (33 percent) of samples and 112 of 174 (64 percent) of total chromium samples during the Round 2A and 3A sampling events.

Total chromium concentrations were generally consistent across the entire study area during the Round 2A and 3A sampling events. The overall range of detected concentrations for all total chromium samples was 0.2 to 1.92 µg/L. The range of detected concentrations of dissolved chromium was narrower, from 0.1 to 0.83 µg/L.

5.4.13.2 Chromium Relationship to River Flow Conditions

In general, total chromium concentrations were slightly lower in samples collected during low-flow sampling events with concentrations ranging from 0.2 to 1.09 µg/L compared to results from high-flow sampling events where total chromium concentrations ranged from 0.58 to 1.92 µg/L. Dissolved chromium concentrations were generally lower in low-flow samples. Detected dissolved chromium concentrations ranged from 0.43 to 0.83 µg/L in high-flow samples and from 0.1 to 0.33 µg/L in low-flow samples.

Forty stormwater-influenced flow samples were analyzed for total and dissolved chromium. Neither total chromium nor dissolved chromium was detected in any of those samples.

Chromium concentrations in samples collected during low-flow conditions ranged as follows (the station listed is for the maximum):

- Total chromium, single point: 0.2 to 0.91 µg/L at station W004 (RM 3.7E)
- Dissolved chromium, single point: 0.1 to 0.33 µg/L at station W004 (RM 3.7E)
- Total chromium, transect: 0.29 to 1.1 µg/L at station W005 (RM 3.9)
- Dissolved chromium, transect: 0.12 to 0.29 µg/L at station W011 (RM 6.3).

Chromium concentrations in samples collected during high-flow conditions ranged as follows (the station listed is for the maximum):

- Total chromium, single point: 0.7 to 1.9 J µg/L at station W031 (RM 6.1W)
- Dissolved chromium, single point: 0.43 to 0.64 µg/L at station W034 (RM 7.5W)
- Total chromium, transect: 0.58 to 1.7 at station W027 (Multnomah Channel)
- Dissolved chromium, transect: 0.46 to 0.83 µg/L at station W024 (RM 16).

Neither total nor dissolved chromium was detected in any single-point or transect samples collected during the November 2006 stormwater-influenced flow sampling event.

5.4.13.3 Spatial Distribution of Chromium

All of the total and dissolved chromium surface water results were less than the drinking water MCL of 100 µg/L. DEQ does not have human health or aquatic life criteria for total chromium.

5.4.14 Copper in Surface Water

Copper data are summarized in Tables 5.4-6 through 5.4-11. Transect samples are summarized by flow event in Tables 5.4-6, 5.4-8, and 5.4-10. Single-point samples are summarized by flow event in Tables 5.4-7a-d, 5.4a-d, and 5.4-11a-d. All total and dissolved copper surface water sample results are presented in Tables 5.4-23a-b by sample event and sample location.

Dissolved and particulate copper concentrations in surface water collected from peristaltic pumps are presented in bar graphs by flow event on Figure 5.4-52 and by river mile/channel position on Figure 5.4-53.

Figure 5.4-54 is a line plot of transect copper concentrations in surface water by river mile (RM 2–16). The data points presented in this figure are averages of all data points collected at a particular transect for each measured flow event.

Figure 5.4-55 is a scatter plot of detected copper concentrations in surface water by river mile (RM 2–16). The symbols and colors indicate the sample type—point vs.

transect—and the general flow conditions of the sampling event—low flow, stormwater-influenced flow, or high flow.

5.4.14.1 Copper Data

Peristaltic samples were collected and analyzed by USEPA Method 6020 for total and dissolved copper during Rounds 2A and 3A. Dissolved copper was detected in 99 percent of 174 samples and 100 percent of 174 total copper samples during the Round 2A and 3A sampling events. The overall range of detected concentrations for all total copper samples ranged from 0.65 to 3.68 µg/L.

5.4.14.2 Copper Relationship to River Flow Conditions

Total copper concentrations were generally consistent across the entire study area during the Round 2A and 3A sampling events. Concentrations were generally higher in samples collected during the high-flow sampling events, with concentrations ranging from 1.1 to 3.68 µg/L compared to samples collected during low-flow sampling events, with concentrations ranging from 0.68 to 2.09 µg/L. Forty stormwater-influenced flow samples displayed a narrow range of detections between 0.65 to 1.14 µg/L. Dissolved and particulate copper concentrations in surface water are depicted in histograms by flow event type on Figure 5.4-52 for high-flow, low-flow, and stormwater-influenced flow events.

Copper concentrations in samples collected during low-flow conditions ranged as follows (the station listed is for the maximum):

- Total copper, single point: 0.68 to 2.1 µg/L at station W004 (RM 3.7)
- Dissolved copper, single point: 0.37 to 1.64 µg/L at station W022 (NB; RM 9.7W)
- Total copper, transect: 0.68 to 1.5 µg/L at station W005 (NB; RM 3.9)
- Dissolved copper, transect: 0.45 to 0.83 J µg/L at station W011 (RM 6.3).

Copper concentrations in samples collected during high-flow conditions ranged as follows (the station listed is for the maximum):

- Total copper, single point: 1.5 to 3.5 µg/L at station W031 (NB; RM 6.1W)
- Dissolved copper, single point: 0.55 to 1.2 µg/L at station W035 (NS; RM 8.5E)
- Total copper, transect: 1.1 to 3.7 J µg/L at station W023 (RM 11)
- Dissolved copper, transect: 0.43 to 2.4 J µg/L at station W023 (RM 11).

Copper concentrations in samples collected during stormwater–influenced flow conditions ranged as follows (the station listed is for the maximum):

- Total copper, single point: 0.79 to 1.1 µg/L at station W035 (NS; RM 8.5E)

- Dissolved copper, single point: 0.5 to 0.78 µg/L at station W035 (NS; RM 8.5E)
- Total copper, transect: 0.65 to 1.1 µg/L at station W024 (RM 16)
- Dissolved copper, transect: 0.46 to 1.2 µg/L at station W023-M (RM 11).

5.4.14.3 Spatial Distribution of Copper

All of the total and dissolved copper surface water results were less than the drinking water MCL of 1,300 µg/L and the DEQ human health threshold value of 1,300 µg/L developed to be protective of drinking water and consumption of organisms.

These results do not suggest potential source areas for copper.

5.4.15 Zinc in Surface Water

Data for zinc in surface water are summarized in Tables 5.4-6 through 5.4-11. Transect samples are summarized by flow event in Tables 5.4-6, 5.4-8, and 5.4-10. Single-point samples are summarized by flow event in Tables 5.4-7a-d, 5.4-9a-d, and 5.4-11a-d. All total and dissolved zinc surface water sample results are presented in Tables 5.4-24a-b by sample event and sample location.

Dissolved and particulate zinc concentrations in surface water collected from peristaltic pumps are presented in bar graphs by flow event on Figure 5.4-56 and by river mile/channel position on Figure 5.4-57a-b.

Figure 5.4-58 is a line plot of transect zinc concentrations in surface water by river mile (RM 2–16). The data points presented in this figure are averages of all data points collected at a particular transect for each measured flow event.

Figure 5.4-59 is a scatter plot of detected zinc concentrations in surface water by river mile (RM 2–16). The symbols and colors indicate the sample type—point vs. transect—and the general flow conditions of the sampling event—low flow, stormwater-influenced flow, or high flow.

5.4.15.1 Zinc Data

Peristaltic samples were collected and analyzed by USEPA Method 6020 for total and dissolved zinc during Rounds 2A and 3A. Dissolved zinc was detected in 73 of 174 (42 percent) of samples and 133 of 174 (76 percent) of total zinc samples during the Round 2A and 3A sampling events.

Detected total zinc concentrations in all surface water samples during the Round 2A and 3A sampling events ranged from 1.65 to 57.9 µg/L. The range of detected concentrations of dissolved zinc in all Round 2A and 3A samples was 0.9 to 41.9 µg/L.

5.4.15.2 Zinc Relationship to River Flow Conditions

With the exception of one sample (station W022 on 12/2/2004) with elevated total (57.9 µg/L) and dissolved (41.9 µg/L) zinc concentrations, detected zinc concentrations were within a narrow range regardless of flow. With the exclusion of the highest total result, detected concentrations of total zinc in low-flow samples ranged from 1.65 to 8.8 µg/L at station W004 (RM 3.7E). Comparable to low flow, in high-flow samples, total zinc concentrations ranged from 1.85 to 8.4 µg/L. In contrast, total zinc was not detected during stormwater-influenced flow sampling.

With the exception of the highest dissolved result for W022 on 12/2/2004, detected dissolved zinc concentrations ranged from 0.9 to 4.9 µg/L at station W018 (RM 8.3) in November 2004 in low-flow samples. Dissolved zinc was only detected in one high-flow sample at 2.5 µg/L at station W005 in January 2006. In stormwater-influenced flow samples dissolved zinc was detected in 5 of 39 samples (4.8 to 6.6 µg/L, station W034, NB).

Zinc concentrations in samples collected during low-flow conditions ranged as follows (the station listed is for the maximum):

- Total zinc, single point: 1.6 to 58 µg/L at station W022 (RM 9.7W)
- Dissolved zinc, single point: 0.9 to 42 µg/L at station W022 (RM 9.7W)
- Total zinc, transect: 2.1 to 6.1 µg/L at station W023-W (RM 11W
- Dissolved zinc, transect: 1.4 to 2.2 µg/L at station W023 (RM 11).

Zinc concentrations in samples collected during high-flow conditions ranged as follows (the station listed is for the maximum):

- Total zinc, single point: 3 to 8.4 µg/L at station W031 (NB, RM 6.1W)
- Dissolved zinc, single point: Not detected
- Total zinc, transect: 1.9 to 6.4 µg/L at stations W024 (RM 16) and W023 (RM 11)
- Dissolved Zinc, transect: Detected in only one sample; 2.5 µg/L at station W005 (RM 3.9).

Zinc concentrations in samples collected during stormwater–influenced flow conditions in November 2006 ranged as follows (the station listed is for the maximum):

- Total zinc, single point: Not detected
- Dissolved zinc, single point: 4.8 to 6.6 µg/L at station W034 (NS, RM 7.5W)
- Total zinc, transect: Not detected
- Dissolved zinc, transect: Detected in a single transect stormwater-influenced flow sample at 5.1 µg/L at station W025-M (RM 2).

5.4.15.3 Spatial Distribution of Zinc

All of the total and dissolved concentrations of zinc in surface water were substantially below the ODEQ human health value of 2,100 µg/L developed to be protective of drinking water and consumption of organisms. An MCL has not been established for zinc.

5.4.16 TBT in Surface Water

Data for TBT in surface water are summarized in Tables 5.4-6 through 5.4-11 Transect samples are summarized by flow event in Tables 5.4-6, 5.4-8, and 5.4-10. Single-point samples are summarized by flow event in Tables 5.4-7a-d, 5.4-9a-d, and 5.4-11a-d. All TBT surface water data are presented in Table 5.4-25 by sample event and sample location.

TBT concentrations in surface water collected from peristaltic pumps are presented in bar graphs by flow event and by river mile/channel position on Figures 5.4-60 and Figure 5.4-61, respectively.

Figure 5.4-62 is a line plot of transect TBT concentrations in surface water by river mile (RM 2–16). The data points presented in this figure are averages of all data points collected at a particular transect for each measured flow event.

Figure 5.4-63 is a scatter plot of detected TBT concentrations in surface water by river mile (RM 2–16). The symbols and colors indicate the sample type—point vs. transect—and the general flow conditions of the sampling event—low flow, stormwater-influenced flow, or high flow.

5.4.16.1 TBT Data

Peristaltic samples of surface water were collected and analyzed by the Krone Method (Krone et al. 1989) for TBT during Rounds 2A and 3A. TBT was detected in a 12 of 174 (7 percent) of all surface water samples collected during the Round 2A and 3A sampling events. Detected TBT concentrations in all surface water samples collected during the Round 2A and 3A sampling events ranged from 0.00095 to 0.011 µg/L.

5.4.16.2 TBT Relationship to River Flow Conditions

The small number of TBT detections in surface water samples was associated with a narrow range of detected concentrations regardless of flow. Detected concentrations of TBT in low-flow samples ranged from 9.5×10^{-4} to 0.0023 µg/L. During high-flow sampling events TBT was detected twice at the same station, W035 RM 8.5E, with concentrations of 0.0021 µg/L (NS) and 0.0035 µg/L (NB).

Forty stormwater-influenced flow samples were analyzed for TBT. TBT was detected in only four of these samples at concentrations ranging from 0.001 to 0.011 µg/L.

TBT concentrations in samples collected during low-flow conditions ranged as follows (the station listed is for the maximum):

- Single point: 9.5×10^{-4} to 0.0023 µg/L at station W004 (NB, RM 3.7E)
- Transect: Not detected.

TBT concentrations in samples collected during high-flow conditions ranged as follows (the station listed is for the maximum):

- Single point: 0.0021 to 0.0035 µg/L at station W035 (RM 8.5)
- Transect: Not detected.

TBT concentrations in samples collected during stormwater–influenced flow conditions ranged as follows (the station listed is for the maximum):

- Single point: 0.0013 to 0.0014 µg/L at W035 (NS, RM 8.5E)
- Transect: 0.001 to 0.011 µg/L at W024 (NB, RM 16).

5.4.16.3 Spatial Distribution of TBT

There is neither a DEQ human health nor an aquatic life criteria for TBT ion.

5.4.17 Site-Specific Evaluation of Hydrophobic Contaminants

For the purposes of this evaluation and presentation, hydrophobic contaminants are defined as those contaminants or groups of contaminants that are insoluble or minimally soluble in water and are, therefore, expected to bind strongly to sediments and suspended particulates. The subset of hydrophobic contaminants included in this evaluation are PCBs, dioxins and furans, DDT and related compounds (DDx), and PAHs.

5.4.17.1 Distribution between Total PCBs Dissolved and Particulate Fractions

The following subsections describe observed trends in dissolved and particulate total PCB congener concentration fractions by river mile, event type, and sample type in the Round 2A and 3A data set. The spatial distribution of dissolved and particulate PCBs concentrations and relationships to flow rate, TSS, and f_{oc} are described. PCB congeners were detected in all XAD filter and column samples collected during Round 2A and 3A sampling events.

5.4.17.1.1 Total PCBs Dissolved and Particulate Concentrations

Total PCBs concentrations as a function of flow rate are presented in Figure 5.4-64. Figures 5. 4-65, and 5.4-66 show the dissolved and particulate fractions of total PCBs plotted against flow rate. All of the particulate and dissolved samples with concentrations >0.001 µg/L were collected during low-flow conditions, as well as a single dissolved sample collected during the stormwater-influenced flow sampling event. For the particulate fraction, low-flow single-point samples span a greater concentration range (up to almost 0.01 µg/L) as compared to the remaining samples, which are typically less than 0.001 µg/L. For the dissolved fraction of total PCBs, low-

flow and stormwater-influenced flow samples cover similar concentration ranges, while high-flow samples exhibit generally lower concentrations. Low-flow point samples collected at the upper end of the dissolved concentration range (>5.0×10^{-4} µg/L) tended to have a higher particulate component of the total concentration.

The high-flow samples (both point and transect) tend to exhibit lower dissolved concentrations relative to the stormwater-influenced flow and low-flow samples. This suggests a different character/source of PCB-contaminated sediment and/or suspended solids concentration and character during high-flow events.

The transect sample collected at RM 11 during the low-flow event in November 2004 exhibited a high particulate to dissolved concentration ratio. As noted previously in Section 5.4.4.2, during collection of this sample, the field crews observed runoff from a nearby storm drain, which may have contributed to this result.

5.4.17.1.2 Total PCBs Associations with Suspended Solids

Total PCBs concentrations as a function of TSS are presented on Figure 5.4-67. High-flow samples (single-point and transect) exhibited the widest range and highest concentrations of TSS, from approximately 10 to 60 mg/L, but the lowest PCBs concentrations. Conversely, the remaining samples exhibited a greater range in concentration over a small range in TSS—low-flow TSS concentrations were less than 10 mg/L and stormwater–influenced flow concentrations ranged from approximately 0 to 20 mg/L TSS. The high-flow samples also exhibited a lower dissolved:particulate concentration ratio relative to the stormwater-influenced flow and low-flow samples.

Particulate total PCBs concentrations and particulate organic carbon (POC) concentrations are compared on Figures 5.4-68a-b. The high-flow samples (single-point and transect) exhibited lower PCBs concentrations for the corresponding POC than other flow regimes. The low POC values are consistent with the lower f_{oc} associated with TSS observed in high-flow samples, as shown on Figure 5.4-67. This observation suggests the introduction of suspended particles with low organic carbon content during high-flow events. Further, the solids that become suspended in the water column during high-flow events may have a different character (low f_{oc} and low PCBs concentrations) than those introduced during low-flow or stormwater-influenced flow events.

5.4.17.2 Distribution between Total PCDD/Fs Dissolved and Particulate Fractions

The following subsections describe the observed trends in dissolved and particulate total PCDD/Fs fractions by river mile, event type, sample type, TSS, and f_{oc} of the TSS. This analysis was specific to total PCDD/Fs and, therefore, does not extend to individual dioxins and furans.

5.4.17.2.1 Total PCDD/Fs Dissolved and Particulate Concentrations

The dissolved and particulate fractions of total PCDD/Fs concentrations for each surface water sample are presented as histograms by flow event type on Figure 5.4-14

and by channel position on Figure 5.4-15. As expected for hydrophobic compounds, total PCDD/Fs tend to partition to the particulate fraction in surface water within the study area. The two highest concentrations measured at RM 6.7 and 11 during low-flow and stormwater-influenced flow conditions, respectively, exhibit high particulate to dissolved ratios (greater than an order of magnitude difference between the two phases). This partitioning is consistent for all the samples.

5.4.17.2.2 Total PCDD/Fs Associations with Suspended Solids

Total concentrations as a function of TSS are presented on Figure 5.4-69. Total PCDD/Fs concentrations in high-flow transect samples appear to exhibit a slightly increasing PCDD/Fs concentration trend with higher suspended solids. Concentrations in low-flow and stormwater-influenced flow samples appear to vary independently of suspended solids concentration. Transect and single-point samples collected during low-flow and stormwater–influenced flow events were characterized by TSS values less than those of the high-flow event (Figures 5.4-70).

Particulate total PCDD/Fs concentrations and POC concentrations are compared on Figure 5.4-70. Relative to other flow regimes, POC was relatively low in high flow samples (single point and transect). The stormwater-influenced flow samples tended to exhibit marginally higher POC. Solids that become suspended during stormwater-influenced flow events may have a unique character of high f_{oc} and varying loads of PCDD/Fs. Samples characterized by higher concentrations of total PCDD/Fs did not have corresponding high TSS concentrations. However, these high total PCDD/Fs concentration samples did exhibit a high particulate-phase PCDD/Fs concentration as a function of POC.

5.4.17.3 Distribution between DDx Dissolved and Particulate Fractions

The following subsections describe the observed trends in DDx dissolved and particulate fractions by river mile, event type, sample type, TSS, and f_{oc} of the TSS.

5.4.17.3.1 DDx Dissolved and Particulate Concentrations

The distribution of DDx by river mile is presented on histograms by flow event type on Figures 5.4-20 and histograms by channel position on Figures 5.4-21a-b. Three samples collected at RM 2 (station W025) during low-flow conditions exhibited higher dissolved to particulate ratios. This may be due to the lower suspended solids load in the downstream portion of the study area (at RM 2) rather than an actual shift in partitioning behavior. However, these higher dissolved:particulate ratios are not exclusive to these samples.

DDx concentrations as a function of flow rate are presented in Figures 5.4-71a-b. With the exception of the highest DDx concentrations that were measured at RM 6.9 and 7.2, a relationship between flow rate and DDx concentrations is not evident during low-flow conditions (Figure 5.4-71a). Considering the uncertainty associated with the discharge measurements noted in Section 5.4-2, the similarity in concentration for low-flow

events is not surprising. However, it is apparent in Figure 5.4-71b that there is a general increase in concentration with flow.

5.4.17.3.2 DDx Associations with Suspended Solids

Total concentrations as a function of TSS are presented on Figures 5.4-72a-b. The highest ratios of DDx to TSS were exhibited in low-flow samples, while high-flow samples exhibited a much lower ratio of DDx concentration to TSS. The low-flow and stormwater-influenced flow samples had low suspended solids loads (25 mg/L or lower) compared to high-flow samples (up to 62 mg/L). When the single-point samples with elevated DDx concentrations are excluded, DDx concentrations tend to increase with TSS.

Particulate DDx concentrations and POC concentrations are compared on Figures 5.4-73a-b. With the exception of low-flow single-point samples, DDx concentrations appear independent of POC. High-flow samples exhibited higher TSS concentrations and lower f_{oc} on TSS percentages. Therefore, the higher concentrations in the surface water during high-flow events (Figures 5.4-72a-b) were present in spite of lower POC in the water column. Again, this may suggest a different source or sources of particles, upstream of the study area, given the high inflow concentrations at RM 16 and 11 during high-flow events. Higher POC concentrations were found in transect and single-point stormwater-influenced flow and low-flow samples with lower total particulate DDx concentrations.

5.4.17.4 Distribution between Total PAHs Dissolved and Particulate Fractions

The following subsections describe the observed trends in the dissolved and total PAHs fractions by river mile, event type, sample type, TSS, and f_{oc} of the TSS.

5.4.17.4.1 Total PAH s Dissolved and Particulate Concentrations

The spatial distribution of dissolved and particulate total PAHs concentrations is presented on histograms by flow event type and river mile on Figure 5.4-24 and by channel position on Figures 5.4-25a-b.

Total PAHs concentrations as a function of flow rate are presented in Figure 5.4-74. Four of the five highest concentrations of total PAHs were measured in single-point samples collected during low-flow conditions. Total PAHs concentrations tended to vary independently of flow condition. However, samples with elevated total PAHs concentrations were more evident in low-flow samples from RM 7 to 2 compared to the high-flow and stormwater-influenced flow sampling events. Downstream near RM 2, the low-flow sample concentrations were generally lower than those observed further upstream within the study area.

While a general trend of greater partitioning in the dissolved phased is evident, a notable exception was observed at station W035 at RM 8.5 during the January 2007 high-flow event. Both the NB and NS samples exhibited a greater particulate to

dissolved concentration ratio. Also, at stations W011 (RM 6.3) and W005 (RM 4) the NB samples had noticeably higher particulate total PAHs concentrations in the low-flow and stormwater-influenced flow sampling events. In the January 2007 high-flow sampling event, this pattern was reversed at station W035 (RM 8.5), and the NS sample had the highest particulate total PAHs concentration.

5.4.17.4.2 PAHs Associations with Suspended Solids

Total PAHs concentrations as a function of TSS are presented on Figures 5.4-75. High-flow samples (single-point and transect) exhibited the widest range and highest concentrations of TSS but generally lower total PAHs concentrations. However, there does appear to be a trend of gradually increasing total PAHs concentrations with higher TSS values for the high-flow samples. Low-flow and stormwater-influenced flow samples tended to exhibit low TSS but a wider range of total PAHs concentrations.

Particulate total PAHs concentrations and POC concentrations are compared on Figure 5.4-76. The high-flow samples (single-point and transect) exhibited relatively low total PAHs concentrations and POC. The low POC values are consistent with the lower observed f_{oc} of the suspended solids during this flow condition. Several high-flow samples exhibited POC values equal to zero (Figure 5.4-76) because the calculated POC was considered to be zero if the DOC was greater than the TOC. These low POC values indicate that the high-flow events are associated with low f_{oc} sediments.

5.5 INDICATOR CONTAMINANTS IN TRANSITION ZONE WATER AND GROUNDWATER SEEPS

This section summarizes the study area data for TZW and groundwater seeps. As described in Section 3, the transition zone is defined as the interval where both groundwater and surface water comprise some percentage of the water occupying pore space in the sediments. The primary focus of the transition zone for this investigation is within the shallow sediment (0 to 38 cm bml), which includes the biologically active zone.[12] Deeper (>90 cm bml) TZW samples are also discussed here to lend insight into observed chemical distribution patterns.

The following subsections present tables, plan view maps with histograms, and scatter plots to support brief discussions of nature and extent for the select indicator contaminant list (Table 5.1-2). The full RI data sets for TZW and groundwater seeps for all sampled chemicals (those data of adequate quality) are presented in the RI SCRA database. Indicator contaminant data are summarized in Tables 5.5-1 and 5.5-2, and data for the other contaminants are summarized in Appendix D4.1, Tables D4.1-1 and D4.1-2.

[12] The biologically active zone is defined by the depth of biological processes. The depth of the true biologically active zone varies widely throughout the study area, based on factors that control benthic community structure, such as sediment texture, sediment-water interface dynamics, and organic loading.

5.5.1 Transition Zone Water

The TZW sampling effort was not a harbor-wide study of TZW, but instead was a focused investigation offshore of nine study sites. Other areas of groundwater discharge to the river are not captured in this data set. Further, the sampling investigation of TZW did not seek to distinguish between areas impacted by upland sourced groundwater plumes and areas impacted by river sediments.[13] The approach to site selection is discussed in greater detail in Appendix C2.

The TZW investigations performed for the RI focused solely on areas of confirmed or likely groundwater plume discharge to the river and did not seek to characterize TZW pore water chemistry elsewhere in the study area. Accordingly, this discussion does not address TZW chemistry in areas with no upland groundwater discharge, or areas of clean groundwater flowing through contaminated sediments. Additionally, this study does not distinguish between the relative contribution of upland groundwater plumes and contaminants in sediment to the concentrations measured in TZW.

TZW data are presented on plan-view maps and/or scatter plots for select contaminants to support evaluation of sample composition. These presentations vary by analyte and the data are summarized in Table 5.5-1. As reflected in Table 5.5-1, the TZW analyte lists varied by study site; therefore, it was often unnecessary to produce maps for each river mile for a given analyte.

Maps: Map presentations of TZW data use color-coded symbols and fly out labels to provide the individual concentration values. This presentation includes distinction of peeper samples (0 to 38 cm bml), shallow TZW Trident samples (0 to 30 cm bml) and deeper Trident samples (90 to 150 cm bml), as well as non-LWG (0 to 90 cm bml) Geoprobe samples. Paired map sets are presented for each river mile to show filtered and unfiltered results, where available. Diffusion-based (peeper) samples are presented with a unique symbol on both filtered *and* unfiltered images to allow for a detailed evaluation of results. A histogram of detected contaminant concentrations is inset on each map to provide context for the results presented on the given river mile relative to the results from the entire study area. Histogram bins and concentration color ranges were selected based on professional judgment to best present the complete range of filtered and unfiltered concentration values observed across the study area. Maps 5.5-1 through 5.5-6 are provided for DDx, total PAHs, arsenic, chromium, copper, and zinc.

Scatter Plots: Scatter-plot presentations of TZW data show sample concentrations plotted according to the river mile of the sample location. Color-coded symbols distinguish sample type and depth. Paired plot sets are presented for each contaminant to show filtered and unfiltered results, where available. Peeper samples are presented

[13] In areas not directly affected by transport of contaminants originating in upland groundwater, contaminants may be present in TZW as a result of desorption from contaminated sediments and/or geochemical processes within the sediments and associated TZW.

with a unique symbol on both filtered *and* unfiltered images to allow for a detailed evaluation of results. Scatter plots are provided for DDx, total PAHs, arsenic, chromium, copper and zinc as Figures 5.5-1a-f.

5.5.1.1 TZW Data Set

The TZW presentation provided in this section supports the detailed site-by-site presentation and analysis of groundwater pathways provided in Appendix C2. The Appendix C2 presentation of TZW provides data analysis focused on identification of complete groundwater pathways from upland plumes to the transition zone, including some cross-media analysis. This section focuses on presentation of the distribution of indicator contaminants observed in the transition zone. As such, this section does not discuss all contaminants from groundwater sources within the study area or relate observations to sources. The TZW chemistry data used in this investigation were generated during the following field events:

- **2004 Pilot Study**—Integral (2005f [Appendix B])
- **2005 Round 2 GWPA**—Integral (2006f)
- **2005 Siltronic Investigation**—HAI (2005b); MFA (2005b)
- **2007 Gasco Investigation**—Anchor (2008d).

These sampling activities focused on the offshore area of nine sites along the west bank of the river (see Map 2.1-20):

- Kinder Morgan Linnton Terminal (RM 4.1 to 4.2)
- ARCO Terminal 22T (RM 4.7 to 4.9)
- ExxonMobil Oil Terminal (RM 4.8 to 5.1)
- Gasco (RM 6.1 to 6.5)
- Siltronic (RM 6.3 to 6.5)
- Rhone Poulenc (RM 6.7 to 6.9)
- Arkema (Acid Plant and Chlorate Plant areas; RM 7.2 to 7.5)
- Willbridge Terminal (RM 7.6 to 7.8)
- Gunderson (RM 8.3 to 8.5).

Two general types of sampling techniques were used to collect the TZW samples: diffusion samplers (small-volume peepers) and push probe samplers (Trident and Geoprobe tools were used as push probe samplers). These are described in detail in the Pilot Study FSP (Integral 2004c). All peeper samples were collected over the depth interval of 0 to 38 cm bml. Trident samples were collected at 30 cm bml, with a few

deeper samples collected between 90 and 150 cm bml.[14] Geoprobe samples were collected at depths ranging from 30 to 6,300 cm bml, though only Geoprobe samples from 0 to 90 cm bml are presented in this discussion of TZW nature and extent.[15,16]

Because TZW samples were collected at a single point in time (for Trident and Geoprobe sampling) or over a 3-week equilibration period (for peeper sampling), LWG field sampling events were carefully timed to maximize the expected upland groundwater signal (i.e., the time of greatest groundwater discharge rate). For the Pilot Study and Round 2 TZW investigations, TZW analytical samples were collected from November 2004 to January 2005 and October to December 2005, respectively, before river water levels increased to the higher levels that typically occur from mid-winter through spring. The non-LWG TZW samples collected at Gasco that are included in this nature and extent discussion were collected between July and September 2007. The non-LWG TZW samples collected at Siltronic that are discussed here were collected in May and June of 2005.

5.5.1.2 Total PCBs

TZW samples collected from the offshore areas of the nine sites were not analyzed for PCBs.

5.5.1.3 Total PCDD/Fs

Samples were collected using Trident sampling methodology from two locations adjacent to Rhone Poulenc for PCDD/Fs analyses, RP03C and RP07B. Sample RP03C was collected from a depth of 30 cm bml and analyzed for filtered and unfiltered PCDD/Fs, which were not detected above laboratory reporting limits. A parent and duplicate sample were collected from RP07B from a depth of 30 cm bml for filtered and unfiltered PCDD/F analyses. Total PCDD/Fs were detected in the parent and duplicate unfiltered samples, with concentrations of 29 pg/L and 51.3 pg/L, respectively. Total PCDD/Fs were detected in the parent filtered sample, with a concentration of 0.865 pg/L. Due to the limited set of data, the observed distribution of total PCDD/Fs inTZW could not be adequately described; scatter plots and distribution maps are not presented.

[14] One Trident sample was collected at 60 cm bml at location CP-07-B. This sample is included with the 90 to 150 cm bml data set.

[15] Geoprobe data collected at 91 cm bml was collected for naphthalene and is included in Appendix D.

[16] For the Gasco study (sample IDs that begin with "GS-"), the sample collected at the uppermost depth in the 0 to 90 cm bml interval at each location is presented on maps to represent the TZW concentrations in the shallow layer. No deeper data collected as part of the Gasco study is presented. Only one sample (GS-C2, 73 to 103 cm bml) in the 2007 Gasco investigation was collected in the deeper (90 to 150 cm bml) sample interval; this sample is not included in this nature and extent discussion. For the Siltronic study (sample IDs that begin with "GP-"), samples collected at 31 cm bml are presented as shallow TZW.

5.5.1.4 TCDD TEQ

As described above, samples were collected using Trident sampling methodology from two locations adjacent to Rhone Poulenc for PCDD/Fs analysis, RP03C and RP07B. TCDD TEQs were calculated for the detected results in the parent and duplicate unfiltered samples collected from RP07B. The calculated concentrations were 1.72 J and 1.32 J pg/L, respectively. Due to the limited set of data, the observed distribution of TCDD TEQ in TZW could not be adequately described; scatter plots and distribution maps are not presented.

5.5.1.5 DDx

DDx was sampled offshore of the former Arkema Acid Plant and Rhone Poulenc sites. All but two of the sample locations were offshore of the Arkema Acid Plant site. As shown in Table 5.5-1, the following samples were collected:

- 8 peeper samples (0 to 38 cm bml), including two duplicates, collected offshore of the Arkema site
- 18 shallow (0 to 30 cm bml) Trident samples, including four duplicates, collected offshore of the Arkema site and Rhone Poulenc (with eight collocated filtered and unfiltered samples)
- 5 deep (90 to 150 cm bml) Trident samples (with collocated filtered and unfiltered samples collected at one location), including one location offshore of the Rhone Poulenc site.

DDx compounds were detected in two of the peeper samples, with concentrations of 0.032 J µg/L at AP03B-1 and 0.0135 J µg/L at AP04D. DDx compounds were detected in each of the shallow Trident unfiltered samples with concentrations ranging from 0.0075 J µg/L at AP04D to 3.05 J µg/L at AP03A. DDx compounds were detected in all but three of the shallow Trident filtered samples with detected concentrations ranging from 0.0084 NJA µg/L at AP03B-1 to 0.158 NJ µg/L at RP03C. DDx compounds were detected in all three of the deep Trident unfiltered samples collected offshore of the Arkema site (0.169 J to 5.73 J µg/L) and the one offshore of Rhone Poulenc (0.17 J µg/L). DDx compounds were also detected in the deep filtered sample collected offshore of Rhone Poulenc (0.179 J µg/L).

Map 5.5-1 presents filtered (top panel) and unfiltered (bottom panel) DDx (constituent sums 2,4'- and 4,4'-DDD; 2,4'- and 4,4'-DDE; and 2,4'- and 4,4'-DDT are presented in Appendix D4.2)[17] concentrations measured in shallow (0 to 30 cm bml) Trident and deep (90 to 150 cm bml) Trident samples. Peeper samples (0 to 38 cm bml) are presented with a unique symbol on both filtered *and* unfiltered images to allow for a

[17] Note that 2,4'-DDD, 2,4'-DDE, and 2,4'-DDT were not sampled during the 2004 Pilot Study; therefore, the DDx sum for these samples consists of only the 4,4'-DDx isomers. These results are distinguished with an "A" descriptor on Maps D4.2-1a-c.

detailed evaluation of results. Inset histograms on Map 5.5-1 show the distribution of DDx sample concentrations for detected filtered, unfiltered, and peeper results. Scatter plots of filtered and unfiltered DDx TZW concentrations from Trident and peeper samples are provided on Figure 5.5-1a. All sample results for summed and individual DDx isomers in TZW are presented in the SCRA database.

5.5.1.6 Total PAHs

Total PAHs were sampled at six of the nine TZW study sites: Kinder Morgan, ARCO, ExxonMobil, Gasco, Siltronic, and Willbridge Terminal. The discussion below focuses on total PAH results, which are summarized in Table 5.5-1. High molecular weight PAHs (HPAHs), low molecular weight PAHs (LPAHs), cPAHs, as well as individual PAH results, are presented in Appendix D4.1, Table D4.1-1.

Total PAHs data include the following samples:

- 24 peeper samples (0 to 38 cm bml), including 6 duplicates
- 81 shallow (0 to 30 cm bml) Trident samples, including 15 duplicates, collected from 35 locations (with collocated filtered and unfiltered samples collected at 31 locations)
- 14 deep (90 to 150 cm bml) Trident samples in this data set (with collocated filtered and unfiltered samples collected at 4 locations); duplicate samples collected at 2 locations
- 35 unfiltered samples collected with a Geoprobe from depths of 0 to 90 cm bml.

PAHs were detected in TZW samples offshore of all six sites. Total PAHs were identified in all of the peeper samples, with concentrations ranging from 0.105 J µg/L at KM10A, offshore of Kinder Morgan, to 300 J µg/L at GS01B, offshore of Gasco. Total PAHs were detected in all but three of the shallow Trident unfiltered samples, with concentrations ranging from 0.0025 J µg/L at EM02A, offshore of ExxonMobil, to 3,490 µg/L at GS07B, offshore of Gasco. Total PAHs were identified in all but two of the shallow Trident filtered samples, with detected concentrations ranging from 0.0031 J µg/L at W09A to 1,200 J µg/L at GS02A, which are offshore of Willbridge Terminal and Gasco, respectively.

For the deep Trident samples, total PAHs were detected in all seven unfiltered samples, with the minimum concentration of 0.61 J µg/L measured offshore of ARCO at R2AR02, and the maximum concentration of 430 µg/L measured offshore of Gasco at GS08D. Total PAHs were detected in all four Trident filtered deep samples, with concentrations ranging from 0.182 µg/L to 15.8 µg/L. The minimum filtered concentration was collocated with the minimum unfiltered deep measurement, at R2AR02. The maximum filtered deep concentration was measured at EM03A, offshore of ExxonMobil. Total PAHs were detected in all 35 Geoprobe samples collected from 0 to 90 cm bml, with a minimum concentration of 0.093 µg/L measured at GS-D3

offshore of Gasco, and a maximum concentration of 15,100 µg/L measured at GP73 offshore of the Gasco/Siltronic property boundary.

Total PAHs sample results are presented on Maps 5.5-2a–e. The map set presents filtered (top panel) and unfiltered (bottom panel) TZW results, where available, with inset histograms summarizing the distribution of samples shown on each map relative to the distribution across the TZW data set. Sample results collected between RM 6 and 7 are presented on two maps to allow for presentation of all sample concentration results in this densely sampled area (the first map shows concentration labels for LWG-collected data, and the second map shows concentration labels for non-LWG collected data). Observed total PAHs concentration ranges varied among the offshore study areas, with the highest total PAHs concentrations consistently being observed offshore of the Gasco and Siltronic sites. The lowest range of TZW total PAHs concentrations was observed offshore of the Willbridge Terminal site. These relative concentration ranges are apparent on the inset histograms on Maps 5.5-2a–e.

Scatter plots of filtered and unfiltered total PAHs TZW concentrations from Trident, peeper, and Geoprobe samples are provided on Figure 5.5-1b. These figures show sample concentrations along an x-axis noting the river mile of each sample location. Color-coded symbols distinguish sample type and depth. Paired plot sets are presented for each chemical to show filtered and unfiltered results, where available.

5.5.1.7 BEHP

TZW samples collected from the offshore areas of the nine study sites were not analyzed for BEHP.

5.5.1.8 Total Chlordanes

TZW samples collected from the offshore areas of the nine study were not analyzed for chlordanes.

5.5.1.9 Aldrin

TZW samples collected from the offshore areas of the nine study sites were not analyzed for aldrin.

5.5.1.10 Dieldrin

TZW samples collected from the offshore areas of the nine study sites were not analyzed for dieldrin.

5.5.1.11 Arsenic

TZW samples were analyzed for arsenic at all nine TZW study sites. Sampling results for arsenic are presented on scatter plots in Figure 5.5-1c. This figure shows sample concentrations along an x-axis noting the river mile of each sample location. Color-coded symbols distinguish sample type and depth. Paired plot sets are presented for each chemical to show filtered and unfiltered results, where available. Additionally, arsenic results are presented on Maps 5.5-3a–e. The map set presents filtered (top panel)

and unfiltered (bottom panel) TZW results, where available, with inset histograms summarizing the distribution of samples shown on each map relative to the distribution across the TZW data set.

As shown in Table 5.5-1, arsenic data collected for TZW include results from the following samples:

- 39 peeper samples (0 to 38 cm bml), including 10 duplicates
- 60 shallow (0 to 30 cm bml) filtered Trident samples, including 11 duplicates
- 64 shallow (0 to 30 cm bml) unfiltered Trident samples, including 11 duplicates
- 24 unfiltered and 12 filtered deep (90 to 150 cm bml) Trident samples, including 5 duplicates
- 35 unfiltered and 4 filtered samples collected with a Geoprobe from depths of 0 to 90 cm bml.

Arsenic was detected in TZW samples offshore of all nine sites. Arsenic was detected in all but two of the peeper samples, with concentrations ranging from 0.3 J µg/L (locations ARC03B, ARC06B-1, and ARC06B-2) to 17.2 µg/L at W04C. The maximum detected concentration was identified offshore of the Willbridge Terminal site. Arsenic was detected in 55 of the shallow Trident filtered samples, with detected concentrations ranging from 0.55 µg/L at W09A, offshore of Willbridge Terminal, to 76.8 µg/L at EM03A, offshore of ExxonMobil. Arsenic was detected in all but three of the shallow Trident unfiltered samples with concentrations ranging from 0.72 µg/L at CP08B to 51.2 µg/L at W12A, which are offshore of Arkema and Willbridge Terminal, respectively.

For the unfiltered deep Trident samples, total arsenic was detected in all but one sample. The minimum detected concentration of 1.36 J µg/L was measured offshore of Gunderson at GN05A, and the maximum concentration of 77.1 µg/L was measured offshore of ExxonMobil at EM03A. Dissolved arsenic was detected in all 12 filtered deep Trident samples, with concentrations ranging from 0.98 to 77.3 µg/L. The minimum and maximum filtered concentrations were collocated with the minimum and maximum unfiltered concentrations, at stations GN05A and EM03A, respectively. Arsenic was detected in 22 of the 35 unfiltered Geoprobe samples, with the minimum detected concentration of 0.77 µg/L measured at GS-C3, and the maximum concentration of 65.4 J µg/L measured at GS-D3, both offshore of Gasco. Dissolved arsenic concentrations in the four filtered Geoprobe samples ranged from 0.94 to 5.52 µg/L, measured offshore of Gasco at stations GS-B1 and GS-B5, respectively.

5.5.1.12 Chromium

Samples collected at all nine TZW study sites were analyzed for chromium. Analytical results for chromium are presented on scatter plots in Figure 5.5-1d. These figures show sample concentrations along an x-axis noting the river mile of each sample location. Color-coded symbols distinguish sample type and depth. Paired plot sets are presented

for each chemical to show filtered and unfiltered results, where available. Additionally, chromium results are presented on Maps 5.5-4a–e. The map set presents filtered (top panel) and unfiltered (bottom panel) TZW results, where available, with inset histograms summarizing the distribution of samples shown on each map relative to the distribution across the TZW data set.

As shown in Table 5.5-1, chromium data collected within the study area offshore of the nine sites referenced above include results from the following samples:

- 39 peeper samples (0 to 38 cm bml), including 10 duplicates
- 62 shallow (0 to 30 cm bml) filtered Trident samples, including 11 duplicates
- 65 shallow (0 to 30 cm bml) unfiltered Trident samples, including 11 duplicates
- 25 unfiltered and 13 filtered deep (60 to 150 cm bml) Trident samples, including 3 unfiltered and 2 filtered duplicates
- 35 unfiltered and 4 filtered samples collected with a Geoprobe from depths of 0 to 90 cm bml.

Chromium was detected in TZW samples collected from locations offshore of all nine sites. Chromium was detected in 17 of the Peeper samples, with concentrations ranging from 0.92 µg/L at location CP09D to 31.6 µg/L at CP07B, both of which were identified offshore of the Arkema site. Chromium was detected in 34 of the shallow Trident filtered samples, with detected concentrations ranging from 0.2 J µg/L at W09A, offshore of Willbridge Terminal, to 98.3 µg/L at CP07B, offshore of Arkema. Chromium was detected in 45 of the shallow Trident unfiltered samples with concentrations ranging from 0.79 µg/L at SL03A to 122 µg/L at CP07B, which are offshore of Siltronic and Arkema, respectively.

For the unfiltered deep Trident samples, total chromium was detected 20 samples. The minimum detected concentration of 0.8 µg/L was measured adjacent to Rhone Poulenc at RP02E, and the maximum concentration of 102 µg/L was measured offshore of the Arkema site at CP07B. Dissolved chromium was detected in seven filtered deep Trident samples, with concentrations ranging from 0.36 µg/L at EM01A, offshore of ExxonMobil, to 49.6 µg/L at CP07B. Chromium was detected in all of the 35 unfiltered Geoprobe samples, with the minimum detected concentration of 2.07 µg/L measured at GS-D2 offshore of Gasco, and the maximum concentration of 537 µg/L measured at GS-B9 offshore of Siltronic. Dissolved chromium concentrations in the three detected filtered Geoprobe samples ranged from 0.45 to 0.69 µg/L, measured offshore of Gasco at stations GS-B4 and GS-B5, respectively.

5.5.1.13 Copper

Samples collected at all nine TZW study sites and non-LWG Gasco and Siltronic field events were analyzed for copper. Analytical results for copper are presented on scatter plots in Figure 5.5-1e. These figures show sample concentrations along an x-axis noting the river mile of each sample location. Color-coded symbols distinguish sample type

and depth. Paired plot sets are presented for each chemical to show filtered and unfiltered results, where available. Additionally, copper results are presented on Maps 5.5-5a–e. The map set presents filtered (top panel) and unfiltered (bottom panel) TZW results, where available, with inset histograms summarizing the distribution of samples shown on each map relative to the distribution across the TZW data set.

As shown in Table 5.5-1, copper data collected within the study area offshore of the nine sites referenced above include results from the following samples:

- 39 peeper samples (0 to 38 cm bml), including 10 duplicates
- 50 shallow (0 to 30 cm bml) filtered Trident samples, including 9 duplicates
- 53 shallow (0 to 30 cm bml) unfiltered Trident samples, including 9 duplicates
- 18 unfiltered and 12 filtered deep (90 to 150 cm bml) Trident samples, including 3 unfiltered and 2 filtered duplicates
- 35 unfiltered and 4 filtered samples collected with a Geoprobe from depths of 0 to 90 cm bml.

Copper was detected in TZW samples collected from locations offshore of all nine sites. Copper was detected in five peeper samples, with concentrations ranging from 1.63 µg/L at location ARC02B to 22.1 µg/L at CP07D. The maximum detected concentration was identified offshore of the Arkema site. The remaining four detected copper concentrations were identified in samples collected from locations offshore of ARCO.

Copper was detected in 10 of the shallow Trident filtered samples, with detected concentrations ranging from 0.36 µg/L at R2KM01 to 3.63 µg/L at R2RP03, which are offshore of Kinder Morgan and Rhone Poulenc, respectively. Copper was detected in 35 of the shallow Trident unfiltered samples with concentrations ranging from 1.54 µg/L at ARC02B to 63.1 µg/L at EM02C, which are offshore of ARCO and ExxonMobil, respectively.

For the unfiltered deep Trident samples, total copper was detected 13 samples. The minimum detected concentration of 1.79 µg/L was measured adjacent to Rhone Poulenc at RP02E, and the maximum concentration of 43.7 µg/L was measured offshore of the Siltronic site at SL03F. Dissolved copper was detected in 7 filtered deep Trident samples, with concentrations ranging from 0.24 µg/L at GN05A, offshore of Gunderson, to 1.89 J µg/L at R2AR02, offshore of ARCO. Copper was detected in 29 of the unfiltered Geoprobe samples, with the minimum detected concentration of 1.01 J µg/L measured at GS-C6, offshore of Gasco, and the maximum concentration of 555 µg/L measured at GS-B9, offshore of Siltronic. Dissolved copper concentrations were detected in all four filtered Geoprobe samples; concentrations ranged from 0.28 µg/L at locations GS-B4 and GS-B5 to 0.79 µg/L at GS-B2, all measured offshore of Gasco.

5.5.1.14 Zinc

Samples collected from all nine TZW study sites and non-LWG Gasco and Siltronic field events were analyzed for zinc. Analytical results for zinc are presented on scatter plots in Figure 5.5-1f. These figures show sample concentrations along an x-axis noting the river mile of each sample location. Color-coded symbols distinguish sample type and depth. Paired plot sets are presented for each chemical to show filtered and unfiltered results, where available. Additionally, zinc results are presented on Maps 5.5-6a–e. The map set presents filtered (top panel) and unfiltered (bottom panel) TZW results, where available, with inset histograms summarizing the distribution of samples shown on each map relative to the distribution across the TZW data set.

As shown in Table 5.5-1, zinc data collected within the study area offshore of the nine sites referenced above include results from the following samples:

- 39 peeper samples (0 to 38 cm bml), including 10 duplicates
- 60 shallow (0 to 30 cm bml) filtered Trident samples, including 11 duplicates
- 64 shallow (0 to 30 cm bml) unfiltered Trident samples, including 11 duplicates
- 24 unfiltered and 12 filtered deep (60 to 150 cm bml) Trident samples, including 3 unfiltered and 2 filtered duplicate samples
- 35 unfiltered and 4 filtered samples collected with a Geoprobe from depths of 0 to 90 cm bml.

Zinc was detected in TZW samples collected from locations offshore of all nine sites. Zinc was detected in 18 peeper samples, with concentrations ranging from 7.11 J µg/L at location R2KM02, which is offshore of Kinder Morgan, to 418 µg/L at R2CP01. The maximum detected concentration was identified offshore of the Arkema site.

Zinc was detected in 32 of the shallow Trident filtered samples, with detected concentrations ranging from 0.95 µg/L at R2KM01 to 526 µg/L at R2AR01, which are offshore of Kinder Morgan and ARCO, respectively. Zinc was detected in 39 of the shallow Trident unfiltered samples with concentrations ranging from 7.81 J µg/L at W09A to 556 µg/L at R2AR01, which are offshore of Willbridge Terminal and ARCO, respectively.

For the unfiltered deep Trident samples, total zinc was detected 17 samples. The minimum detected concentration of 18.6 J µg/L was measured at AP03D offshore of Arkema Acid Plant area, and the maximum concentration of 161 µg/L was measured at CP07B offshore of the Arkema Chlorate Plant area. Dissolved zinc was detected in seven filtered deep Trident samples, with concentrations ranging from 1.87 J µg/L at AR01A to 9.78 µg/L at R2AR02, both offshore of ARCO. Zinc was detected in all but one of the 35 unfiltered Geoprobe samples, with the minimum detected concentration of 8.3 µg/L measured at GS-C6 and the maximum concentration of 3,590 µg/L measured at GS-B4, both offshore of Gasco. Dissolved zinc concentrations in the filtered

Geoprobe samples ranged from 2.93 to 22.5 µg/L, measured offshore of Gasco at stations GS-B2 and GS-B5, respectively.

5.5.1.15 TBT

TZW samples collected from the offshore areas of the nine study sites were not analyzed for TBT.

5.5.2 Groundwater Seeps

This section summarizes the location, available chemical data, and data quality assessment for upland groundwater seeps. The groundwater seep data set is limited because a comprehensive seep characterization was not part of the Portland Harbor RI program. Consequently, the data set does not lend itself to the same contaminant distribution discussions applied to TZW and other media in this report (specifically, discussion of select analytes).

5.5.2.1 Groundwater Seep Locations

A seep reconnaissance survey was conducted during Round 1 of the Portland Harbor RI/FS (GSI 2003a) to support the BHHRA and development of the CSM. This survey documented readily identifiable groundwater seeps based on visual observations along approximately 17 miles of riverbank from RM 2 to 10.5. For the purposes of this survey, a seep was defined as groundwater discharge above the Willamette River waterline as observed during the seep reconnaissance survey. This groundwater may be discharged from local shallow groundwater systems, perched groundwater, water seeping through utility backfill, or return flow from tidally influenced bank storage. Observed seeps were classified into one or more of five types:

- Seepage line at the base of embankments (nine seeps)
- Linear and point seeps at the foot of beaches (six seeps)
- Seepage through backfill surrounding outfalls (four seeps)
- Seepage of NAPL (two seeps)
- Potential seep locations identified by observation of extensive ferric hydroxide staining of bank materials (eight potential seeps).

Additionally, eight seeps were categorized as combinations of the above seep types.

5.5.2.2 Groundwater Seep Water Quality Data

Seep water quality samples have been collected at six seeps in four general areas (Map 5.4-7). The water quality sampling efforts conducted for upland groundwater seeps include:

- City of Portland stormwater Outfalls 22B and 22C, located directly north and south of the Railroad Bridge at RM 6.89 and 6.82, respectively, are type 3 (backfill surrounding outfalls) seeps. Both Rhone Poulenc and NW Natural

have collected water quality samples in Outfalls 22B and 22C to evaluate potential groundwater infiltration to the conveyance systems. These results are described in the next two bullets in this list.

- Rhone Poulenc sampled Outfall 22B on five occasions between October 1, 1993 and September 23, 2004, and Outfall 22C four times between August 13, 2002 and September 23, 2004. Samples were collected at the end of the pipe and were analyzed for 231 individual parameters, including conventionals, total PCDD/Fs, herbicides, metals, total PAHs, PCB Aroclors, pesticides, petroleum hydrocarbons, phenols, phthalates, SVOCs, and VOCs. The results are Category 1 data validated to the QA2 level, with the exception of petroleum hydrocarbon results measured on September 23, 2004, which are Category 2 data and will be excluded from this discussion.
- NW Natural sampled Outfall 22C on February 24, 2005 for 89 individual parameters, including conventionals, metals, total PAHs, phenols, phthalates, SVOCs, and VOCs. Data were validated to Category 2, QA1 level.
- Seeps-01, -02, and -03 are located at the Gunderson site near RM 8.5. These type 3 seeps are associated with cracked stormwater drain pipes. Each seep was sampled once in November 2004 and again in April 2005, with samples analyzed for 31 individual parameters, including conventionals, metals, PCB Aroclors, PAHs, petroleum hydrocarbons, SVOCs, VOCs, and phthalates. Data were validated to Category 1, QA1.
- ExxonMobil sampled areas with visible sheen on sand and in pooled water along the riverbank at the ExxonMobil site under the direction of DEQ on August 13, 2004 (Kleinfelder 2004a) and October 6, 2003. Two composite samples were analyzed as soils for total petroleum hydrocarbons (diesel), total petroleum hydrocarbons (gasoline), and total petroleum hydrocarbons (residual). Data were validated to the QA1 level. All results were below instrument detection limits.

A summary of the indicator contaminant data collected at each of the above mentioned locations is provided in Table 5.5-2. Seep data collected from these locations for other contaminants are presented in Appendix D4.1 (Table D4.1-2).

5.6 INDICATOR CONTAMINANTS IN BIOTA

This section summarizes the fish and invertebrate tissue data collected in support of the RI. Fish and invertebrate tissue chemistry data were collected to estimate exposure concentrations (as tissue residues or diet) for each of the targeted species, which were selected to represent a variety of feeding guilds. The discussion of the indicator contaminants addressed in this section focuses primarily on the following elements:

- A description of the data set for each indicator contaminant, including the number of samples collected of each fish and invertebrate species by tissue type and the locations from which those samples were collected
- A summary of the range of detected indicator contaminant concentrations in the tissue samples collected of each species from locations in the study area, as well as in samples collected from the downstream reach, the study area, the downtown reach and from the upriver reach including locations above Willamette Falls
- A presentation of the locations with the highest indicator contaminant concentrations found in the study area, as well as in samples collected from the other reaches listed in previous bullet.

The following subsections include presentation of tables and other graphical formats to support brief discussions of the nature and extent of contamination in biota tissue associated with the selected indicator contaminants (Table 5.1-2). Table 5.6-1 provides a summary of data for fish tissue collected from the study area (RM 1.9–11.8). Table 5.6-2 provides a summary of data for fish tissue collected from the downstream reach (RM 0–1.9 and Multnomah Channel). Table 5.6-3 provides a list of the fish and invertebrate samples collected from the downtown reach (RM 11.8–15.3), and from the upriver reach (RM 15.3–28.4), including locations above Willamette Falls. Table 5.6-4 provides a summary of data for fish tissue collected from the Downtown and upriver Reaches. Table 5.6-5 provides a summary of data for invertebrate tissue collected from the study area. Table 5.6-6 provides a summary of data for invertebrate tissue collected from the downstream reach. Table 5.6-7 provides a summary of data for invertebrate tissue collected from the downtown Reach and the upriver Reach. The full RI data sets for biota samples for all analyzed contaminants (those data of adequate quality) are presented in the RI SCRA database and summarized in Appendix D5.

All contaminant concentrations in tissue are reported on a wet-weight basis. Summary statistics for indicator contaminants in fish and invertebrate tissue samples are provided in Tables 5.6-1, 5.6-2, and 5.6-4 through 5.6-7. Two sets of summary information are provided in the summary statistics tables:

- Detected concentrations only
- Detected and non-detected concentrations combined.

The nature and extent of indicator contaminants in fish and invertebrate tissue provided in this section is based on the data and statistics calculated for detected concentrations only. Summary statistics for all analytes measured in tissue samples are provided in Tables D5.1-1 through D5.1-6 in Appendix D5. Indicator contaminant data are presented for the study area, downstream reach and downtown reach, followed by a presentation of the upriver reach including above the Willamette Falls areas. Data are not available for every indicator contaminant in every tissue since study designs varied and insufficient material was available in some cases to complete all planned analyses.

Tables 2.3-8 and 2.3-9a-b summarize the samples and analyses available for the study area as provided in the SCRA database. The discussion of the indicator contaminants includes a description of the data set, concentration ranges, and references to figures and tables to help interpret the distribution of indicator contaminants in biological tissues.

The biota data are depicted in several graphical formats: scatter plots, box-whisker plots, and concentration maps. Because the number of tissue samples collected from areas immediately adjacent to the study area (i.e., downstream reach and downtown reach) was small, these biota data are combined with the study area data set in the graphical displays. However, the discussion of the nature and extent of indicator contaminants, presented below per each individual indicator contaminant, and the associated tables, provide a summary of the data by species (e.g., clam) and tissue type (e.g., whole body fish or depurated clam tissue without shell) for samples collected from the downstream reach, within the study area, from the downtown reach, and from the upriver reach. Thus, the data from the referenced composite samples in Table 5.6-8, which are here combined for presentation purposes only, are not part of the study area data set and were not included in the study area BHHRA (Appendix F) and BERA (Appendix G) data sets.

Scatter Plots: A series of scatter plots (Figures 5.6-1 through 5.6-14) for each indicator contaminant provides contaminant concentrations by river mile for select species (smallmouth bass, sculpin, clam, crayfish, and *Lumbriculus variegatus* worms) and tissue type (e.g., whole body fish, depurated clam tissue without shell). A number of species were caught within target fishing zones (1-mile fishing zones; 3-mile fishing zones; and 3-mile fishing zones for Round 1 and 4-mile fishing zones for Round 3 for carp specifically). Individual fish caught in different locations within each fishing zone were composited to create a sample for analysis. The centroid of each fishing zone is used to represent these composite samples on the scatter plots.

Box-Whisker Plots: Figures 5.6-15 through 5.6-28 are a series of box-whisker plots that present the concentrations of indicator contaminants for whole body tissue samples of the various fish and invertebrate species. These plots were developed using R for Windows v. 2.7.0. (R Development Core Team 2008). The horizontal center line in each box represents the median concentration, and the top and bottom of the box represent the upper and lower quartiles, respectively. The upper whisker represents the highest concentration that is less than the upper quartile plus 1.5 times the interquartile range, and the lower whisker represents the lowest concentration that is greater than the lower quartile minus 1.5 times the interquartile range. Outliers are represented individually by small circles above and below the boxes.

Box-whisker plots and scatter plots for additional contaminants identified in Table 5.1-2 are provided as part of Appendix D5.

Concentration Maps: Concentration maps (Maps 5.6-1 through 5.6-16) plot indicator contaminant concentrations (and qualifiers) for each tissue sample used in the BHHRA or BERA. All forms of tissue (i.e., whole body, fillet, fillet without skin, stomach contents, etc.) are shown. Individual fish collection locations from each sample composite are color coded to match the appropriate sample composite identification code from the concentration table. Units are indicated for each contaminant in the individual sample concentration tables. The summary of indicator contaminant concentrations presented below for each species and tissue type includes a parenthetical reference to the river mile and associated map for the maximum detected concentration.

5.6.1 Biota Data Set

The biota data set includes fish and invertebrate samples collected by the LWG as part of Rounds 1, 2, and 3 of the Portland Harbor RI/FS, as well as samples collected by other parties, as described in Section 2. The number and type of tissues collected from the study area are provided in Section 2 of this RI. Table 2.3-8 provides the study name, sample count, and a summary of analyses for each species and tissue type, and Tables 2.3-9a-b detail the sample count for each individual contaminant analyzed for each species and tissue type for LWG and non-LWG samples. Table 2.3-10 provides the number of fish and invertebrates in each sample composite.

Eleven fish species, four benthic invertebrate species, epibenthic communities, and fish stomach contents are represented. Fish and invertebrate tissue samples were collected from the study area and from adjacent areas, including the downstream reach and Multnomah Channel near its divergence from the lower Willamette River and the downtown reach. Biota data were also available from samples collected at locations within the upriver reach (RM 15.3–28.4) of the river.

5.6.2 Total PCBs in Biota

PCBs in tissue samples were analyzed as Aroclors or congeners. In most Round 1 samples, both analyses were completed; however, Round 1 whole-body largescale sucker, northern pikeminnow, peamouth, all fillets, and crayfish samples were only analyzed for Aroclors. In Rounds 2 and 3, LWG biota samples were analyzed for all 209 PCB congeners. Biota samples collected by other parties were sometimes analyzed for a limited number of congeners. In accordance with the RI data summation rules, samples with fewer than 100 PCB congeners were not summed. This section presents a summary of the distribution of total PCBs using total congeners, when available. When congener data are unavailable, total PCBs concentrations are based on total Aroclors for each species and tissue type. Scatter plots showing the distribution of total PCBs concentrations in select biota tissue collected from the study area are provided on Figures 5.6-1a-e. A box-whisker plot showing the distribution of PCB concentrations in whole body tissue samples collected of each species is provided on Figure 5.6-15.

5.6.2.1 PCBs in Fish Tissue

This section presents a summary of the distribution of total PCBs in fish tissue by presenting total PCBs concentrations. As shown in Table 5.6-1, PCBs were detected in all fish samples collected from the study area. Additional sculpin samples were collected from the downstream reach, as presented in Table 5.6-2. Selected fish species were also collected from the downtown reach, as shown in Table 5.6-4. Species-specific data are summarized below by tissue type.

Black Crappie

Individual black crappie samples were collected over a 6-mile reach of the river and were composited for laboratory analysis. A total of four fillet (with skin) composite samples collected within the study area were submitted for laboratory analysis of PCB Aroclors, and presented as total PCBs in Table 5.6-1. PCB Aroclors were detected in all four fillet samples, with concentrations ranging from 19.6 to 32 µg/kg (maximum concentration between RM 6 and 9; Map 5.6-1b).

A total of four whole body composite samples collected from the study area were analyzed for 209 PCB congeners and Aroclors. Total PCB congeners were detected in all samples, ranging from 103 J to 301 J µg/kg (maximum concentration between RM 6 and 9; Map 5.6-1b).

Brown Bullhead

Brown bullhead samples were collected over an approximately 6-mile reach of the river and were composited for laboratory analysis. A total of six skin-off fillet composite samples collected within the study area were submitted for laboratory analyses of PCB Aroclors, which are also presented as total PCBs in Table 5.6-1. PCB Aroclors were detected in all samples, with concentrations ranging from 37 to 1,300 J µg/kg (maximum concentration between RM 6 and 9; Map 5.6-2b).

A total of six whole body composite samples collected within the study area were submitted for laboratory analyses of PCBs. PCBs were detected in all six samples, with total PCBs based on congener analysis ranging from 83.3 J to 1,950 J µg/kg (maximum concentration between RM 6 and 9; Map 5.6-2b).

Two whole body brown bullhead were collected from the upriver reach, with total PCB congener concentrations ranging from 19.1 J to 56.3 J (maximum concentration between RM 23 and 24; Map 5.6-15a).

Carp

Twelve skin-on fillet composite samples of carp were collected within the study area and analyzed for PCB congeners. PCBs were detected in all 12 skin-on fillet composite samples, with concentrations ranging from 265 J to 19,700 J µg/kg (maximum concentration between RM 4 and 8; Map 5.6-3b).

Twelve whole body composite samples of carp were also collected within the study area and analyzed for PCBs. These 12 samples included 6 whole body samples and 6 samples based on combined fillet and body without fillet fractions. PCBs were detected in all 12 samples, with total PCB concentrations ranging from343 J to 25,100 J µg/kg (maximum concentration between RM 4 and 8; Map 5.6-3b). Six body without fillet samples were analyzed, and PCBs were detected all 6 samples, with total PCB concentrations ranging from 405 J to 27,100 µg/kg, also collected between RM 4 and 8.

Nine composite carp samples were collected within the downstream reach (between RM 0 and 1.9 and Multnomah Channel; Map 5.6-3a) and submitted for analysis of PCBs, which were detected in each sample Total PCBs concentrations for three skin-on fillet composite samples ranged from 210 to 260 µg/kg. Total PCBs concentrations for three body without fillet composite samples ranged from 322 J to 417 J µg/kg. Total PCBs concentrations for three combined fillet and body without fillet fractions ranged from 295 J to 377 J µg/kg.

Chinook Salmon

Chinook salmon composite samples were collected within the study area and from the Downtown and upriver reaches. Fifteen juvenile whole body Chinook salmon samples were collected within the study area and were composited for laboratory analyses of PCBs. PCBs were detected in all 15 samples, with total PCB concentrations ranging from 30 J to 277 J µg/kg (maximum concentration between RM 3 and 4; Map 5.6-4a).

Eight juvenile whole body composite samples were also collected from the upriver reach, with concentrations of total PCBs ranging from 12.8 J to 21.6 J µg/kg (between RM 17 and 18; Map 5.6-16).

Also collected from the Clackamas River Fish Hatchery were three skin-on fillet samples, with total PCBs concentrations ranging from 8.71 to 15.3 µg/kg. Finally, three skin-off fillet samples were collected from the upriver reach, and total PCBs concentrations in those samples ranged from 6.89 to 12.4 µg/kg.

Five composites of juvenile Chinook salmon were collected within the study area and submitted for PCB analyses of stomach contents. PCBs were detected in all five samples, with total PCBs based on congener analysis ranging from 53.8 J to 162 J µg/kg (maximum concentration between RM 9 and 10; Map 5.6-4b).

Stomach contents of the single composite sample collected from the upriver reach contained 10.6 J µg/kg of total PCBs (between RM 17 and 18; Map 5.6-16).

Lamprey Ammocoetes and Macropthalmia

Six juvenile (ammocoetes and macropthalmia) lamprey composite samples were collected within the study area and were composited for PCB analyses. PCBs were detected in all six samples, with total PCBs concentrations ranging from 80.6 J to

399 J µg/kg (ammocoete; maximum concentration between RM 1.9 and 10; Map 5.6-8). PCBs were also detected in the eight composite samples collected from the upriver reach, and total PCBs in those composite samples ranged from 31.3 J to 52.8 J µg/kg (maximum concentration between RM 18 and RM 19; Map 5.6-16).

Largescale Sucker

Six whole body composites of largescale sucker were collected from the study area and submitted to the laboratory for PCB analysis. Total PCBs concentrations of these six samples ranged from 95 to 2,020 J µg/kg (maximum concentration between RM 2 and 4; Map 5.6-10a).

Northern Pikeminnow

Six whole body composites of northern pikeminnow were collected from the study area and submitted to the laboratory for PCB analysis. Total PCBs concentrations of these six samples ranged from 370 to 1,800 µg/kg (maximum concentration between RM 6 and 7; Map 5.6-10a).

Peamouth

Four whole body composites of peamouth were collected from the study area and submitted to the laboratory for PCB analysis. Total PCBs concentrations of these four samples ranged from 138 to 290 µg/kg (maximum concentration between RM 8 and 10; Map 5.6-10b).

Sculpin

Forty-two whole body composite samples of sculpin were collected and submitted to the laboratory for PCB analysis. Thirty-eight of these samples were collected from the study area, with total PCBs concentrations ranging from 62 J to 8,770 J µg/kg (RM 11 to 12; Map 5.6-11f).

Two whole body composites were collected below the study area, with total PCB concentrations of 80.9 J and 87.7 J µg/kg (maximum concentration between RM 1 and 2; Map 5.6-11a). Two whole body sculpin composites were also collected from the downtown reach, with total PCBs concentrations of 55.8 J and 277 J µg/kg (maximum concentration between RM 11 and 13; Map 5.6-11f).

Smallmouth Bass

Sixty-one smallmouth bass samples were collected and submitted to the laboratory for PCB analysis. All but 6 of these samples were collected from the study area. Study area samples included 23 fillet composites and 14 whole body composites (Maps 5.6-12a-e). In addition, concentrations were derived for 18 composites by calculating concentrations for fillet and body without fillet fractions.

Total PCBs concentrations of these study area smallmouth bass samples ranged as follows:

- Fillet—27 J to 1,480 J µg/kg (RM 11 to RM 12; Map 5.6-12e)
- Combined fillet and body without fillet fractions—205 J to 6,600 J µg/kg (RM 11 to 12; Map 5.6-12e)
- Body without fillet—264 J to 8,160 J µg/kg (RM 11 to 12)
- Whole body—344 J to 4,530 J µg/kg (RM 8 to near 9)

Total PCB concentrations of the six whole body composites collected from the downtown and upriver reaches ranged from 78.1 J to 317 J µg/kg ((maximum concentration between RM 20 and RM 25; Map 5.6-15a).

Sturgeon

Twenty-one sturgeon samples were collected from the study area and submitted to the laboratory for PCB analysis. These included 5 composite skin-off fillet samples, 15 whole body samples, and 1 sample for stomach contents.

Whole body total PCB concentrations ranged from 69.1 J to 325 J µg/kg (maximum concentration between RM 7 and 8). Total PCB concentrations of skin-off fillet samples ranged from 84.7 to 964 µg/kg (maximum concentration between RM 6 and 7; Map 5.6-13b). The total PCB concentration of the single stomach contents sample equaled 10.6 J µg/kg (between RM 7 and 8; Map 5.6-13b).

5.6.2.2 PCBs in Invertebrate Tissue

This section presents a summary of the distribution of total PCBs concentrations in invertebrate tissue samples. As shown in Table 5.6-5, PCBs were detected in all invertebrate species collected from the study area, with the exception that PCBs were not detected in 15 out of 27 crayfish tissue composites that were only analyzed for Aroclors, which have a higher detection limit than PCB congeners. Aroclors were only measured in Round 1 and non-LWG samples. Additional invertebrate samples were collected from the downstream reach, as presented in Table 5.6-6. Selected invertebrate species were also collected from the downtown reach, as shown in Table 5.6-7. Species-specific data are summarized below by tissue type.

Clams (Resident)

All clam samples consisted of composited soft parts only (body without shell). Forty composites of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for PCB analysis, with concentrations ranging from 50.1 J to 2,650 J µg/kg (maximum concentration between RM 6 and 7; Map 5.6-5d). Three additional depurated composite samples were collected within the study area, with total PCBs concentrations ranging from 82.6 J to 480 µg/kg (maximum concentration between RM 11 and 12; Map 5.6-5f).

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. The total PCB concentrations in the non-depurated samples were 70.4 J and 127 µg/kg, while the total PCB concentration of the depurated sample

was 110 J µg/kg (Map 5.6-5a). An additional non-depurated clam composite sample was collected in the downstream reach with a total PCBs concentration of 70.4 J µg/kg (Map 5.6-5a).

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. The total PCB concentrations in the two non-depurated clam samples were 39.1 J and 141 J µg/kg (Map 5.6-5f). The total PCBs concentration of the depurated sample from the downtown reach was 87.2 J µg/kg (Map 5.6-5f).

Clams (Laboratory-Exposed)

Thirty-four additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by analyses of soft body parts for PCBs. The total PCBs concentrations of these 34 laboratory-exposed samples ranged from 19.1 J to 189 µg/kg (maximum concentration between RM 8 and 9; Map 5.6-6e).

One clam result was generated by exposing laboratory reared clams to downstream reach sediments, followed by analyses of soft body parts for PCBs. The total PCB concentration of this one sample is 19.1 J µg/kg (Multnomah Channel; Map 5.6-6b).

Crayfish

Thirty-two whole body crayfish composites were collected within the study area and analyzed for PCBs. PCBs were not detected in 10 samples, but were detected in 22 samples. Total PCBs concentrations of those 22 samples ranged from 10.1 J to 1,190 J µg/kg (maximum concentration between RM 11 and 12; Map 5.6-7d).

Two composite whole body crayfish samples were collected from the downstream reach. The total PCBs concentrations in these two samples were 7.14 J and 7.16 J µg/kg (between RM 1 and 2; Map 5.6-7a).

Two composite whole body crayfish samples were also collected from the downtown reach. The total PCBs concentrations in these two samples were 7.41 J and 19.4 J µg/kg (between RM 12 and 13; Map 5.6-7d).

Epibenthic Invertebrates

Seven composite samples of epibenthic invertebrates (mixed taxa) were collected from the study area and analyzed for PCBs, with total PCBs concentrations ranging from 33.1 J to 498 µg/kg (maximum concentration between RM 6 and 7; Map 5.6-9a).

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory-reared worms to study area sediments, followed by analyses of whole body worms for PCBs. Total PCBs were detected in all samples, with concentrations ranging from 44.8 J to 4,310 J µg/kg (maximum concentration between RM 8 and 9; Map 5.6-14e).

One result was generated by exposing laboratory reared worms to downstream reach sediments, followed by analyses of whole body worms for PCBs. Total PCBs were detected at a concentration of 48.9 µg/kg (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for PCB analysis, with concentrations ranging from 5.75 J to 108 J µg/kg (maximum concentration between RM 3 and 4; Map 5.6-9a).

5.6.3 Total PCDD/Fs and TCDD TEQ in Biota

This section presents a summary of the distribution of dioxins/furans in fish and invertebrate tissue by presenting total PCDD/Fs and TCDD TEQ concentrations. Scatter plots showing the distribution of total PCDD/Fs and TCDD TEQ concentrations in select biota tissue collected from the study area are provided on Figures 5.6-2a-e and Figures 5.6-3a-e, respectively. Box-whisker plots showing the distribution of total PCDD/Fs and TCDD TEQ concentrations in whole body tissue samples collected of each species across the study area are provided on Figure 5.6-16 and Figure 5.6-17, respectively.

5.6.3.1 Total PCDD/Fs and TCDD TEQ in Fish Tissue

Dioxins/furans were detected in all fish tissue types collected from the study area that were analyzed for this contaminant. Selected fish species were also collected from the downstream reach and the downtown reach for dioxin/furan analysis. Species-specific data are summarized below by tissue type. A summary of the results for total PCDD/Fs and TCDD TEQ in fish species collected from the study area is presented in Table 5.6-1, from the downstream reach in Table 5.6-2, and from the upriver reach in Table 5.6-4.

5.6.3.1.1 Total PCDD/Fs in Fish Tissue

A summary of the results of dioxins and furans (expressed as PCDD/Fs) in fish tissue collected from study area locations is presented in Table 5.6-1. Similar data for samples collected from the downstream and downtown reaches are presented in Tables 5.6-2 and 5.6-4, respectively. Taxon-specific data are summarized below.

Black Crappie

Individual black crappie samples were collected over a 6-mile reach of the river within the study area and were composited for laboratory analysis. A total of four whole body composite samples were submitted for laboratory analysis of dioxins/furans, which were detected in each sample. Total PCDD/Fs concentrations ranged from 7.67 to 16.1 pg/g (maximum concentration between RM 3 and 6; Map 5.6-1a).

Brown Bullhead

Brown bullhead samples were collected over an approximately 6-mile reach of the river within the study area and were composited for laboratory analysis. A total of six whole

body composite samples were submitted for laboratory analysis of dioxins/furans, which were detected in each sample. Total PCDD/Fs concentrations ranged from 12.2 to 17.8 pg/g (maximum concentration between RM 8 and 10; Map 5.6-2b), and a single composite sample at RM 28 had a total PCDD/Fs concentration of 3.03 pg/g (Table 6.5-4).

Two whole body brown bullhead samples were collected from the upriver reach. Total PCDD/Fs concentrations in these samples were 3.03 and 7.45 pg/g (between RM 23 and 24; Map 5.6-15a).

Carp

Six skin-on fillet composite samples of carp were collected within the study area and submitted for laboratory analysis of dioxins/furans, which were detected in each sample. Total PCDD/Fs concentrations ranged from 23.1 J to 43.8 J pg/g (maximum concentration between RM 4 and 8; Map 5.6-3b).

Six whole body composite carp samples were submitted for analysis of dioxins/furans, which were detected in each sample. Total PCDD/Fs concentrations ranged from 26.1 to 80.9 pg/g (between RM 8 to 10; Map 5.6-3c). Six whole body composite samples of carp based on combined fillet and body without fillet fractions were also submitted for laboratory analysis of dioxins/furans, which were detected in each sample and the total PCDD/Fs concentrations ranged from 36.7 J to 90.7 J pg/g (RM 4 to 8; Map 5.6-3b). Additionally, six carp body without fillet samples were collected from the study area. Dioxins/furans were detected in each sample, with total PCDD/Fs concentrations ranging from 26.1 to 80.9 J pg/g (RM 4 to 8; Map 5.6-3b).

Nine composite carp samples were collected within the downstream reach (between RM 0 and 1.9 and Multnomah Channel; Map 5.6-3a) and submitted for analysis of dioxins/furans, which were detected in each sample. Total PCDD/Fs concentrations for three skin-on fillet composite samples ranged from 16.6 J to 26.5 J pg/g. Total PCDD/Fs concentration for three body without fillet composite samples ranged from 31.3 to 49.8 pg/g. Total PCDD/Fs concentrations for three combined fillet and body without fillet fractions ranged from 27.7 J to 43.9 J pg/g.

Chinook Salmon

Nine juvenile whole body Chinook salmon samples were collected within the study area and were composited for laboratory analysis of dioxins/furans, which were detected in each sample. Total PCDD/Fs concentrations ranged from 21.3 J to 42.4 J pg/g (maximum concentration between RM 6 and 7; Map 5.6-4b).

Seven juvenile whole body composite samples were also collected from the upriver reach for dioxin/furan analysis. Dioxins/furans were detected in each sample. Total PCDD/Fs concentrations ranged from 1.32 to 6.18 J pg/g (between RM 17 and 18; Map 5.6-16).

Six Chinook salmon samples were collected from the Clackamas River Fish Hatchery and submitted for laboratory analysis of dioxin/furans. Three skin-on fillet samples were analyzed, with total PCDD/Fs concentrations ranging from 1.31 to 1.71 pg/g. Three fillet without skin samples were analyzed for total PCDD/Fs, with concentrations ranging from 0.652 to 1.09 pg/g.

Lamprey Ammocoetes and Macropthalmia

Six juvenile (ammocoetes and macropthalmia) lamprey samples were collected from the study area for dioxin/furan analysis. Dioxins/furans were detected in each sample, with total PCDD/Fs concentrations ranging from 69.1 to 90.1 J pg/g (maximum concentration between RM 1.9 and 6; Map 5.6-8).

Eight juvenile lamprey samples were also collected from the upriver reach for dioxin/furan analysis. Dioxins/furans were detected in each sample, with total PCDD/Fs concentrations ranging from 5.6 to 63 pg/g (maximum concentration between RM 18 and 19; Map 5.6-16).

Largescale Sucker

Largescale sucker samples collected within the study area and from locations in the downstream and upriver reaches were not analyzed for dioxins/furans.

Northern Pikeminnow

Northern pikeminnow samples collected within the study area and from locations in the downstream and upriver reaches were not analyzed for dioxins/furans.

Peamouth

Peamouth samples collected within the study area and from locations in the downstream and upriver reaches were not analyzed for dioxins/furans.

Sculpin

Twenty-five whole body composite samples of sculpin were collected and submitted to the laboratory for dioxin/furan analysis. Twenty-one of these samples were collected from the study area. Dioxins/furans were detected in each of the samples collected from the study area, with total PCDD/Fs concentrations ranging from 6.19 J to 388 pg/g (maximum concentration between RM 7 and 8; Map 5.6-11d).

Two whole body composites were collected from the downstream reach, with total PCDD/Fs concentrations of 5.85 J and 8.09 J pg/g (between RM 1 and 2; Map 5.6-11a). Two whole body sculpin composites were also collected in the downtown reach for dioxin/furan analysis. Total PCDD/Fs concentrations were 5.27 J and 8.1 J pg/g (between RM 11.8 and 13; Map 5.6-11f).

Smallmouth Bass

Fifty-nine smallmouth bass samples were collected and submitted to the laboratory for dioxin/furan analysis. All but 3 of these samples were collected from the study area.

Study area samples included 18 fillet composites, and 20 whole body composites. In addition, concentrations were derived for 18 composites by calculating concentrations for fillet and body without fillet fractions.

Dioxins/furans were detected in all of the samples collected from the study area. Total PCDD/Fs concentrations of these study area smallmouth bass samples, as presented on Maps 5.6-12a-e, ranged as follows:

- Fillet—0.662 J to 56.9 J pg/g (maximum concentration between RM 6 and 8)
- Combined fillet and body without fillet fractions—5.21 J to 345 J pg/g (RM 6 to 8)
- Body without fillet—7.15 to 433 pg/g (RM 6 to 8)
- Whole body—4.74 to 48.7 pg/g (RM 6 to 8).

Dioxins/furans were detected in the six whole body samples collected from the downtown and upriver reaches, with total PCDD/F concentrations ranging from 3.99 to 10.5 pg/g (maximum concentration between RM 20 and 25; Map 5.6-15a).

Sturgeon

Twenty sturgeon samples were collected from the study area and submitted to the laboratory for dioxin/furan analysis. These included 5 composite skin-off fillet of adult sturgeon samples collected by ODHS, EPA, and ATSDR, and 15 juvenile (pre-breeding) sturgeon whole body samples.

As presented on Maps 5.6-13a-b, dioxins/furans were detected in all of the samples. Total PCDD/Fs concentrations of adult sturgeon skin-off fillet samples ranged from 1.64 to 23.2 pg/g (maximum concentration at RM 6; Map 5.6-13a). Juvenile sturgeon whole body total PCDD/Fs concentrations ranged from 4.32 J to 13.9 J pg/g (maximum concentration between RM 3 and 4; Map 5.6-13a).

5.6.3.1.2 TCDD TEQ in Fish Tissue

A summary of the results of dioxins and furans (expressed as TCDD TEQ) in fish tissue collected from study area locations is presented in Table 5.6-1. Similar data for samples collected from the downstream Reach, and from the downtown and upriver reaches are presented in Tables 5.6-2 and 5.6-4, respectively. Taxon specific data are summarized below.

Black Crappie

Individual black crappie samples were collected over a 6-mile reach of the river within the study area and were composited for laboratory analysis. A total of four whole body composite samples were submitted for laboratory analysis of dioxins/furans, which were detected in each sample. TCDD TEQ ranged from 1.1 J to 1.26 J pg/g (maximum concentration between RM 3 and 6; Map 5.6-1a).

Brown Bullhead

Brown bullhead samples were collected over an approximately 6-mile reach of the river within the study area and were composited for laboratory analysis. A total of six whole body composite samples were submitted for laboratory analysis of dioxins/furans, which were detected in each sample. TCDD TEQ ranged from 1.29 J to 2.12 J pg/g (maximum concentration between RM 6 and 9; Map 5.6-2b).

Three whole body brown bullhead samples were collected from the upriver reach. TCDD TEQ in those samples ranged from 0.807 J to 2.9 J pg/g (maximum concentration between RM 23 and 24; Map 5.6-15a).

Carp

Six skin-on fillet composite samples of carp were collected within the study area and submitted for laboratory analysis of dioxins/furans, which were detected in each sample. TCDD TEQ ranged from 2.07 J to 4.37 J pg/g (RM 4 to 8; Map 5.6-3b).

Six whole body composite carp samples were collected from the study area and submitted for analysis of dioxins/furans, which were detected in each sample. TCDD TEQ ranged from 1.98 to 8.53 pg/g (RM 3 to 6; Map 5.6-3b). Six whole body composite samples of carp based on combined fillet and body without fillet fractions were also submitted for laboratory analysis of dioxins/furans, which were detected in each sample. TCDD TEQ in those samples ranged from 3.15 J to 6.3 J pg/g (RM 5 to 6; Map 5.6-3b). Additionally, six carp body without fillet samples were collected from the study area. Dioxins/furans were detected in each sample, with TCDD TEQ ranging from 3.51 J to 6.99 J pg/g (RM 4 to 7; Map 5.6-3b).

Nine composite carp samples were collected within the downstream reach (between RM 0 and 1.9 and Multnomah Channel; Map 5.6-3a) and submitted for analysis of dioxins/furans, which were detected in each sample. TCDD TEQ for three skin-on fillet composite samples ranged from 1.88 J and 2.59 J pg/g. TCDD TEQ for three body without fillet composite samples ranged from 2.76 to 3.47 J pg/g. TCDD TEQ for three combined fillet and body without fillet fractions ranged from 2.54 J pg/g to 3.23 J pg/g.

Chinook Salmon

Nine juvenile Chinook salmon whole body samples were collected within the study area and were composited for laboratory analysis of dioxins/furans, which were detected in each sample. TCDD TEQ in those samples ranged from 1.2 J to 4.37 J pg/g (maximum concentration between RM 6 and 7; Map 5.6-4b).

Seven juvenile whole body composite samples were also collected from the downtown and upriver reaches for dioxin/furan analysis. Dioxins/furans were detected in each sample. TCDD TEQ ranged from 0.102 to 1.12 J pg/g (between RM 15 and 26; Map 5.6-16).

Three skin-on fillet samples and three skin-off fillet samples were also collected from the Clackamas River Fish Hatchery. TCDD TEQ in the skin-on samples ranged from 0.143 to 0.171 pg/g. TCDD TEQ in the skin-off samples ranged from 0.0506 to 0.157 pg/g.

Lamprey Ammocoetes and Macropthalmia

Six juvenile (ammocoetes and macropthalmia) lamprey samples were collected within the study area for dioxin/furan analysis. Dioxins/furans were detected in each sample, with TCDD TEQ concentrations ranging from 2.36 J to 4.18 J pg/g (maximum concentration from RM 9 and 11.8; Map 5.6-8).

Eight juvenile lamprey samples were also collected from the upriver reach for dioxin/furan analysis. Dioxins/furans were detected in each sample, with TCDD TEQ ranging from 0.218 to 3.1 J pg/g (between RM 15 and 26; Map 5.6-16).

Largescale Sucker

Largescale sucker samples collected within the study area and from locations in the downstream and upriver reaches were not analyzed for dioxins/furans.

Northern Pikeminnow

Northern pikeminnow samples collected within the study area and from locations in the downstream and upriver reaches were not analyzed for dioxins/furans.

Peamouth

Peamouth samples collected within the study area and from locations in the downstream and upriver reaches were not analyzed for dioxins/furans.

Sculpin

Twenty-five whole body composite samples of sculpin were collected and submitted to the laboratory for dioxin/furan analysis. Twenty-one of these samples were collected from the study area. Dioxins/furans were detected in each of the samples collected from the study area, with TCDD TEQ ranging from 0.618 J to 31.8 pg/g (RM 7 to 8; Map 5.6-11d).

Two whole body composites were collected from the downstream reach, with TCDD TEQ of 0.528 J and 0.946 J pg/g (between RM 0 and 1.9; Map 5.6-11a). Two whole body sculpin composites were also collected from the downtown reach for dioxin/furan analysis. TCDD TEQ was 0.617 J and 0.856 J pg/g (between RM 11.8 and 12; Map 5.6-11f).

Smallmouth Bass

Fifty-six smallmouth bass samples were collected and submitted to the laboratory for dioxin/furan analysis. All but 6 of these samples were collected from the study area. Study area samples included 18 composites of body without fillet, 18 fillet composites,

and 14 whole body composites. In addition, concentrations were derived for 18 composites by calculating concentrations for fillet and body without fillet fractions.

Dioxins/furans were detected in all of the samples collected from the study area. TCDD TEQ of these study area smallmouth bass samples, as presented on Maps 5.6-12a-e, ranged as follows:

- Fillet—0.187 J to 8.74 J pg/g (RM 6 to 8)
- Combined fillet and body without fillet fractions—1.26 J to 51.9 J pg/g (RM 6 to 8)
- Body without fillet—1.67 J to 64.9 J pg/g (RM 6 to 8)
- Whole body—1.29 J to 7.77 pg/g (RM 6 to 8).

Dioxins/furans were detected in the six whole body samples collected from the downtown and upriver reaches, with TCDD TEQ ranging from 0.905 J to 2.45 J pg/g (maximum concentration between RM 19 and 24; Map 5.6-15a).

Sturgeon

Twenty sturgeon samples were collected from the study area and submitted to the laboratory for dioxin/furan analysis. These included 5 composite skin-off fillet samples and 15 whole body samples.

As presented on Maps 5.6-13a-b, dioxins/furans were detected in all of the samples. TCDD TEQ of the skin-off fillet samples ranged from 0.135 to 1.33 pg/g (maximum concentration between RM 6 and 7; Map 5.6-13a). Whole body TCDD TEQ ranged from 0.35 J to 1.33 J pg/g (maximum concentration between RM 3 and 4; Map 5.6-13b).

5.6.3.2 Total PCDD/Fs and TCDD TEQ in Invertebrate Tissue

Dioxins/furans were detected in all invertebrate species and tissue types collected from the study area for which dioxin/furan analysis was conducted. Selected invertebrate species were also collected from the downstream, downtown, and upriver reaches. Taxon-specific data are summarized below. A summary of the results for total PCDD/Fs and TCDD TEQ in invertebrate tissue collected from the study area is presented in Table 5.6-5, from the downstream reach in Table 5.6-6, and from the downtown and upriver reaches in Table 5.6-7.

5.6.3.2.1 Total PCDD/Fs in Invertebrate Tissue

A summary of the results of dioxins and furans (expressed as total PCDD/Fs) in invertebrate tissue collected from study area locations is presented in Table 5.6-5. Similar data for samples collected from the downstream reach and from the downtown and upriver reaches are presented in Tables 5.6-6 and 5.6-7, respectively. Taxon-specific data are summarized below.

Clams (Resident)

All clam samples consisted of composited soft parts only (body without shell). Thirty-five composite samples of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for dioxin/furan analysis. Dioxins/furans were detected in all of the samples, with total PCDD/Fs concentrations ranging from 25.3 J to 189 pg/g (maximum concentration from RM 7 to 8; Map 5.6-5d). Three additional depurated samples were collected within the study area for dioxin/furan analysis. Dioxins/furans were detected in each sample, with total PCDD/Fs concentrations ranging from 24.3 J to 42.5 J pg/g (maximum concentration from RM 10 to 11; Map 5.6-5f).

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. Dioxins/furans were detected in the depurated sample with a total PCDD/Fs concentration of 29.3 J pg/g and in the non-depurated samples at concentrations of 33.2 J and 39 pg/g (between RM 0 and 1.9 and Multnomah Channel; Maps 5.6-5a-b).

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. Dioxins/furans were detected in the depurated sample with a total PCDD/Fs concentration of 25.9 J pg/g and in the non-depurated samples at concentrations of 33.4 J and 36.6 J pg/g (between RM 10 and 12; Map 5.6-5f).

Clams (Laboratory-Exposed)

Thirty-four additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by chemical analysis of soft body parts for dioxins/furans, which were detected in all of the samples. Total PCDD/Fs concentrations ranged from 4.48 J to 696 J pg/g (maximum concentration between RM 6 and 7; Map 5.6-6d). One clam result was generated by exposing laboratory reared clams to downstream reach sediments. Total PCDD/Fs concentration was 4.83 pg/g (Multnomah Channel; Map 5.6-6b).

Crayfish

Fifteen whole body crayfish composites were collected within the study area and submitted to the laboratory for dioxin/furan analysis. Dioxins/furans were detected in all of the samples, with total PCDD/Fs concentrations ranging from 12.1 J to 281 pg/g (RM 7 to 8; Map 5.6-7c).

Two composite whole body crayfish samples were collected from the downstream reach. Dioxins/furans were detected, with total PCDD/Fs concentrations of 11.3 and 12.4 pg/g. (between RM 1 and 1.9; Map 5.6-7a).

Two composite whole body crayfish samples were also collected from the downtown reach. Dioxins/furans were detected, with total PCDD/Fs concentrations of 9.46 and 14 pg/g (between RM 11 and 12; Map 5.6-7d).

Epibenthic Invertebrates

Seven composite samples of epibenthic invertebrates (mixed taxa) were collected from the study area and analyzed for dioxins/furans, with total PCDD/Fs concentrations ranging from 49.1 to 213 pg/g (maximum concentration between RM 9 and 10; Map 5.6-9b).

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory-reared *Lumbriculus* worms to study area sediments, followed by chemical analyses of whole body worms for dioxins/furans, which were detected in all of the samples. Total PCDD/Fs concentrations in these laboratory exposed samples ranged from 51 J to 6,440 pg/g (maximum concentration from sediments collected between RM 6 and 7; Map 5.6-14d).

One result was generated by exposing laboratory-reared worms to downstream reach sediments, followed by chemical analyses of whole body worms for dioxins/furans. The total PCDD/Fs concentration in the laboratory-exposed sample was 68.1 J pg/g (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for dioxin/furan analysis. Dioxins/furans were detected in each sample, with total PCDD/Fs concentrations ranging from 14.4 J to 66.2 J pg/g (maximum concentration between RM 3 and 4; Map 5.6-9a).

5.6.3.2.2 TCDD TEQ in Invertebrate Tissue

A summary of the results of dioxins and furans (expressed as TCDD TEQ) in invertebrate tissue collected from study area locations is presented in Table 5.6-5. Similar data for samples collected from the downstream reach, and from the downtown and upriver reaches are presented in Tables 5.6-6 and 5.6-7, respectively. Taxon-specific data are summarized below.

Clams (Resident)

All clam samples consisted of composites of soft parts only (body without shell). Thirty-nine composite samples of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for dioxin/furan analysis. Dioxins/furans were detected in all of the samples, with TCDD TEQs ranging from 0.0963 J to 5.45 J pg/g (maximum concentration between RM 7 and 8; Map 5.6-5d). Five additional depurated samples were collected within the study area for dioxin/furan analysis. Dioxins/furans were detected in each sample, with TCDD TEQs ranging from 0.139 J to 0.367 J pg/g (maximum concentration between RM 2 and 3; Map 5.6-5b).

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. Dioxins/furans were detected in a single depurated sample with a TCDD TEQ of 0.192 J pg/g and in the non-depurated samples with TCDD TEQs

of 0.0963 J and 0.379 J pg/g (between RM 0 and 1.9 and Multnomah Channel; Maps 5.6-5a-b).

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. Dioxins/furans were detected in the depurated sample with a TCDD TEQ of 0.22 J pg/g and in the non-depurated samples at 0.215 J and 0.318 J pg/g (between RM 10 and 12; Map 5.6-5f).

Clams (Laboratory-Exposed)

Thirty-four additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by chemical analysis of soft body parts for dioxins/furans, which were detected in all of the samples. TCDD TEQs ranged from 0.00911 J to 40.5 J pg/g (maximum concentration from sediments collected between RM 6 and 7; Map 5.6-6d).

One clam result was generated by exposing laboratory-reared clams to downstream reach sediments, followed by chemical analysis of soft body parts for dioxins/furans. TCDD TEQ was 0.000714 J pg/g (Multnomah Channel; Map 5.6-6b).

Crayfish

Fifteen whole body crayfish composites were collected within the study area and submitted to the laboratory for dioxin/furan analysis. Dioxins/furans were detected in all of the samples, with TCDD TEQs ranging from 0.203 J to 18.2 pg/g (RM 7 to 8; Map 5.6-7c).

Two composite whole body crayfish samples were collected from the downstream reach. Dioxins/furans were detected, with TCDD TEQs of 0.21 J and 0.321 J pg/g (between RM 0 and 1.9; Map 5.6-7a).

Two composite whole body crayfish samples were also collected from the downtown reach. Dioxins/furans were detected, with TCDD TEQs of 0.283 J and 0.485 J pg/g (between RM 11 and 12; Map 5.6-7d).

Epibenthic Invertebrates

Seven composite samples of epibenthic invertebrates (mixed taxa) were collected from the study area and analyzed for dioxins/furans, with TCDD TEQs ranging from 0.275 J to 3.34 J pg/g (maximum concentration between RM 6 and 7; Map 5.6-9a).

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory-reared *Lumbriculus* worms to study area sediments, followed by chemical analyses of whole body worms for dioxins/furans, which were detected in all of the samples. TCDD TEQs in these laboratory-exposed samples ranged from 0.743 J to 448 J pg/g (maximum concentration from sediments collected between RM 6 and 7; Map 5.6-14d).

One result was generated by exposing laboratory-reared *Lumbriculus* worms to downstream reach sediments, followed by chemical analyses of whole body worms for dioxins/furans. TCDD TEQ in this laboratory-exposed sample was 1.24 J pg/g (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for dioxin/furan analysis. Dioxins/furans were detected in each sample, with TCDD TEQs ranging from 0.0704 J to 0.446 J pg/g (maximum concentration between RM 3 and 4; Map 5.6-9a).

5.6.4 DDx in Biota

This section presents a summary of the distribution of DDx in fish and invertebrate tissue. The distributions of DDx compounds—the sum of ortho (2,4'-) and para (4,4'-) isomers of DDD, DDE, and DDT—are described in this section, including concentration trends and DDx analyte patterns in tissue samples from the study area. Scatter plots showing the distribution of DDx concentrations in select biota tissue collected from the study area are provided on Figures 5.6-4a-e. A box-whisker plot showing the distribution of DDx for each species and tissue type is provided on Figure 5.6-18.

5.6.4.1 DDx in Fish Tissue

As shown in Table 5.6-1, DDx compounds, expressed as DDx, were detected in all fish samples collected from the study area except some Chinook salmon fillet samples and some whole body lamprey samples. Selected fish species were also collected from the outlying reaches. A summary of the results in fish tissue collected from locations within the downstream reach is presented in Table 5.6-2-and from the downtown and upriver reaches in Table 5.6-4. Species-specific data are summarized below, by tissue type.

Black Crappie

Four fillet and four whole body composite black crappie samples were collected from the study area and submitted for laboratory analyses of DDx. DDx was detected in all four fillets, with DDx concentrations ranging from 8.8 J to 13.7 J µg/kg (maximum concentration between RM 6 and 9; Map 5.6-1b).

DDx was also detected in all four whole body samples, with DDx concentrations ranging from 59.2 J to 99.6 J µg/kg (maximum concentration between RM 6 and 9; Map 5.6-1b).

Brown Bullhead

Six skin-off fillet composite samples and 6 whole body composite samples of brown bullhead were collected from the study area and submitted for laboratory analyses of DDx. DDx was detected in all 12 samples, with fillet DDx concentrations ranging from 12 J to 26.5 J µg/kg (maximum concentration between RM 6 and 9; Map 5.6-2b).

DDx was also detected in all six whole body samples, with DDx concentrations ranging from 37.5 J to 141 J µg/kg (maximum concentration between RM 6 and 9; Map 5.6-2b).

Three whole body brown bullhead composites were also collected from the upriver reach, with DDx concentrations ranging from 18 J to 52 J µg/kg (between RM 23 and 24; Map 5.6-15a).

Carp

Twelve skin-on fillet composite samples of carp were collected and submitted for laboratory analyses of DDx. DDx was detected in all study area samples, with concentrations ranging from 47.3 J to 494 J µg/kg (RM 4 to 8; Map 5.6-3b).

Twelve composite samples of carp designated as whole body samples were also submitted for laboratory analyses of DDx. These 12 samples included 6 whole body samples and 6 samples based on combined fillet and body without fillet fractions. DDx was detected in all 12 samples, with DDX concentrations ranging from 73.3 J to 615 J µg/kg (RM 4 to 8; Map 5.6-3b).

The six composite carp samples of body without fillet had a range of DDx concentration between 83.4 J to 658 J µg/kg, also collected between RM 6 and 8 (Map 5.6-3b).

Nine composite carp samples were collected within the downstream reach and submitted for analysis of DDx, which were detected in each sample. DDx for three skin-on fillet composite samples ranged from 70 J to 113 µg/kg. DDx for three body without fillet composite samples ranged from 101 to 149 µg/kg. DDx for three composite samples of combined fillet and body without fillet fractions ranged from 93.3 J to 140 µg/kg (between RM 0 and 1.9 and Multnomah Channel; Map 5.6-3a).

Chinook Salmon

Fifteen juvenile whole body Chinook salmon samples were collected within the study area and were composited for laboratory analyses of DDx. DDx was detected in all 15 samples, with DDx concentrations ranging from 16.9 J to 284 µg/kg (maximum concentration between RM 6 and 7; Map 5.6-4b).

Eight juvenile whole body composite samples were also collected from the upriver reach, with concentrations of DDx ranging from 5.4 to 12.2 J µg/kg (between RM 17 and 18; Map 5.6-16).

Also collected from the Clackamas River Fish Hatchery were three fillet samples, with DDx being detected in two of the three samples. DDx concentrations in these two fillet samples were 10.9 J and 12 J µg/kg.

Five composites of juvenile Chinook salmon were collected from the study area and submitted for DDx analyses of stomach contents. DDx was detected in all five samples, with concentrations ranging from 8.88 J to 327 J µg/kg (maximum concentration between RM 6 and 7; Map 5.6-4b).

Stomach contents of the single composite sample collected from the upriver reach contained 6.61 J µg/kg of DDx (between RM 17 and 18; Map 5.6-16).

Lamprey Ammocoetes and Macropthalmia

Fourteen juvenile (ammocoetes and macropthalmia) lamprey samples were collected within the study area and were composited for DDx analyses. DDx was detected in all six samples collected from the study area, with DDx concentrations ranging from 42.3 to 121 µg/kg (macropthalmia; RM 2 to 3; Map 5.6-8). DDx was also detected in four of eight composite samples collected from the upriver reach, and DDx concentrations in those four composite samples ranged from 36.8 to 77.1 µg/kg (maximum concentration between RM 18 and 19; Map 5.6-16).

Largescale Sucker

Six whole body composites of largescale sucker were collected from the study area and submitted to the laboratory for DDx analyses. DDx concentrations were detected in all six samples, and concentrations ranged from 143 J to 670 µg/kg (maximum concentration between RM 8 and 9; Map 5.6-10b).

Northern Pikeminnow

Six whole body composites of northern pikeminnow were collected from the study area and submitted to the laboratory for DDx analyses. DDx concentrations of these six samples ranged from 145 to 761 µg/kg (maximum concentration between RM 6 and 7; Map 5.6-10a).

Peamouth

Four whole body composites of peamouth were collected from the study area and submitted to the laboratory for DDx analyses. DDx was detected in each of these samples, and concentrations ranged from 132 J to 215 µg/kg (maximum concentration between RM 8 and 9; Map 5.6-10b).

Sculpin

Forty-two whole body composite samples of sculpin were collected and submitted to the laboratory for DDx analyses. Thirty-eight of these samples were collected from the study area, with DDx concentrations ranging from 12.7 J to 3,060 µg/kg (RM 7 to 8; Map 5.6-11d).

Two composites were collected from the downstream reach, with DDx concentrations of 25 J and 37.8 µg/kg (between RM 0 and 1.9; Map 5.6-11a). Two whole body sculpin composites were also collected from the downtown reach, with DDx concentrations of 13.5 J and 15 J µg/kg (between RM 11 and 12; Map 5.6-11f).

Smallmouth Bass

Sixty-one smallmouth bass samples were collected and submitted to the laboratory for DDx analyses. All but 6 of these samples were collected from the study area. Study area

samples included 18 composites of body without fillet, 23 fillet composites, and 14 whole body composites. In addition, concentrations were derived for 18 composites by calculating concentrations for fillet and body without fillet fractions.

DDx concentrations of these study area smallmouth bass samples ranged as follows:

- Fillet—6.41 J to 181 µg/kg (RM 6 to 7; Map 5.6-12c2)
- Combined fillet and body without fillet fractions—34.5 J to 1,460 µg/kg (RM 6 to 7; Map 5.6-12c2)
- Body without fillet—43.1 J to 1,840 µg/kg (RM 6 to 7; Map 5.6-12c2)
- Whole body—65 J to 408 µg/kg (RM 6 to near 8; Map 5.6-12c2).

DDx concentrations of the six composites collected from the downtown and upriver reaches ranged from 56.9 J to 120 J µg/kg (maximum concentration between RM 20 and 25; Map 5.6-15a).

Sturgeon

Twenty-one sturgeon samples were collected from the study area and submitted to the laboratory for DDx analyses. These included 5 composite skin-off fillet samples, 15 whole body samples, and 1 sample for stomach contents.

Whole body DDx concentrations ranged from 77.9 to 176 J µg/kg (maximum concentration between RM 6 and 8; Map 5.6-13b). DDx concentrations of skin-off fillet samples ranged from 38 J to 125 J µg/kg (maximum concentration between RM 6 and 7; Map 5.6-13a). The DDx concentration of the single stomach contents sample equaled 3.61 J µg/kg (between RM 7 and 8; Map 5.6-13b).

5.6.4.2 DDx in Invertebrate Tissue

DDx compounds were detected in all invertebrate types collected from the study area. Selected invertebrate species were also collected from the downstream, downtown, and upriver reaches. A summary of the results for DDx in invertebrate tissue collected from the study area is presented in Table 5.6-5, from the downstream reach in Table 5.6-6, and from the downtown and upriver reaches in Table 5.6-7. Taxon-specific data are summarized below.

Clams (Resident)

All resident clam samples consisted of composites of soft parts only (body without shell). Forty composites of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for DDx analyses, with DDx concentrations ranging from 7.44 J to 463 J µg/kg (maximum concentration between RM 7 and 8; Map 5.6-5d). Three additional depurated samples were collected within the study area, with DDx concentrations ranging from 6.04 J to 27.8 µg/kg (maximum concentration between RM 2 and 3; Map 5.6-5b).

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. The DDx concentrations in the non-depurated samples were 22.8 and 28.5 µg/kg, while the DDx concentration of the depurated sample was 23.1 µg/kg (between RM 0 and 1.9 and Multnomah Channel; Maps 5.6-5a-b).

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. The DDx concentrations in the non-depurated samples were 8.65 and 9.35 J µg/kg. The DDx concentration of the depurated sample was 7.01 J µg/kg (between RM 11 and 12.3; Map 5.6-5f).

Clams (Laboratory-Exposed)

Thirty-four additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by analyses of soft body parts for DDx. The DDx concentrations of these 35 laboratory-exposed samples ranged from 1.13 J to 1,040 µg/kg (maximum concentration from sediments collected between RM 7 and 8; Map 5.6-6d).

One clam result was generated by exposing laboratory-reared clams to downstream reach sediments, followed by analyses of soft body parts for DDx. The DDx concentration of this one sample was 1.23 J µg/kg (Multnomah Channel; Map 5.6-6b).

Crayfish

Thirty-two whole body crayfish composites were collected within the study area and submitted to the laboratory for DDx analyses. DDx compounds were detected in all samples, with DDx concentrations ranging from 1.12 J to 84.9 J µg/kg (RM 7 to 8; Map 5.6-7c).

Two composite whole body crayfish samples were collected from the downstream reach. The DDx concentrations in these two samples were 2.62 J and 3.17 J µg/kg (between RM 1 and 2; Map 5.6-7a).

Two composite whole body crayfish samples were also collected from the downtown reach. The DDx concentrations in these two samples were 1.75 J and 2.47 J µg/kg (between RM 12 and 12.3; Map 5.6-7d).

Epibenthic Invertebrates

Seven composite samples of epibenthic invertebrates (mixed taxa) were collected from the study area and analyzed for DDx, with concentrations ranging from 2.67 to 94.8 µg/kg (maximum concentration between RM 6 and 7; Map 5.6-9a).

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory-reared *Lumbriculus* worms to study area sediments, followed by analyses of whole body worms for DDx. DDx compounds were detected in all samples, with DDx concentrations ranging from 14.5 J to 1,490 µg/kg (maximum concentration between RM 6 and 7; Map 5.6-14d).

One result was generated by exposing laboratory-reared *Lumbriculus* worms to downstream reach sediments, followed by analyses of whole body worms for DDx. DDx concentrations were 24.4 J µg/kg (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for DDx analyses, with detected DDx concentrations in all samples ranging from 0.979 J to 4.44 J µg/kg (maximum concentration between RM 8 and 9; Map 5.6-9b).

5.6.5 Total PAHs in Biota

This section presents a summary of the distribution of total PAHs in fish and invertebrate tissue. Scatter plots showing the distribution of PAHs concentrations in select biota tissue collected from the study area are provided on Figures 5.6-5. A box-whisker plot showing the distribution of PAHs concentrations in whole body tissue samples collected of each species across the study area is provided on Figure 5.6-19.

5.6.5.1 Total PAHs in Fish Tissue

As shown in Table 5.6-1, PAHs were detected in all fish samples collected from the study area that were analyzed for this class of contaminants. Selected fish species were also collected from the downstream, downtown, and upriver reaches for PAH analyses. A summary of the total PAHs results in fish tissue collected from locations from the downstream reach is presented in Table 5.6-2 and from the downtown and upriver reaches in Table 5.6-4. Species-specific data are summarized below by tissue type.

Black Crappie

Black crappie samples collected from the study area were not analyzed for PAHs.

Brown Bullhead

A total of six skin-off fillet composite samples were submitted for laboratory analyses of PAHs. PAHs were detected in two of the samples, with total PAHs concentrations of 110 J and 250 µg/kg (maximum concentration between RM 3 and 6; Map 5.6-2a).

A total of six whole body composite samples were submitted for laboratory analyses of PAHs. PAHs were detected in one sample, with a total PAHs concentration of 100 µg/kg (maximum concentration between RM 3 and 6; Map 5.6-2a).

Three whole body brown bullhead were collected from the upriver reach. Total PAHs were not present in any of the samples.

Carp

Six skin-on fillet composite samples of carp were collected within the study area and submitted for laboratory analyses of PAHs. PAHs were detected in all six samples, with total PAHs concentrations ranging from 11 to 140 µg/kg (RM 4 to 8; Maps 5.6-3a-b).

Twelve whole body composite samples of carp were also submitted for laboratory analyses of PAHs. These 12 samples included 6 whole body samples and 6 samples based on combined fillet and body without fillet fractions. PAHs were detected in all but 4 of the whole body samples, with total PAHs concentrations ranging from 11 J to 222 J µg/kg (between RM 8 to 12; Map 5.6-3 c). Additionally, 6 carp body without fillet samples were collected from the study area. PAHs were detected in each sample, with total PAHs concentrations ranging from 10 to 170 µg/kg (RM 4 to 12; Maps 5.6-3—b-c).

Nine composite carp samples were collected within the downstream reach (between RM 0 and 1.9 and Multnomah Channel; Map 5.6-3a) and submitted for analysis of PAHs, which were detected in each sample. Total PAHs for three skin-on fillet composite samples ranged from 30 to 42 µg/kg. Total PAHs for three body without fillet composite samples ranged from 33 J to 50 µg/kg. Total PAHs for three composite samples of combined fillet and body without fillet fractions ranged from 41 J to 53 J µg/kg.

Chinook Salmon

Fifteen juvenile whole body Chinook salmon samples were collected within the study area and were composited for laboratory analyses of PAHs. PAHs were detected in 10 samples out of 15, with total PAHs concentrations ranging from 9.96 J to 33 µg/kg (maximum concentration between RM 2 and 3; Map 5.6-4a).

Eight juvenile whole body composite samples were also collected from the upriver reach. PAHs were detected in six samples, with total PAH concentrations ranging from 5.2 J to 10.1 J µg/kg (between RM 17 and 18; Map 5.6-16).

Also collected from the Clackamas River Fish Hatchery were three skin-on fillet samples. PAHs were detected in two of the samples, with total PAH concentrations of 1.8 J and 5.4 J µg/kg.

Five composites of juvenile Chinook salmon were collected from the study area and submitted for PAH analyses of stomach contents. PAHs were detected in all samples, with total PAHs ranging from 95.5 J to 2,460 J µg/kg (maximum concentration between RM 6 and 7; Map 5.6-4b).

Stomach contents of the single composite sample collected from the upriver reach contained a total PAHs concentration of 87.4 J µg/kg (between RM 17 and 18; Map 5.6-16).

Lamprey Ammocoetes and Macropthalmia

Three juvenile (ammocoetes and macropthalmia) lamprey samples were collected within the study area for PAH analyses. PAHs were detected in each sample, with total PAH concentrations ranging from 48 J to 270 J µg/kg (ammocoete composite maximum concentration between RM 1.9 and 6; Map 5.6-8). PAHs were also detected in all four

composite samples collected from the upriver reach, and total PAHs in those composite samples ranged from 18 to 41 µg/kg (maximum concentration between RM 18 and 19; Map 5.6-16).

Largescale Sucker

Six whole body composites of largescale sucker were collected from the study area and submitted to the laboratory for PAH analyses. PAHs were detected in two of the six samples, with total PAH concentrations of 42 J and 147 J µg/kg (maximum concentration with RM 6 and 8; Map 5.6-10a).

Northern Pikeminnow

Northern pikeminnow samples collected within the study area and from locations in the downstream and upriver reaches were not analyzed for PAHs.

Peamouth

Peamouth samples collected within the study area and from locations in the downstream and upriver reaches were not analyzed for PAHs.

Sculpin

Forty-two whole body composite samples of sculpin were collected and submitted to the laboratory for PAH analyses. Thirty-eight of these samples were collected from the study area. PAHs were detected in 22 of the 38 samples collected from the study area. Total PAHs concentrations ranged from 7.8 J to 550 µg/kg (RM 6 to 12; Maps 5.6-11d-f).

Two whole body composites were collected from the downstream reach, with total PAHs concentrations of 13 and 18 µg/kg (between RM 0 and 1.9; Map 5.6-11a). Two whole body sculpin composites were also collected from the downtown reach, with total PAHs concentrations of 9.2 and 31 µg/kg (between RM 11.7 and 12.3; Map 5.6-11f).

Smallmouth Bass

Fifty-six smallmouth bass samples were collected and submitted to the laboratory for PAH analyses. All but 6 of these samples were collected from the study area. Study area samples included 18 composites of body without fillet, 18 fillet composites, and 14 whole body composites. In addition, concentrations were derived for 18 composites by calculating concentrations for fillet and body without fillet fractions.

PAHs were detected in all but seven of the whole body samples collected from the study area. Total PAH concentrations of these study area smallmouth bass samples, as presented on Maps 5.6-12a-e, ranged as follows:

- Fillet—0.58 to 84 µg/kg (RM 8 to 9)
- Combined fillet and body without fillet fractions—11 to 180 µg/kg (RM 5 to 6)
- Body without fillet—5.2 to 230 µg/kg (RM 6 to 7)

- Whole body—31 to 308 µg/kg (RM 6 to 8).

PAHs were not detected in the six whole body samples collected from the downtown and upriver reaches.

Sturgeon

Twenty-three sturgeon samples were collected from the study area and submitted to the laboratory for PAH analyses. These included 5 composite skin-off fillet samples, 15 whole body samples, and 3 samples of stomach contents.

As presented on Maps 5.6-13a-b, total PAHs were detected in all of the samples, with the exception of two of the fillet samples. Total PAHs concentrations of skin-off fillet samples ranged from 4 J to 23.1 µg/kg (maximum concentration between RM 5 and 6). Whole body total PAHs concentrations ranged from 1.1 to 61 µg/kg (maximum concentration between RM 6 and 7). Total PAHs were detected in all three stomach contents samples, and concentrations ranged from 3.6 to 9,000 µg/kg (maximum concentration between RM 6 and 7).

5.6.5.2 Total PAHs in Invertebrate Tissue

PAHs were detected in all invertebrate species and tissue types collected from the study area for which analysis was conducted. Selected invertebrate species were also collected above and below the study area. A summary of the results for total PAHs in invertebrate tissue collected from the study area is presented in Table 5.6-5, from the downstream reach in Table 5.6-6, and from the downtown and upriver reaches in Table 5.6-7. Taxon-specific data are summarized below.

Clams (Resident)

All clam samples consisted of soft parts only (body without shell). Thirty-nine composites of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for PAH analyses, with total PAHs concentrations ranging from 23 to 4,980 µg/kg (RM 6 to 7; Map 5.6-5d). Three additional depurated samples were collected within the study area, with total PAHs concentrations ranging from 30 to 220 µg/kg (RM 2 to 3; Map 5.6-5b).

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. The total PAHs concentrations in the non-depurated samples were 95 and 551 µg/kg, while the total PAHs concentration in the depurated sample was 76 µg/kg (between RM 0 and 1.9 and Multnomah Channel; Maps 5.6-5a-b).

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. The total PAHs concentrations in the non-depurated samples were 22 µg/kg and 110 µg/kg. The total PAHs concentration of the depurated sample from above the study area was 23 J µg/kg (between RM 11 and 12.2; Map 5.6-5f).

Clams (Laboratory-Exposed)

Thirty-four additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by laboratory analyses of soft body parts for PAHs. Total PAHs were detected in each sample, with concentrations of these 34 laboratory exposed samples ranging from 18.2 J to 1,320 µg/kg (maximum concentration from sediments collected within RM 4 and 5; Map 5.6-6c).

One clam result was generated by exposing laboratory reared clams to downstream reach sediments, followed by laboratory analyses of soft body parts for PAHs. Total PAHs were detected at a concentration of 27.5 J µg/kg (Multnomah Channel; Map 5.6-6b).

Crayfish

Thirty-two whole body crayfish composites were collected within the study area and submitted to the laboratory for PAH analyses. PAHs were detected in eight of the samples. Total PAHs concentrations of those eight samples ranged from 1.2 J to 477 J µg/kg (RM 6 to 7; Map 5.6-7c).

Two composite whole body crayfish samples were collected from the downstream reach. The total PAH concentrations in these two samples were 0.99 J and 3.5 J µg/kg (between RM 1 and 1.5; Map 5.6-7a).

Two composite whole body crayfish samples were also collected from the downtown reach. The total PAHs concentrations in these two samples were 1.3 J and 1.7 J µg/kg (between RM 12 and 12.3; Map 5.6-7d).

Epibenthic Invertebrates

Epibenthic invertebrates (mixed taxa) collected from the study area were not analyzed for total PAHs.

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory-reared *Lumbriculus* worms to study area sediments, followed by laboratory analyses of whole body worms for PAHs. PAHs were detected in each sample, with total PAHs concentrations in these laboratory-exposed samples ranging from 83 to 37,300 µg/kg (maximum concentration from sediments collected with RM 5 and 6; Map 5.6-14c).

One result was generated by exposing laboratory reared *Lumbriculus* worms to downstream reach sediments, followed by laboratory analyses of whole body worms for PAHs. Total PAHs concentrations were 517 µg/kg (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for PAH analyses. PAHs were detected in each sample, with

total PAH concentrations ranging from 16 J to 150 J µg/kg (maximum concentration between RM 3 and 4; Map 5.6-9a).

5.6.6 Bis(2-ethylhexyl)phthalate in Biota

This section presents a summary of the distribution of BEHP in fish and invertebrate tissue. Scatter plots showing the distribution of BEHP concentrations in select biota tissue collected from the study area are provided on Figures 5.6-6a-e. A box-whisker plot showing the distribution of BEHP for each species and tissue type is provided on Figure 5.6-20.

5.6.6.1 BEHP in Fish Tissue

BEHP, the most frequently detected phthalate, was analyzed in brown bullhead, carp, Chinook salmon, lamprey, smallmouth bass, and sturgeon. Black crappie, northern pikeminnow, and peamouth were not analyzed for phthalates. The BEHP results for fish samples collected from the study area are shown in Table 5.6-1. Selected fish species were also collected from the downstream, downtown, and upriver reaches for BEHP analysis. A summary of the BEHP results in fish tissue collected from locations in the downstream reach is presented in Table 5.6-2 and from the downtown and upriver reaches in Table 5.6-4. Species-specific data are summarized below by tissue type.

Black Crappie

Tissue samples of this fish species were not analyzed for BEHP.

Brown Bullhead

Brown bullhead samples were collected within the study area and were composited for laboratory analysis of BEHP. A total of six skin-off fillet composite samples were collected from the study area and submitted for laboratory analysis of BEHP. BEHP was detected in only one of six samples, with the detected concentration equaling 100 µg/kg (between RM 6 and 9; Maps 5.6-2b).

A total of six whole body composite samples were collected from the study area and submitted for laboratory analysis of BEHP. BEHP was detected in one of these samples at 2,700 µg/kg (between RM 3 and 6; Maps 5.6-2a).

Three whole body brown bullhead composites were also collected from the upriver reach, with BEHP being detected in only one of these at 3,000 J µg/kg (between RM 23 and 24; Map 5.6-15a).

Carp

Thirty-three composite samples of carp were collected from the study area and the downstream reach. These included nine body without fillet samples, nine fillet samples, six whole body samples, and nine samples based on combined fillet and body without fillet. BEHP was not detected in any of these samples.

Chinook Salmon

Eleven Chinook salmon composite samples were collected from the study area and four samples were collected from the upriver reach for analysis of BEHP. BEHP was not detected in any sample from the study area, but was detected in two out of four samples collected from the upriver reach, both at 140 J µg/kg (between RM 17 and 18; Map 5.6-16).

Lamprey Ammocoetes and Macropthalmia

One single juvenile lamprey (ammocoete) was collected within the study area. The BEHP concentration in the single study area sample equaled 170 J µg/kg (between RM 2 and 10; Map 5.6-8).

Four juvenile (ammocoetes and macropthalmia) lamprey samples (whole body composites) were collected and analyzed for BEHP. BEHP was detected in all four samples collected from the upriver reach, with concentrations ranging from 120 J to 160 J µg/kg (maximum concentration between RM 18 and 19; Map 5.6-16).

Largescale Sucker

Six whole body composites of largescale sucker were collected from the study area and submitted to the laboratory for BEHP analysis. BEHP was detected in two of six composite samples at concentrations ranging from 800 to 3,000 J µg/kg (maximum concentration between RM 7 and 9; Map 5.6-10b).

Northern Pikeminnow

Tissue samples of this fish species were not analyzed for BEHP.

Peamouth

Tissue samples of this fish species were not analyzed for BEHP.

Sculpin

Thirty-eight whole body composite samples of sculpin were collected from the study area and submitted to the laboratory for BEHP analysis. BEHP was detected in seven of these samples at concentrations ranging from 73 J to 28,000 J µg/kg (RM 7 to 8; Map 5.6-11d).

Two composites were collected from the downstream reach and two were collected from the downtown reach, but BEHP was not detected in any of these samples.

Smallmouth Bass

Fifty-five smallmouth bass samples were collected and submitted to the laboratory for BEHP analysis. All but 6 of these samples were collected from the study area. Study area samples included 17 composites of body without fillet, 18 fillet composites, and 14 whole body composites. In addition, concentrations were derived for 17 composites by calculating concentrations for fillet and body without fillet fractions.

BEHP concentrations of these study area smallmouth bass samples ranged as follows:

- Fillet—BEHP detected in 3 of 18 samples, with detected concentrations ranging from 69 J to 130 J µg/kg (RM 8 to 10; Map 5.6-12d1)
- Combined fillet and body without fillet fractions—BEHP detected in 3 of 17 samples, with detected concentrations ranging from 44 J to 2,800 µg/kg (RM 11 to 12; Map 5.6-12e)
- Body without fillet—BEHP detected in 2 of 17 samples, with detected concentrations at 3,700 and 4,000 µg/kg (RM 10 to 12; Map 5.6-12e)
- Whole body—BEHP detected in 2 of 14 samples, with detected concentrations at 32,000 J and 87,000 J µg/kg (RM 3 to near 5; Map 5.6-12b).

BEHP was detected in one of six composite samples collected from the downtown and upriver reaches at 4,800 µg/kg (maximum concentration between RM 20 and 25; Map 5.6-15a).

Sturgeon

Fifteen whole body composite sturgeon samples were collected from the study area and submitted to the laboratory for BEHP. BEHP was detected in four of these samples at concentrations ranging from 67 J to 300 µg/kg (maximum concentration between RM 7 and 8; Map 5.6-13b).

5.6.6.2 BEHP in Invertebrate Tissue

BEHP was most frequently detected in laboratory-exposed clams (82.2 percent), followed by laboratory-exposed *Lumbriculus* worms (60 percent) and field mussels (57 percent). BEHP was not detected in crayfish. Epibenthic community composites were not analyzed for phthalates. A summary of the results for BEHP in invertebrate tissue collected from the study area is presented in Table 5.6-5, from the downstream reach in Table 5.6-6, and from the downtown and upriver reaches in Table 5.6-7. Taxon-specific data are summarized below.

Clams (Resident)

All clam samples consisted of soft parts only (body without shell). Thirty-seven composites of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for BEHP analysis. BEHP was detected in six of these samples, with detected concentrations ranging from 77 J to 150 J µg/kg (maximum concentration between RM 12 and 13; Map 5.6-5f).

Two additional depurated samples were collected within the study area, but BEHP was not detected in those samples.

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. BEHP was not detected in the non-depurated samples, and

the BEHP concentration in the depurated sample was 89 J µg/kg (between RM 0 and 1.9 and Multnomah Channel; Maps 5.6-5a-b).

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. BEHP was detected in only one of the non-depurated samples at 150 J µg/kg. The BEHP concentration of the depurated sample from above the study area was 190 J µg/kg.

Clams (Laboratory-Exposed)

Thirty-four additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by analysis of soft body parts for BEHP. BEHP was detected in 26 of these samples at concentrations ranging from 53 J to 8,600 µg/kg (maximum concentration from sediments collected between RM 8 and 10; Map 5.6-6e).

One clam result was generated by exposing laboratory-reared clams to downstream reach sediments, followed by analysis of soft body parts for BEHP. The BEHP concentration was 120 J µg/kg (Multnomah Channel; Map 5.6-6b).

Crayfish

BEHP was not detected in any crayfish samples.

Epibenthic Invertebrates

Epibenthic invertebrates (mixed taxa) samples were not analyzed for BEHP.

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory reared *Lumbriculus* worms to study area sediments, followed by analysis of whole body worms for BEHP. BEHP was detected in 19 of these samples, with concentrations ranging from 69 J to 220 J µg/kg (maximum concentration between RM 4 and 5; Map 5.6-14c).

One result was generated by exposing laboratory reared *Lumbriculus* worms to downstream reach sediments, followed by analysis of whole body worms for BEHP. BEHP was detected at a concentration of 130 J µg/kg (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for BEHP analysis. BEHP was detected in four of these samples at concentrations ranging from 54 J to 120 J µg/kg (maximum concentration between RM 3 and 4; Map 5.6-9a).

5.6.7 Total Chlordanes in Biota

This section presents a summary of the distribution of total chlordanes in fish and invertebrate tissue. Scatter plots showing the distribution of total chlordane

concentrations in select biota tissue collected from the study area are provided on Figures 5.6-7a-e. A box-whisker plot showing the distribution of total chlordanes for each species and tissue type is provided on Figure 5.6-21.

5.6.7.1 Total Chlordanes in Fish Tissue

Total chlordanes were detected with varying frequency in all species except northern pikeminnow. As shown in Table 5.6-1, total chlordanes were detected in all fish samples collected from the study area. Selected fish species were also collected from the downstream reach (Table 5.6-2) and above the study area (Table 5.6-4). Species-specific data are summarized below, by tissue type.

Black Crappie

Four fillet and four whole body composite black crappie samples were collected from the study area and submitted for laboratory analysis of total chlordanes.

Total chlordanes were detected in one of four fillet samples at 1.1 J µg/kg (between RM 3 and 6; Map 5.6-1a).

Total chlordanes were also detected in all four whole body samples, with concentrations ranging from 2.1 J to 9.2 J µg/kg (maximum concentration between RM 3 and 6; Map 5.6-1a).

Brown Bullhead

Fifteen brown bullhead composite samples were analyzed for total chlordanes, including six skin-off fillet samples and seven whole body composite samples collected from the study area.

Total chlordanes were detected in four of six fillet samples, with concentrations ranging from 1.2 J to 1.6 J µg/kg (maximum concentration between RM 6 and 9; Map 5.6-2b).

Total chlordanes were also detected in five of seven whole body samples collected within the study area, with concentrations ranging from 1.8 J to 67 µg/kg (maximum concentration between RM 3 and 6; Map 5.6-2a).

Two whole body brown bullhead composites were also collected from the upriver reach, with total chlordanes concentrations of 1.1 N and 3.7 J µg/kg (between RM 23 and 24; Map 5.6-15a).

Carp

Twelve skin-on fillet composite samples of carp were collected within the study area and submitted for laboratory analysis of total chlordanes. Total chlordanes were detected in 10 of these samples, with total chlordanes concentrations ranging from 4.3 J to 12 J µg/kg (RM 4 to 8; Map 5.6-3b).

Twelve whole body composite samples of carp were analyzed for total chlordanes. These 12 samples collected from the study area included 6 whole body samples and 6 samples based on combined fillet and body without fillet fractions. Total chlordanes were detected in all samples, with concentrations ranging from 3.2 J to 15.4 J µg/kg (RM 4 to 8; Map 5.6-3b).

The composite carp sample with the highest level of total chlordanes was a body-without-fillet sample associated with a total chlordanes concentration of 16.8 J µg/kg, which was also collected between RM 4 and 8.

Nine composite carp samples were collected within the downstream reach and submitted for analysis of total chlordanes, which were detected in each sample. Total chlordanes for three skin-on fillet composite samples ranged from 7.87 J to 11.8 J µg/kg. Total chlordanes for three body without fillet composite samples ranged from 10.9 J to 14.5 J µg/kg. Total chlordanes for three composite samples of combined fillet and body with out fillet fractions ranged from 10.2 J to 13.8 J µg/kg (between RM 0 and 1.9; Map 5.6-3a).

Chinook Salmon

Fifteen whole body Chinook salmon composite samples were collected from the study area and eight whole body samples were collected from the upriver reach. Total chlordanes were detected in 12 of 15 whole body samples collected from the study area with concentrations ranging from 0.59 J to 7.8 J µg/kg (maximum concentration between RM 3 and 4; Map 5.6-4a). Total chlordanes were detected in 4 of 8 whole body samples collected from the upriver reach with concentrations ranging from 1.2 J to 3.02 J µg/kg.

Three fillet samples were also collected from the Clackamas River Fish Hatchery, but total chlordanes were not detected in those fillet samples.

Five composites of juvenile Chinook salmon stomach contents were collected from the study area and submitted for total chlordanes analysis. Total chlordanes were detected in all five samples, with concentrations ranging from 1.08 J to 4.61 J µg/kg (with maximum concentration between RM 6 and 7; Map 5.6-4b).

Stomach contents of the single composite sample collected from the upriver reach contained 2.26 J µg/kg of total chlordanes (between RM 17 and 18; Map 5.6-16).

Lamprey Ammocoetes and Macropthalmia

Six juvenile (ammocoetes) lamprey whole body composite samples were collected within the study area and were composited for total chlordanes analysis. Total chlordanes were detected in each sample, with concentrations ranging from 12.5 J to 29.3 J µg/kg (maximum concentration between RM 2 and 3; Map 5.6-8).

Total chlordanes were also detected in all four samples of ammocoetes and macropthalmia lamprey collected from the upriver reach, and total chlordanes concentrations ranged from 8.71 J to 25.2 µg/kg (maximum concentration between RM 18 and 19, Map 5.6-16).

Largescale Sucker

Six whole body composites of largescale sucker were collected from the study area and submitted to the laboratory for total chlordanes analysis. Total chlordanes were detected in two of six samples at concentrations ranging from 8.6 J to 9.6 J µg/kg (maximum concentration between RM 2 and 4; Map 5.6-10a).

Northern Pikeminnow

Six whole body composites of northern pikeminnow were collected from the study area and submitted to the laboratory for total chlordanes analysis. Total chlordanes were not detected in any of these samples.

Peamouth

Four whole body composites of peamouth were collected from the study area and submitted to the laboratory for total chlordanes analysis. Total chlordanes were detected in two of these samples, with concentrations of 3.1 and 3.4 µg/kg (maximum concentration with RM 4 and 6; Map 5.6-10a).

Sculpin

Forty-two whole body composite samples of sculpin were collected and submitted to the laboratory for total chlordanes analysis. Thirty-eight of these samples were collected from the study area, and total chlordanes were detected in 26 of those samples at concentrations ranging from 2.5 J to 16 J µg/kg (RM 7 to 8; Map 5.6-11d).

Two whole body composites were collected from the downstream reach, with total chlordanes concentrations in those two samples of 5.83 J and 7.38 J µg/kg (between RM 0 and 1.9; Map 5.6-11a). Two whole body sculpin composites were also collected from the downtown reach, with total chlordanes concentrations of 6.28 and 8.23 µg/kg in those samples (between RM 11 and 12.3; Map 5.6-11f).

Smallmouth Bass

Sixty-one smallmouth bass samples were collected and submitted to the laboratory for total chlordanes analysis. All but 6 of these samples were collected from the study area. Study srea samples included 18 composites of body without fillet, 23 fillet composites, and 14 whole body composites. In addition, concentrations were derived for 18 composites by calculating concentrations for fillet and body without fillet fractions.

Total chlordanes concentrations of these study area smallmouth bass samples ranged as follows:

- Fillet—Total chlordanes detected in 21 of 23 samples, with concentrations ranging from 0.92 J to 4.1 J µg/kg (RM 6 to 7; Map 5.6-12c2)
- Combined fillet and body without fillet fractions—Total chlordanes detected in all 18 samples, with concentrations ranging from 7.66 J to 21.7 J µg/kg (RM 8 to 9; Map 5.6-12d2)
- Body without fillet—Total chlordanes detected in all 18 samples, with concentrations ranging from 9.57 J to 29.5 µg/kg (RM 8 to 9; Map 5.6-12d2)
- Whole body—Total chlordanes detected in 2 of 14 samples, with detected concentrations ranging from5.4 to 5.6 µg/kg (RM 6.6 to near 7.5; Map 5.6-12c2).

Total chlordanes concentrations of the six whole body composites collected from the downtown and Uuriver reaches ranged from 4.5 J to 15 J µg/kg (maximum concentration between RM 20 and 25; Map 5.6-15a).

Sturgeon

Twenty-one sturgeon samples were collected from the study area and submitted to the laboratory for total chlordanes analysis. These included 5 composite skin-off fillet samples, 15 whole body samples, and 1 sample for stomach contents. Total chlordanes were detected in all samples except 1 fillet sample.

Whole body total chlordanes concentrations ranged from 6.22 J to 20.4 µg/kg (maximum concentration between RM 7 and 8; Map 5.6-13b). Total chlordanes detected concentrations in skin-off fillet samples ranged from 2.5 J to 5.6 J µg/kg (maximum concentration between RM 6 and 7; Map 5.6-13a).

The total chlordanes concentration of the single stomach contents sample equaled 0.914 J µg/kg (between RM 7 and 8; Map 5.6-13b).

5.6.7.2 Total Chlordanes in Invertebrate Tissue

Total chlordanes were detected in all invertebrate samples collected from the study area except 22 crayfish tissues, as shown in Table 5.6-5. Selected invertebrate species were also collected from the downstream reach (Table 5.6-6) and from the downtown and upriver reaches (Table 5.6-7). Taxon-specific data are summarized below.

Clams (Resident)

All clam samples consisted of composites of soft parts only (body without shell). Forty-four composites of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for total chlordanes analysis. Total chlordanes were detected in all samples, with concentrations ranging from 1.1 NJ to 16 J µg/kg (maximum concentration between RM 8 and 9; Map 5.6-5e).

Five additional depurated samples were collected within the study area, with total chlordanes concentrations ranging from 1.35 J to 3.11 J µg/kg (maximum concentration between RM 2 and 3; Map 5.6-5b).

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. The total chlordanes concentrations in the non-depurated samples were 2.41 J and 3.02 J µg/kg, while the total chlordanes concentration of the depurated sample was 2.46 J µg/kg (between RM 0 and 1.9 and Multnomah Channel; Maps 5.6-5a-b).

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. The total chlordanes concentrations in the non-depurated samples were 1.99 J and 2.52 J µg/kg (between RM 11.9 and RM 12.3; Map 5.6-5f). The total chlordanes concentration of the depurated sample from above the study area was 1.9 J µg/kg (near RM 12.3; Map 5.6-5f).

Clams (Laboratory-Exposed)

Thirty-four additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by analysis of soft body parts for total chlordanes. Total chlordanes were detected in all samples. The total chlordanes concentrations of these 45 laboratory-exposed samples ranged from 1.61 J to 8.2 J µg/kg (maximum concentration from sediments collected between RM 6 and 7; Map 5.6-6d).

One clam result was generated by exposing laboratory-reared clams to downstream reach sediments, followed by analysis of soft body parts for total chlordanes. Total chlordanes were detected at a concentration of 1.92 J µg/kg (Multnomah Channel; Map 5.6-6b).

Crayfish

Thirty-two whole body crayfish composites were collected within the study area and submitted to the laboratory for chlordane analysis. Total chlordanes were not detected in 22 of these samples. Total detected chlordanes concentrations in those samples ranged from 0.164 J to 2.7 NJ µg/kg (RM 4 to 5; Map 5.6-7b).

Two composite whole body crayfish samples were collected from the downstream reach. The total chlordanes concentrations in these two samples were 0.20 J and 0.207J µg/kg (between RM 1 and 1.5; Map 5.6-7a).

Two composite whole body crayfish samples were also collected from the downtown reach. The total chlordanes concentrations in these two samples were 0.226 J and 0.382 J µg/kg (near RM 12; Map 5.6-7d).

Epibenthic Invertebrates

Seven composite samples of epibenthic invertebrates (mixed taxa) were collected from the study area and analyzed for total chlordanes, with detected concentrations in all

samples ranging from 0.313 J to 2.06 J µg/kg (maximum concentration between RM 6 and 7; Map 5.6-9a).

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory-reared *Lumbriculus* worms to study area sediments, followed by analysis of whole body worms for total chlordanes. Total chlordanes were detected in all samples, with concentrations ranging from 1.89 J to 71.9 µg/kg (maximum concentration between RM 8 and 9; Map 5.6-14e).

One result was generated by exposing laboratory-reared *Lumbriculus* worms to downstream reach sediments, followed by analysis of whole body worms for total chlordanes. Total chlordanes were detected at a concentration of 1.89 J µg/kg (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for total chlordanes analysis. Total chlordanes were detected in all samples with concentrations ranging from 0.191 J to 0.866 J µg/kg (maximum concentration between RM 8 and 9; Map 5.6-9b).

5.6.8 Aldrin in Biota

This section presents a summary of the distribution of aldrin in fish and invertebrate tissue. Scatter plots showing the distribution of aldrin concentrations in select biota tissue collected from the study area are provided on Figures 5.6-8a-e. A box-whisker plot showing the distribution of aldrin for each species and tissue type is provided on Figure 5.6-22.

5.6.8.1 Aldrin in Fish Tissue

Aldrin was only detected in juvenile lamprey, Chinook salmon (stomach contents only), carp, smallmouth bass, sturgeon, and sculpin. Laboratory detection limits were lower for Round 2 and Round 3 samples than for Round 1 samples. Study area data are summarized in Table 5.6-1. Tables 5.6-2 and 5.6-4 present data for samples collected below and above the study area, respectively. Species-specific data are summarized below by tissue type.

Black Crappie

Aldrin was not detected in any black crappie samples.

Brown Bullhead

Aldrin was not detected in any brown bullhead samples.

Carp

Twelve skin-on fillet composite samples of carp were collected within the study area and submitted for laboratory analysis of aldrin. Aldrin was detected in six of these samples, with concentrations ranging from 0.0541 J to 0.119 J µg/kg (RM 4 to 8; Map 5.6-3b).

Aldrin was not detected in the six whole body carp samples analyzed for aldrin. In contrast, aldrin was detected in all six body without fillet samples and in all six combined fillet and body without fillet samples. Aldrin concentrations in these samples ranged from 0.0839 J to 0.185 J µg/kg (RM 8 to 12; Map 5.6-3c) and from 0.0755 J to 0.163 µg/kg (RM 8 to 12; Map 5.6-3c), respectively.

Nine composite carp samples were collected within the downstream reach (between RM 0 and 1; Map 5.6-3a) and submitted for analysis of aldrin, which was detected in each sample. Aldrin concentrations for three skin-on fillet composite samples ranged from 0.046 J to 0.079 J µg/kg. Aldrin concentrations for three body without fillet composite samples ranged from 0.0634 J to 0.125 J µg/kg. Aldrin concentrations for three composite samples of combined fillet and body without fillet fractions ranged from 0.059 J to 0.11 J µg/kg.

Chinook Salmon

Fifteen juvenile Chinook salmon whole body composite samples were collected within the study area and eight whole body composite samples were collected from the upriver reach and submitted to the laboratory for aldrin analysis. Aldrin was not detected in any of these samples or any of the fillet samples from the Clackamas River Fish Hatchery.

Aldrin was detected in two out of five juvenile Chinook salmon stomach contents samples collected from the study area. Aldrin concentrations in these samples ranged from 0.00576 J to 0.0426 J µg/kg (maximum concentration between RM 6 and 7; Map 5.6-4b).

Lamprey Ammocoetes and Macropthalmia

Six whole body juvenile (ammocoetes and macropthalmia) lamprey samples were collected within the study area and were composited for aldrin analysis. Aldrin was detected in all six samples, with concentrations ranging from 0.874 to 1.82 µg/kg (ammocoete; maximum concentration between RM 2 and 3; Map 5.6-8). Aldrin was also detected in all four of the composite samples collected from the upriver reach, at concentrations ranging from 0.65 to 2.72 µg/kg (maximum concentration between RM 18 and 19; Map 5.6-16).

Largescale Sucker

Aldrin was not detected in any largescale sucker samples.

Northern Pikeminnow

Northern pikeminnow samples were not analyzed for aldrin.

Peamouth

Peamouth samples were not analyzed for aldrin.

Sculpin

Forty-two whole body composite samples of sculpin were collected and submitted to the laboratory for aldrin analysis. Aldrin was detected in 10 of the 38 samples collected from the study area, with concentrations ranging from 0.00532 to 0.0348 µg/kg (RM 8 to 9; Map 5.6-11e).

Two composites were collected from the downstream reach, with aldrin being detected in only one of those samples at 0.00814 µg/kg (between RM 1 and 2; Map 5.6-11a). One whole body sculpin composite was also collected from the downtown reach, at a detected aldrin concentration of 0.0101 µg/kg (near RM 11.8; Map 5.6-11f).

Smallmouth Bass

Sixty-one smallmouth bass samples were collected and submitted to the laboratory for aldrin analysis. All but 6 of these samples were collected from the study area. Study area samples included 18 composites of body without fillet, 23 fillet composites, and 14 whole body composites. In addition, concentrations were derived for 18 composites by calculating concentrations for fillet and body without fillet fractions.

Aldrin concentrations of these study area smallmouth bass samples ranged as follows:

- Fillet—Aldrin was detected in 6 of 23 samples at concentrations ranging from 0.005 J to 0.011 J µg/kg (RM 8 to 9; Map 5.6-12d2)
- Combined fillet and body without fillet fractions—Aldrin was detected in 15 of 18 samples at concentrations ranging from 0.0104 J to 0.04 J µg/kg (RM 8 to 9; Map 5.6-12d2)
- Body without fillet—Aldrin was detected in 13 of 18 samples at concentrations ranging from 0.0104 J to 0.0566 J µg/kg (RM 8 to 10; Map 5.6-12d1)
- Whole body—Aldrin was not detected in the 14 samples analyzed for aldrin.

Aldrin was also not detected in the six whole body composites collected from the downtown and upriver reaches.

Sturgeon

Twenty-one sturgeon samples were collected from the study area and submitted to the laboratory for aldrin analysis. These included 5 composite skin-off fillet samples, 15 whole body samples, and 1 sample for stomach contents.

Aldrin was not detected in the fillet samples nor was it detected in 2 of the 15 whole body samples. Whole body detected concentrations ranged from 0.0103 J to 0.0554 J µg/kg (maximum concentration between RM 2 and 3; Map 5.6-13a).

The aldrin concentration of the single stomach contents sample equaled 0.00442 J µg/kg (between RM 7 and 8; Map 5.6-13b).

5.6.8.2 Aldrin in Invertebrate Tissue

Aldrin was detected in all sampled invertebrate species collected within the study area (Table 5.6-5). Selected invertebrate species were also collected from the downstream reach and from the downtown and upriver reaches (Tables 5.6-6 and 5.6-7, respectively). Taxon-specific data are summarized below.

Clams (Resident)

All clam samples consisted of composites of soft parts only (body without shell). Forty composites of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for aldrin analysis. Aldrin was detected in 36 of these samples, with concentrations ranging from 0.126 J to 5.07 µg/kg (maximum concentration between RM 9 and 10; Map 5.6-5e).

Three additional depurated samples were collected within the study area, and aldrin was detected in two of these samples at concentrations of 0.173 J and 0.278 J µg/kg (maximum concentration between RM 2 and 3; Map 5.6-5b).

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. Aldrin was detected in both samples, with the concentrations in the non-depurated samples equaling 0.144 J and 0.23 J µg/kg (between RM 0 and 1.9 and Multnomah Channel: Maps 5.6-5a-b). The aldrin concentration of the depurated sample equaled 0.187 J µg/kg (near RM 1.6; Map 5.6-5a).

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. The aldrin concentrations in the two non-depurated samples were 0.11 J and 0.13 J µg/kg (between RM 11.9 and 12.3; Map 5.6-5f). Aldrin was not detected in the depurated sample from the downtown reach.

Clams (Laboratory-Exposed)

Thirty-five additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by analysis of soft body parts for aldrin. Aldrin was detected in 28 of these samples, with concentrations ranging from 0.0119 J to 2.14 µg/kg (maximum concentration from sediments collected between RM 8 and 9; Map 5.6-6e).

One clam result was generated by exposing laboratory-reared clams to downstream reach sediments, followed by analysis of soft body parts for aldrin. Aldrin was detected at a concentration of 0.0118 J µg/kg (Multnomah Channel; Map 5.6-6b).

Crayfish

Thirty-two whole body crayfish composites were collected within the study area and submitted to the laboratory for aldrin. Aldrin was detected in one of the samples at 0.037 J µg/kg (RM 8 to 9; Map 5.6-7c).

Aldrin was not detected in the two composite whole body crayfish samples collected from the downstream reach, nor was it detected in the two composite whole body crayfish samples collected from the downtown reach.

Epibenthic Invertebrates

Seven composite samples of epibenthic invertebrates (mixed taxa) were collected from the study area and analyzed for aldrin. Aldrin was detected in six of those samples at concentrations ranging from 0.00926 J to 0.0872 µg/kg (maximum concentration between RM 9 and 10; Map 5.6-9b).

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory reared *Lumbriculus* worms to study area sediments, followed by analysis of whole body worms for aldrin. Aldrin was detected in 34 of 35 samples, with concentrations ranging from 0.043 J to 37 µg/kg (maximum concentration between RM 8 and 9; Map 5.6-14e).

One result was generated by exposing laboratory-reared *Lumbriculus* worms to downstream reach sediments, followed by analysis of whole body worms for aldrin. Aldrin was detected at a concentration of 0.073 J µg/kg (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for aldrin analysis. Aldrin was detected in four of these samples at concentrations ranging from 0.007 J to 0.067 J µg/kg (maximum concentration between RM 8 and 9; Map 5.6-9b).

5.6.9 Dieldrin in Biota

This section presents a summary of the distribution of dieldrin in fish and invertebrate tissue. Scatter plots showing the distribution of dieldrin concentrations in select biota tissue collected from the study area are provided on Figures 5.6-9a-e. A box-whisker plot showing the distribution of dieldrin for each species and tissue type is provided on Figure 5.6-23.

5.6.9.1 Dieldrin in Fish Tissue

Dieldrin was detected in all sampled fish species, except largescale sucker, northern pikeminnow, and peamouth. study area data are summarized in Table 5.6-1. Data on samples collected from the downstream and downtown reaches are shown in Tables 5.6-2 and 5.6-4, respectively. Species-specific data are summarized below, by tissue type.

Black Crappie

Dieldrin was detected in one of four whole body black crappie composite samples collected within the study area, with a detected concentration of 2.5 J µg/kg (between RM 6 and 9; Map 5.6-1b). Dieldrin was not detected in any of the four composites of fillet samples collected from the study area.

Brown Bullhead

Dieldrin was detected in one of six skin-off fillet composite samples collected within the study area, at a concentration of 2.1 J µg/kg (between RM 3 and 6; Map 5.6-2a). Dieldrin was also detected in two of six whole body composite samples collected within the study area, with concentrations ranging from 1.2 J to 2.6 J µg/kg (maximum concentration between RM 3 and 6; Map 5.6-2a).

Dieldrin was detected in one of two whole body composite samples collected from the upriver reach, with concentrations in both samples equaling 1.2 J µg/kg (between RM 23 and 24 and at RM 28; Maps 5.6-15a-b).

Carp

Twelve skin-on fillet composite samples of carp were collected within the study area and submitted for laboratory analysis of dieldrin. Dieldrin was detected in six of these samples, with concentrations ranging from 1.29 to 2.3 µg/kg (maximum concentration between RM 4 and 8; Map 5.6-3b).

Dieldrin was not detected in the six whole body carp samples collected from the study area. In contrast, dieldrin was detected all six body without fillet samples and in all six combined fillet and body without fillet samples. Dieldrin concentrations in these samples ranged from 2.14 to 3.22 µg/kg (RM 5 to 8; Map 5.6-3b) and from1.9 to 3 µg/kg (RM 4 to 8; Map 5.6-3b), respectively.

Nine composite carp samples were collected within the downstream reach (between RM 0 and 1.9; Map 5.6-3a) and submitted for analysis of dieldrin, which was detected in each sample. Dieldrin concentrations for three skin-on fillet composite samples ranged from 1.66 to 2.03 µg/kg. Dieldrin concentrations for three body without fillet composite samples ranged from 2.24 to 2.95 µg/kg. Dieldrin concentrations for three composite samples of combined fillet and body without fillet fractions ranged from 2.1 to 2.72 µg/kg.

Chinook Salmon

Fifteen juvenile Chinook salmon whole body composite samples were collected from the study area and three whole body composite samples were collected from the upriver reach of the study area and submitted to the laboratory for dieldrin analysis. No fillet samples were collected within the study area, but three fillet composites were collected from the upriver reach.

Dieldrin was detected in one of three fillet composites from the Clackamas River Fish Hatchery at 2 J µg/kg.

Dieldrin was detected in 6 out of 15 whole body composites from the study area and ranged from 0.23 J to 2.6 µg/kg (maximum concentration between RM 3 and 4; Map 5.6-4a). Detected concentrations of dieldrin in 7 of 8 whole body composites collected from the Clackamas River Fish Hatchery ranged from 0.65 J µg/kg to 1.6 µg/kg (between RM 17 and RM 18; Map 5.6-16).

Five Chinook salmon stomach contents samples collected from the study area contained dieldrin at concentrations ranging from 0.471 J to 2.92 µg/kg (maximum concentration between RM 7 and 8; Map 5.6-4b). The dieldrin concentration in the single stomach contents sample collected from the upriver reach equaled 0.905 µg/kg (Table 5.6-4).

Lamprey Ammocoetes and Macropthalmia

Six whole body juvenile (ammocoetes and macropthalmia) lamprey samples were collected within the study area and were composited for dieldrin analysis. Dieldrin was detected in all six samples, with concentrations in macropthalmia ranging from 0.89 to 6.38 µg/kg (maximum concentration between RM 2 and 9; Map 5.6-8). Dieldrin was also detected in all four of the macropthalmia lamprey composite samples collected from the upriver reach, at concentrations ranging from 0.698 to 5.36 µg/kg (maximum concentration between RM 18 and 19; Map 5.6-16).

Largescale Sucker

Dieldrin was not detected in any largescale sucker samples.

Northern Pikeminnow

Dieldrin was not detected in any northern pikeminnow samples.

Peamouth

Dieldrin was not detected in any peamouth samples.

Sculpin

Forty-two whole body composite samples of sculpin were collected and submitted to the laboratory for dieldrin analysis. Dieldrin was detected in 26 of the 38 samples collected from the study area, with concentrations ranging from 0.867 J to 24 J µg/kg (RM 2 to 3; Map 5.6-11b).

Two composites were collected from the downstream reach, with dieldrin being detected in both samples at concentrations of 0.89 J and 1.47 µg/kg (between RM 1 and 1.9; Map 5.5-11a). Dieldrin was also detected in both samples collected from the downtown reach at concentrations of 1.11 and 1.26 µg/kg (between RM 11.8 and 12.3; Map 5.6-11f).

Smallmouth Bass

Sixty-one smallmouth bass samples were collected and submitted to the laboratory for dieldrin analysis. All but 6 of these samples were collected from the study area. Study area samples included 18 composites of body without fillet, 23 fillet composites, and 14 whole body composites. In addition, concentrations were derived for 18 composites by calculating concentrations for fillet and body without fillet fractions.

Dieldrin concentrations of these study area smallmouth bass samples ranged as follows:

- Fillet—Dieldrin was detected in 21 of 23 samples at concentrations ranging from 0.183 to 3.3 J µg/kg (RM 2 to 4; Map 5.6-12a)
- Combined fillet and body without fillet fractions—Dieldrin was detected in all 18 samples at concentrations ranging from 1.38 to 2.94 µg/kg (RM 8 to 10; Map 5.6-12d1)
- Body without fillet—Dieldrin was detected in all 18 samples at concentrations ranging from 1.76 to 4.17 µg/kg (RM 8 to 10; Map 5.6-12d1)
- Whole body—Dieldrin was detected in 1 of 14 samples analyzed for dieldrin at 7.3 J µg/kg (RM 7 to 8; Map 5.6-12d2).

Dieldrin was detected in the six whole body composites collected from the downtown and upriver reaches at concentrations ranging from 1.9 J to 4.5 J µg/kg (maximum concentration between RM 20 and 25; Map 5.6-15a).

Sturgeon

Twenty-one sturgeon samples were collected from the study area and submitted to the laboratory for dieldrin analysis. These included 5 composite skin-off fillet samples, 15 whole body samples, and 1 sample for stomach contents.

Dieldrin was detected in two of five fillet samples collected from the study area at concentrations ranging from 0.67 J to 1.4 J µg/kg (maximum concentration between RM 6 and 7; Map 5.6-13a).

Dieldrin was detected in all 15 whole body samples at concentrations ranging from 1.24 to 3.11 µg/kg (maximum concentration between RM 7 and 8; Map 5.6-13b).

The dieldrin concentration of the single stomach contents sample collected from the study area equaled 0.359 µg/kg (between RM 7 and 8; Map 5.6-13b).

5.6.9.2 Dieldrin in Invertebrate Tissue

Dieldrin was detected in all sampled invertebrate species and in most but not all samples. Selected invertebrate species were collected from within the study area (Table 5.6-5), and some samples were also collected from the downstream reach (Table 5.6-6) and the downtown and upriver reaches (Table 5.6-7). Taxon-specific data are summarized below.

Clams (Resident)

All clam samples consisted of composites of soft parts only (body without shell). Forty composites of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for dieldrin analysis. Dieldrin was detected in 37 of these samples, with concentrations ranging from 0.338 J to 2.62 µg/kg (RM 8 to 9; Map 5.6-5e).

Three additional depurated samples were collected within the study area, and dieldrin was detected in all of these samples at concentrations ranging from 0.339 J to 0.593 J µg/kg (RM 2 to 3; Map 5.6-5b).

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. Dieldrin was detected in both samples, with the concentrations in the non-depurated samples equaling 0.591 J and 0.609 µg/kg (near RM 1.6 and Multnomah Channel; Maps 5.6-5a-b). The dieldrin concentration of the depurated sample equaled 0.504 J µg/kg (near RM 1.6; Map 5.6-5a).

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. The dieldrin concentrations in the two non-depurated samples were 0.495 J and 0.61 J µg/kg (between RM 11.8 and 12.3; Map 5.6-5f). The dieldrin concentration of the depurated sample from above the downtown reach was 0.425 J µg/kg (near RM 11.8; Map 5.6-5f).

Clams (Laboratory-Exposed)

Thirty-four additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by analysis of soft body parts for dieldrin. Dieldrin was detected in all of these samples, with concentrations ranging from 0.139 J to 4.14 µg/kg (maximum concentration from sediments collected between RM 8 and 9; Map 5.6-6e).

One clam result was generated by exposing laboratory-reared clams to downstream reach sediments, followed by analysis of soft body parts for dieldrin. Dieldrin was detected at a concentration of 0.155 J µg/kg (Multnomah Channel; Map 5.6-6b).

Crayfish

Thirty-two whole body crayfish composites were collected within the study area and submitted to the laboratory for dieldrin. Dieldrin was detected in 5 of 32 samples at

concentrations ranging from 0.00943 J to 0.0471 J µg/kg (maximum concentration between RM 8 to 9; Map 5.6-7c).

Dieldrin was detected in one of two composite whole body crayfish samples collected from the downstream reach at 0.0134 J µg/kg (near RM 1.4; Map 5.6-7a). Dieldrin was also detected in the two composite whole body crayfish samples collected from the downtown reach at concentrations of 0.0105 J and 0.0164 J µg/kg (between RM 12 and 12.3; Map 5.6-7d).

Epibenthic Invertebrates

Seven composite samples of epibenthic invertebrates (mixed taxa) were collected from the study area and analyzed for dieldrin. Dieldrin was detected in all of those samples at concentrations ranging from 0.098 to 0.396 µg/kg (maximum concentration between RM 6 and 7; Map 5.6-9a).

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory-reared *Lumbriculus* worms to study area sediments, followed by analysis of whole body worms for dieldrin. Dieldrin was detected in all samples, with concentrations ranging from 0.127 J to 26.7 µg/kg (maximum concentration between RM 8 and 9; Map 5.6-14e).

One result was generated by exposing laboratory-reared *Lumbriculus* worms to downstream reach sediments, followed by analysis of whole body worms for dieldrin. Dieldrin was detected at a concentration of 0.499 µg/kg (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for dieldrin analysis. Dieldrin was detected in all of these samples at concentrations ranging from 0.0742 J to 0.186 J µg/kg (maximum concentration between RM 8 and 9; Map 5.6-9b).

5.6.10 Arsenic in Biota

This section presents a summary of the distribution of arsenic in fish and invertebrate tissue. Scatter plots showing the distribution of arsenic concentrations in select biota tissue collected from the study area are provided on Figures 5.6-10a-e. A box-whisker plot showing the distribution of arsenic concentrations in whole body tissue samples collected of each species across the study area is provided on Figure 5.6-24.

5.6.10.1 Arsenic in Fish Tissue

Arsenic was detected in all fish tissue types collected from the study area (Table 5.6-1) that were analyzed for this contaminant. Selected fish species were also collected from the downstream Reach (Table 5.6-2) and the downtown and upriver reaches (Table 5.6-4) for arsenic analysis. Species-specific data are summarized below by tissue type.

Black Crappie

Individual black crappie samples were collected over a 6-mile reach of the river within the study area and were composited for laboratory analysis. A total of four fillet (with skin) composite samples were submitted for laboratory analysis of arsenic. Arsenic was detected in all four samples, with concentrations ranging from 0.1 J to 0.18 mg/kg (maximum concentration between RM 6 and 9; Map 5.6-1b).

A total of four whole body composite samples were submitted for laboratory analysis of arsenic. Arsenic was detected in all four samples, with concentrations ranging from 0.185 to 0.42 mg/kg (maximum concentration within RM 6 and 9; Map 5.6-1b).

Brown Bullhead

Brown bullhead samples were collected over an approximately 6-mile reach of the river within the study area and were composited for laboratory analysis. A total of six skin-off fillet composite samples were submitted for laboratory analysis of arsenic. Arsenic was detected in all six samples, with a concentration of 0.02 J mg/kg in each sample (between RM 3 and 9; Maps 5.6-2a-b).

A total of six whole body composite samples collected from the study area were submitted for laboratory analysis of arsenic. Arsenic was detected in all six samples, with concentrations ranging from 0.04 J to 0.08 J mg/kg (maximum concentration between RM 6 and 9; Map 5.6-2b).

Three whole body brown bullhead samples were collected from the upriver reach. Arsenic was detected in each sample, with concentrations ranging from 0.07 J to 0.09 J mg/kg (between RM 23 and 24; Map 5.6-15a).

Carp

Twelve skin-on fillet composite samples of carp were collected within the study area and submitted for laboratory analysis of arsenic. Arsenic was detected in each sample, with concentrations ranging from 0.04 J to 0.160 mg/kg (RM 0 to 4; Map 5.6-3a).

Six whole body composite carp samples were submitted for arsenic analysis, which was detected in each sample at concentrations ranging from 0.125 J to 0.22 mg/kg (maximum concentration between RM 0 and 4; Map 5.6-3a). Six whole body composite samples of carp based on combined fillet and body without fillet fractions were also submitted for laboratory analysis of arsenic. Arsenic was detected in each sample, with concentrations ranging from 0.034 J to 0.12 J mg/kg (between RM 0 and 4; Map 5.6-3a). Additionally, six carp body without fillet samples were collected from the study area. Arsenic was detected in five of the samples, with concentrations ranging from 0.086 J to 0.136 J mg/kg (between RM 0 and 4; Map 5.6-3a).

Nine composite carp samples were collected within the downstream reach (between RM 0 and 1; Map 5.6-3a) and submitted for analysis of arsenic, which was detected in each sample. Arsenic concentrations for three skin-on fillet composite samples ranged

from 0.06 J to 0.21 mg/kg. Arsenic concentrations for three body without fillet composite samples ranged from 0.088 J to 0.234 mg/kg. Arsenic concentrations for three composite samples of combined fillet and body without fillet fractions ranged from 0.081 J to 0.23 mg/kg.

Chinook Salmon

Fifteen juvenile whole body Chinook salmon samples were collected within the study area and were composited for laboratory analysis of arsenic. Arsenic was detected in each sample, with concentrations ranging from 0.0465 to 0.25 mg/kg (maximum concentration between RM 3 and 4; Map 5.6-4a).

Eight whole body composite samples were also collected from the Clackamas River Fish Hatchery for arsenic analysis. Arsenic was detected in each sample, with concentrations ranging from 0.03 J to 0.979 mg/kg.

Three fillet composite samples were collected from the Clackamas River Fish Hatchery and submitted for laboratory analysis of arsenic. Arsenic was detected in each sample, with concentrations ranging from 0.72 to 1.26 mg/kg.

Lamprey Ammocoetes and Macropthalmia

Four juvenile (ammocoetes and macropthalmia) lamprey samples were collected from the study area for arsenic analysis. Arsenic was detected in each sample, with concentrations ranging from 0.05 J to 0.19 mg/kg (maximum concentration between RM 1 and 10; Map 5.6-8).

Four juvenile lamprey samples were also collected from the upriver reach for arsenic analysis. Arsenic was detected in each sample, with concentrations in macropthalmia ranging from 0.08 J to 0.19 mg/kg (maximum concentration between RM 18 and 19; Map 5.6-16).

Largescale Sucker

Six whole body composites of largescale sucker were collected from the study area and submitted to the laboratory for arsenic analysis. Arsenic was detected in each sample, with concentrations ranging from 0.18 to 0.27 mg/kg (maximum concentration between RM 2 and 4; Map 5.6-10a).

Northern Pikeminnow

Six whole body composites of northern pikeminnow were collected from the study area and submitted to the laboratory for arsenic analysis. Arsenic concentrations were detected in these six samples and concentrations ranged from 0.19 to 0.36 mg/kg (maximum concentration between RM 2 and 4; Map 5.6-10a).

Peamouth

Four whole body composites of peamouth were collected from the study area and submitted to the laboratory for arsenic analysis. Arsenic concentrations in these samples

ranged from 0.35 to 0.48 mg/kg (maximum concentration with RM 8 and 10; Map 5.6-10b).

Sculpin

Forty-two whole body composite samples of sculpin were collected and submitted to the laboratory for arsenic analysis. Thirty-eight of these samples were collected from the study area. Arsenic was detected in each of the samples collected from the study area, with concentrations ranging from 0.13 to 0.35 mg/kg (RM 10 to 11; Map 5.6-11f).

Two whole body composites were collected from the downstream reach, with a detected concentration of 0.33 mg/kg in both samples (between RM 1 and 1.9; Map 5.6-11a). Two whole body sculpin composites were also collected from the downtown reach for arsenic analysis, which was detected at a concentration of 0.2mg/kg in both samples (between RM 11.8 and 12.3; Map 5.6-11f).

Smallmouth Bass

Sixty-one smallmouth bass samples were collected and submitted to the laboratory for arsenic analysis. All but 6 of these samples were collected from the study area. Study area samples included 18 composites of body without fillet, 23 fillet composites, and 14 whole body composites. In addition, concentrations were derived for 18 composites by calculating concentrations for fillet and body without fillet fractions.

Arsenic was detected in all of the samples collected from the study area. Detected concentrations in these study area smallmouth bass samples, as presented on Maps 5.6-12a-e, ranged as follows:

- Fillet—0.14 to 0.34 mg/kg (RM 2 to 3)
- Combined fillet and body without fillet fractions—0.16 to 0.36 mg/kg (RM 2 to 5)
- Body without fillet—0.17 to 0.38 mg/kg (RM 2 to 5)
- Whole body—0.17 to 0.39 mg/kg (RM 2 to 5).

Arsenic was detected in the six whole body samples collected from the downtown and upriver reaches, with concentrations ranging from 0.1 J to 0.36 mg/kg (maximum concentration between RM 20 and 25; Map 5.6-15a).

Sturgeon

Twenty-three sturgeon samples were collected from the study area and submitted to the laboratory for arsenic analysis. These included 5 composite skin-off fillet samples, 15 whole body samples, and 3 samples of stomach contents.

As presented on Maps 5.6-13a-b, arsenic was detected in all of the samples. Detected arsenic concentrations of skin-off fillet samples ranged from 0.157 to 0.538 mg/kg (maximum concentration between RM 5 and 6). Whole body arsenic concentrations

ranged from 0.298 to 1.06 mg/kg (maximum concentration between RM 6 and 7). The arsenic concentrations in the three stomach contents samples ranged from 0.17 to 0.82 mg/kg (maximum concentration between RM 6 and 7).

5.6.10.2 Arsenic in Invertebrate Tissue

As shown in Table 5.6-5, arsenic was detected in all invertebrate species and tissue types collected from the study area for which arsenic analysis was conducted. Selected invertebrate species were also collected from the downstream reach and from the downtown and upriver reaches (Tables 5.6-6 and 5.6-7, respectively). Taxon-specific data are summarized below.

Clams (Resident)

All clam samples consisted of soft parts only (body without shell). Thirty-seven composite samples of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for arsenic analysis. Arsenic was detected in all of the samples, with concentrations ranging from 0.654 to 1.25 mg/kg (RM 2 to 3; Map 5.6-5b). Three additional depurated samples were collected within the study area for arsenic analysis. Arsenic was detected in each sample, with concentrations ranging from 0.798 to 1.35 mg/kg (RM 2 to 3; Map 5.6-5b).

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. Arsenic was detected in the depurated sample at a concentration of 1.02 mg/kg and in the non-depurated samples at concentrations of 1.03 and 1.07 mg/kg (between RM 0 and 1.9 and Multnomah Channel; Maps 5.6-5a-b).

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. Arsenic was detected in the depurated sample at a concentration of 0.76 mg/kg and in the non-depurated samples at concentrations of 0.615 and 0.799 mg/kg (between RM 11.9 and 12.3; Map 5.6-5f).

Clams (Laboratory-Exposed)

Thirty four additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by analysis of soft body parts for arsenic. Arsenic was detected in all of the samples, with concentrations ranging from 0.303 J to 0.548 mg/kg (maximum concentration from sediments collected between RM 8 and 9; Map 5.6-6e).

One clam result was generated by exposing laboratory-reared clams to downstream reach sediments, followed by analysis of soft body parts for arsenic. Arsenic was detected at a concentration of 0.411 mg/kg (Multnomah Channel; Map 5.6-6b).

Crayfish

Thirty-two whole body crayfish composites were collected within the study area and submitted to the laboratory for arsenic analysis. Arsenic was detected in all but one of the samples, with concentrations ranging from 0.235 to 0.5 J mg/kg (RM 7 to 8; Map 5.6-7c).

Two composite whole body crayfish samples were collected from the downstream reach. Arsenic was detected at concentrations of 0.34 and 0.4 mg/kg (between RM 1 and 1.5; Map 5.6-7a).

Two composite whole body crayfish samples were also collected from the downtown reach. Arsenic was detected at a concentration of 0.29 mg/kg in both samples (between RM 12 and 12.3; Map 5.6-7d).

Epibenthic Invertebrates

Two composite samples of epibenthic invertebrates (mixed taxa) were collected from the study area and analyzed for arsenic, with detected concentrations of 0.349 and 0.45 mg/kg (between RM 2 and 3; Map 5.6-9a).

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory-reared *Lumbriculus* worms to study area sediments, followed by analysis of whole body worms for arsenic. Arsenic was detected in all of the samples, with concentrations in these laboratory-exposed samples ranging from 0.285 to 3.04 mg/kg (maximum concentration from sediments collected between RM 7 and 8; Map 5.6-14d).

One result was generated by exposing laboratory-reared *Lumbriculus* worms to downstream reach sediments, followed by analysis of whole body worms for arsenic. Arsenic was detected at a concentration of 0.469 mg/kg (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for arsenic analysis. Arsenic was detected in each sample, with concentrations ranging from 0.224 to 0.616 mg/kg (maximum concentration between RM 7 and 8; Map 5.6-9b).

5.6.11 Chromium in Biota

This section presents a summary of the distribution of chromium in fish and invertebrate tissue. Scatter plots showing the distribution of chromium concentrations in select biota tissue collected from the study area are provided on Figures 5.6-11a-e. A box-whisker plot showing the distribution of chromium concentrations in whole body tissue samples collected of each species across the study area is provided on Figure 5.6-25.

5.6.11.1 Chromium in Fish Tissue

Chromium was detected in all fish samples collected from the study area that were analyzed for this contaminant, with the exception of whole body black crappie samples (Table 5.6-1). Selected fish species were also collected from the downstream reach

(Table 5.6-2) and the downtown and upriver reaches (Table 5.6-4) for chromium analysis. Species-specific data are summarized below by tissue type.

Black Crappie

Individual black crappie samples were collected over a 6-mile reach of the river within the study area and were composited for laboratory analysis. A total of four fillet (with skin) composite samples were submitted for laboratory analysis of chromium. Chromium was detected in two of the four samples, with concentrations of 0.14 and 0.28 mg/kg (maximum concentration between RM 3 and 6; Map 5.6-1a).

A total of four whole body composite samples were submitted for laboratory analysis of chromium. Chromium was not detected above laboratory reporting limits in any of the samples.

Brown Bullhead

Brown bullhead samples were collected over an approximately 6-mile reach of the river within the study area and were composited for laboratory analysis. A total of six skin-off fillet composite samples were submitted for laboratory analysis of chromium. Chromium was detected in three of the samples, with concentrations ranging from 0.05 J to 0.23 mg/kg (maximum concentration between RM 3 and 6; Map 5.6-2a).

A total of six whole body composite samples collected from the study area were submitted for laboratory analysis of chromium. Chromium was detected in all six samples, with concentrations ranging from 0.39 to 1.32 mg/kg (maximum concentration between RM 3 and 6; Map 5.6-2a).

Three whole body brown bullhead samples were collected from the upriver reach. Chromium was detected in each sample, with concentrations ranging from 0.485 to 2.04 mg/kg (maximum concentration between RM 28 and 33; Map 5.6-15b).

Carp

Twelve skin-on fillet composite samples of carp were collected within the study area and submitted for laboratory analysis of chromium. Chromium was detected in four of the samples, with concentrations ranging from 0.12 J to 1.49 mg/kg (maximum concentration between RM 3 and 6; Maps 5.6-3a-b).

Six whole body composite carp samples were submitted for chromium analysis, which was detected in each sample at concentrations ranging from 0.305 to 2.02 mg/kg (maximum concentration between RM 3 and 6; Maps 5.6-3a-b). Six whole body composite samples of carp based on combined fillet and body without fillet fractions were also submitted for laboratory analysis of chromium. Chromium was detected in each sample, with concentrations ranging from 0.23 to 0.8 mg/kg (between RM 0 to 4; Map 5.6-3a). Additionally, six carp body without fillet samples were collected from the study area. Chromium was detected in each sample, with concentrations ranging from 0.3 to 1.09 mg/kg (RM 0 to 4; Map 5.6-3a).

Nine composite carp samples were collected within the downstream reach (between RM 0 and 1; Map 5.6-3a) and submitted for analysis of chromium, which was detected in six of nine samples. Chromium was not detected for the skin-on fillet composite samples. Chromium concentrations for three body without fillet composite samples ranged from 0.47 to 1.91 mg/kg. Chromium concentrations for three composite samples of combined fillet and body without fillet fractions ranged from 0.36 to 1.5 mg/kg.

Chinook Salmon

Fifteen juvenile whole body Chinook salmon samples were collected within the study area and were composited for laboratory analysis of chromium. Chromium was detected in three of the samples, with concentrations ranging from 0.09 J to 0.19 mg/kg (maximum concentration between RM 2 and 3; Map 5.6-4a).

Eight juvenile whole body composite samples were also collected from the Clackamas River Fish Hatchery for chromium analysis. Chromium was detected in four of the samples, with concentrations ranging from 0.182 to 0.402 mg/kg.

Three fillet composite samples were collected from the Clackamas River Fish Hatchery and submitted for laboratory analysis of chromium. Chromium was detected in each sample, with concentrations ranging from 0.282 to 0.33 mg/kg.

Lamprey Ammocoetes and Macropthalmia

Four juvenile (ammocoetes and macropthalmia) lamprey samples were collected from the study area for chromium analysis. Chromium was detected in each sample, with concentrations ranging from 0.13 J to 0.32 mg/kg (ammocoetes; maximum concentration between RM 1 and 10; Map 5.6-8).

Four juvenile lamprey samples were also collected from the upriver reach for chromium analysis. Chromium was detected in 3 of the samples, with concentrations in macropthalmia ranging from 0.256 to 0.3 mg/kg (maximum concentration between RM 18 and 19; Map 5.6-16).

Largescale Sucker

Six whole body composites of largescale sucker were collected from the study area and submitted to the laboratory for chromium analysis. Chromium was detected in each sample, with concentrations ranging from 0.38 to 2.77 mg/kg (maximum concentration between RM 7 and 9; Map 5.6-10a).

Northern Pikeminnow

Six whole body composites of northern pikeminnow were collected from the study area and submitted to the laboratory for chromium analysis. Chromium was detected in five samples, with concentrations ranging from 0.09 J to 0.67 mg/kg (maximum concentration between RM 6 and 8; Map 5.6-10a).

Peamouth

Four whole body composites of peamouth were collected from the study area and submitted to the laboratory for chromium analysis. Chromium was detected in three samples, with concentrations ranging from 0.2 to 0.49 mg/kg (maximum concentration between RM 2 and 4; Map 5.6-10a).

Sculpin

Forty-two whole body composite samples of sculpin were collected and submitted to the laboratory for chromium analysis. Thirty-eight of these samples were collected from the study area. Chromium was detected in 22 of the samples collected from the study area, with concentrations ranging from 0.1 J to 0.6 mg/kg (RM 9 to 10; Map 5.6-11e).

Two whole body composites were collected from the downstream reach, with detected concentrations of 0.2 J mg/kg and 0.4 mg/kg (near RM 1.5; Map 5.6-11a). Two whole body sculpin composites were also collected from the downtown reach for chromium analysis, which was detected at concentrations of 0.15 J mg/kg and 0.3mg/kg (between RM 11.8 and 12.3; Map 5.6-11f).

Smallmouth Bass

Sixty-one smallmouth bass samples were collected and submitted to the laboratory for chromium analysis. All but 6 of these samples were collected from the study area. Study area samples included 18 composites of body without fillet, 23 fillet composites, and 14 whole body composite samples. In addition, concentrations were derived for 18 composites by calculating concentrations for fillet and body without fillet fractions.

Chromium was detected in 8 composites of body without fillet, 9 composites of combined fillet and body without fillet fractions, 2 fillet composites, and 12 whole body composite samples collected from the study area. Detected chromium concentrations in these study area smallmouth bass samples, as presented on Maps 5.6-12a-e, ranged as follows:

- Fillet—0.2 J to 0.9 mg/kg (RM 8 to 9)
- Combined fillet and body without fillet fractions—0.13 J to 0.4 J mg/kg (RM 8 to 9)
- Body without fillet—0.2 J mg/kg in each sample (RM 8 to 10)
- Whole body—0.17 to 1.14 mg/kg (RM 8 to 10).

Chromium was detected in the six whole body samples collected from above the downtown and upriver reaches, with concentrations ranging from 0.16 to 2.79 mg/kg (maximum concentration between RM 20 and 25; Map 5.6-15a).

Sturgeon

Twenty-three sturgeon samples were collected from the study area and submitted to the laboratory for chromium analysis. These included 5 composite skin-off fillet samples, 15 whole body samples, and 3 samples of stomach contents.

As presented on Maps 5.6-13a-b, chromium was detected in all of the fillet and stomach content samples, but only in two of the whole body samples. Detected chromium concentrations of skin-off fillet samples ranged from 0.412 to 3.25 mg/kg (maximum concentration between RM 5 and 6). Whole body chromium concentrations were 0.2 J and 40.2 mg/kg (maximum concentration between RM 2 and 3). The chromium concentrations in the three stomach contents samples ranged from 0.15 J to 4.1 mg/kg (maximum concentration between RM 6 and 7).

5.6.11.2 Chromium in Invertebrate Tissue

As shown in Table 5.6-5, chromium was detected in all invertebrate species and tissue types collected from the study area for which chromium analysis was conducted. Selected invertebrate species were also collected from the downstream reach and from the downtown and upriver reaches (Tables 5.6-6 and 5.6-7, respectively). Taxon-specific data are summarized below.

Clams (Resident)

All clam samples consisted of soft parts only (body without shell). Thirty-eight composite samples of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for chromium analysis. Chromium was detected in all of the samples, with concentrations ranging from 0.4 to 1.05 mg/kg (RM 3 to 4; Map 5.6-5b). Three additional depurated samples were collected within the study area for chromium analysis. Chromium was detected in each sample, with concentrations ranging from 0.4 to 0.5 mg/kg (RM 2 to 3 and RM 11 to 12; Maps 5.6-5b and f).

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. Chromium was detected in the depurated sample at a concentration of 0.4 mg/kg and in the non-depurated samples at concentrations of 0.5 and 0.62 mg/kg (between RM 0 and 1.9 and Multnomah Channel; Maps 5.6-5a-b).

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. Chromium was detected in the depurated sample at a concentration of 0.5 mg/kg and in the non-depurated samples at concentrations of 0.5 and 0.7 mg/kg (between RM 11.8 and RM 12.3; Map 5.6-5f).

Clams (Laboratory-Exposed)

Thirty-four additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by analysis of soft body parts for chromium. Chromium was detected in all of the samples, with concentrations ranging from 0.14 to 0.49 mg/kg (maximum concentration from sediments collected between RM 9 and 10; Map 5.6-6e).

One clam result was generated by exposing laboratory-reared clams to downstream reach sediments, followed by analysis of soft body parts for chromium. Chromium was detected at a concentration of 0.17 mg/kg (Multnomah Channel; Map 5.6-6b).

Crayfish

Thirty-two whole body crayfish composites were collected within the study area and submitted to the laboratory for chromium analysis. Chromium was detected in all of the samples, with concentrations ranging from 0.09 J to 0.9 mg/kg (RM 6 to 7; Map 5.6-7c).

Two composite whole body crayfish samples were collected from the downstream reach. Chromium was detected at concentrations of 0.2 J and 0.4 mg/kg (between RM 1 and 1.5; Map 5.6-7a).

Two composite whole body crayfish samples were also collected from the downtown reach. Chromium was detected at concentrations of 0.3 J and 0.4 mg/kg (between RM 12 and 12.3; Map 5.6-7d).

Epibenthic Invertebrates

Two composite samples of epibenthic invertebrates (mixed taxa) were collected from the study area and analyzed for chromium, with detected concentrations of 0.64 and 1.73 mg/kg (between RM 9 and 10; Map 5.6-9b).

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory-reared *Lumbriculus* worms to Study area sediments, followed by analysis of whole body worms for chromium. Chromium was detected in all of the samples, with concentrations in these laboratory exposed samples ranging from 0.14 to 0.89 mg/kg (maximum concentration from sediments collected between RM 8 and 9; Map 5.6-14e).

One result was generated by exposing laboratory-reared *Lumbriculus* worms to downstream reach sediments, followed by analysis of whole body worms for chromium. Chromium was detected at a concentration of 0.35 mg/kg (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for chromium analysis. Chromium was detected in three samples, with concentrations ranging from 0.21 to 0.28 mg/kg (maximum concentration between RM 3 and 4; Map 5.6-9a).

5.6.12 Copper in Biota

This section presents a summary of the distribution of copper in fish and invertebrate tissue. Scatter plots showing the distribution of copper concentrations in select biota tissue collected from the study area are provided on Figures 5.6-12a-e. A box-whisker

plot showing the distribution of copper concentrations in whole body tissue samples collected of each species across the study area is provided on Figure 5.6-26.

5.6.12.1 Copper in Fish Tissue

Copper was detected in all fish samples collected from the study area that were analyzed for this contaminant (Table 5.6-1). Selected fish species were also collected from the downstream reach (Table 5.6-2) and the downtown and upriver reaches (Table 5.6-4) for copper analysis. Species-specific data are summarized below by tissue type.

Black Crappie

Individual black crappie samples were collected over a 6-mile reach of the river within the study area and were composited for laboratory analysis. A total of four fillet (with skin) composite samples were submitted for laboratory analysis of copper. Copper was detected in all four samples, with concentrations ranging from 0.166 to 0.184 mg/kg (maximum concentration between RM 3 and 6; Map 5.6-1a).

A total of four whole body composite samples were submitted for laboratory analysis of copper. Copper was detected in all four samples, with concentrations ranging from 0.688 to 0.946 mg/kg (maximum concentration between RM 3 and 6; Map 5.6-1a).

Brown Bullhead

Brown bullhead samples were collected over an approximately 6-mile reach of the river within the study area and were composited for laboratory analysis. A total of six skin-off fillet composite samples were submitted for laboratory analysis of copper. Copper was detected in all six samples, with concentrations ranging from 0.203 to 0.292 mg/kg (maximum concentration between RM 3 and 6; Map 5.6-2a).

A total of six whole body composite samples collected from the study area were submitted for laboratory analysis of copper. Copper was detected in all six samples, with concentrations ranging from 0.586 to 0.798 mg/kg (maximum concentration between RM 6 and 9; Map 5.6-2b).

Three whole body brown bullhead samples were collected from the upriver reach. Copper was detected in each sample, with concentrations ranging from 0.625 to 0.89 mg/kg (maximum concentration between RM 28 and 33; Map 5.6-15b).

Carp

Twelve skin-on fillet composite samples of carp were collected within the study area and submitted for laboratory analysis of copper. Copper was detected in each sample, with concentrations ranging from 0.313 to 0.566 mg/kg (RM 0 to 4; Map 5.6-3a).

Six whole body composite carp samples were submitted for copper analysis, which was detected in each sample at concentrations ranging from1.04 to 1.42 mg/kg (maximum concentration between RM 0 and 6; Maps 5.6-3a-b). Six whole body composite samples

of carp based on combined fillet and body without fillet fractions were also submitted for laboratory analysis of copper. Copper was detected in each sample, with concentrations ranging from 0.897 to 1.23 mg/kg (between RM 0 to 4; Map 5.6-3a). Additionally, six carp body without fillet samples were collected from the study area. Copper was detected in each sample, with concentrations ranging from 1.02 to 1.53 mg/kg (RM 3 to 4; Map 5.6-3a).

Nine composite carp samples were collected within the downstream reach (between RM 0 and 1; Map 5.6-3a) and submitted for analysis of copper, which was detected in all nine samples. Copper concentrations for the skin-on fillet composite samples ranged from 0.476 to 0.686 mg/kg. Copper concentrations for three body without fillet composite samples ranged from 1.07 to 1.67 mg/kg. Copper concentrations for three composite samples of combined fillet and body without fillet fractions ranged from 0.92 to 1.42 mg/kg.

Chinook Salmon

Fifteen juvenile whole body Chinook salmon samples were collected within the study area and were composited for laboratory analysis of copper. Copper was detected in each sample, with concentrations ranging from 0.755 to 2.15 mg/kg (maximum concentration between RM 2 and 3; Map 5.6-4a).

Eight juvenile whole body composite samples were also collected from the Clackamas River Fish Hatchery for copper analysis. Copper was detected in each sample, with concentrations ranging from 0.879 to 1.5 mg/kg (between RM 17 and 18; Map 5.6-16).

Three fillet composite samples were collected from the Clackamas River Fish Hatchery and submitted for laboratory analysis of copper. Copper was detected in each sample, with concentrations ranging from 0.507 to 0.532 mg/kg.

Lamprey Ammocoetes and Macropthalmia

Four juvenile (ammocoetes and macropthalmia) lamprey samples were collected from the study area for copper analysis. Copper was detected in each sample, with concentrations in macropthalmia ranging from 3.08 to 6.2 mg/kg (maximum concentration with RM 1 and 9; Map 5.6-8).

Four juvenile lamprey samples were also collected from the upriver reach for copper analysis. Copper was detected in each sample, with concentrations in macropthalmia ranging from 3.92 to 4.8 mg/kg (maximum concentration between RM 18 and 19; Map 5.6-16).

Largescale Sucker

Six whole body composites of largescale sucker were collected from the study area and submitted to the laboratory for copper analysis. Copper was detected in each sample, with concentrations ranging from 0.735 to 1.1 mg/kg (maximum concentration between RM 7 and 9; Map 5.6-10b).

Northern Pikeminnow

Six whole body composites of northern pikeminnow were collected from the study area and submitted to the laboratory for copper analysis. Copper was detected in all six samples and concentrations ranged from 0.575 to 0.89 mg/kg (maximum concentration between RM 8 and 10; Map 5.6-10b).

Peamouth

Four whole body composites of peamouth were collected from the study area and submitted to the laboratory for copper analysis. Copper was detected in all four samples and concentrations ranged from 0.73 to 1.61 mg/kg (maximum concentration between RM 2 and 4; Map 5.6-10a).

Sculpin

Forty-two whole body composite samples of sculpin were collected and submitted to the laboratory for copper analysis. Thirty-eight of these samples were collected from the study area. Copper was detected in each of the samples collected from the study area, with concentrations ranging from 0.929 to 7.16 mg/kg (RM 10 to 11; Map 5.6-11f).

Two whole body composites were collected from the downstream reach, with detected concentrations of 1.25 and 3.77 mg/kg (near RM 1.5; Map 5.6-11a). Two whole body sculpin composites were also collected from the downtown reach for copper analysis, which was detected at concentrations of 0.856 and 2.98 mg/kg (between RM 11.8 and 12.3; Map 5.6-11f).

Smallmouth Bass

Sixty-one smallmouth bass samples were collected and submitted to the laboratory for copper analysis. All but 6 of these samples were collected from the study area. Study area samples included 18 composites of body without fillet, 23 fillet composites, and 14 whole body composites. In addition, concentrations were derived for 18 composites by calculating concentrations for fillet and body without fillet fractions.

Copper was detected in all of the samples collected from the study area. Detected copper concentrations of these study area smallmouth bass samples, as presented on Maps 5.6-12a-e, ranged as follows:

- Fillet—0.187 to 1.12 mg/kg (RM 5 to 6)
- Combined fillet and body without fillet fractions—0.444 to 1.92 mg/kg (RM 10 to 11)
- Body without fillet—0.464 to 2.59 mg/kg (RM 10 to 11)
- Whole body—0.365 to 1.29 mg/kg (RM 7 to 9).

Copper was detected in the six whole body samples collected from the downtown and upriver reaches, with concentrations ranging from 0.37 to 0.54 mg/kg (maximum concentration between RM 20 and 25; Map 5.6-15a).

Sturgeon

Twenty-three sturgeon samples were collected from the study area and submitted to the laboratory for copper analysis. These included 5 composite skin-off fillet samples, 15 whole body samples, and 3 samples of stomach contents.

As presented on Maps 5.6-13a-b, copper was detected in all of the samples. Detected copper concentrations of skin-off fillet samples ranged from 0.127 to 0.253 mg/kg (maximum concentration between RM 5 and 6). Whole body copper concentrations ranged from 0.544 to 0.959 mg/kg (maximum concentration between RM 2 and 3). The copper concentrations in the three stomach contents samples ranged from 6.73 J to 11 J mg/kg (maximum concentration between RM 2 and 3).

5.6.12.2 Copper in Invertebrate Tissue

As shown in Table 5.6-5, copper was detected in all invertebrate species and tissue types collected from the study area for which copper analysis was conducted. Selected invertebrate species were also collected from the downstream reach and from the downtown and upriver reaches (Tables 5.6-6 and 5.6-7, respectively). Taxon-specific data are summarized below.

Clams (Resident)

All clam samples consisted of composites of soft parts only (body without shell). Thirty-seven composite samples of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for copper analysis. Copper was detected in all of the samples, with concentrations ranging from 5.99 to 13.5 mg/kg (RM 8 to 9; Map 5.6-5e). Three additional depurated samples were collected within the study area for copper analysis. Copper was detected in each sample, with concentrations ranging from 6.85 to 9.03 mg/kg (RM 9 to 10; Map 5.6-5e).

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. Copper was detected in the depurated sample at a concentration of 7.59 mg/kg and in the non-depurated samples at concentrations of 8.23 and 9.35 mg/kg (RM 1.6 and Multnomah Channel; Maps 5.6-5a-b).

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. Copper was detected in the depurated sample at a concentration of 7.62 mg/kg and in the non-depurated samples at concentrations of 4.57 and 6.97 mg/kg (between RM 11.9 and 12.3; Map 5.6-5f).

Clams (Laboratory-Exposed)

Thirty-four additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by analysis of soft body parts for copper. Copper was detected in all of the samples, with concentrations ranging from 2.64 to 5.94 J mg/kg (maximum concentration from sediments collected between RM 8 and 9; Map 5.6-6e).

One clam result was generated by exposing laboratory reared clams to downstream reach sediments, followed by analysis of soft body parts for copper. Copper was detected at a concentration of 3.67 J mg/kg (Multnomah Channel; Map 5.6-6b).

Crayfish

Thirty-two whole body crayfish composites were collected within the study area and submitted to the laboratory for copper analysis. Copper was detected in all of the samples, with concentrations ranging from 10.4 to 20.2 mg/kg (RM 11 to 12; Map 5.6-7d).

Two composite whole body crayfish samples were collected from the downstream reach. Copper was detected at concentrations of 14.3 and 15.5 mg/kg (between RM 1 and 1.5; Map 5.6-7a).

Two composite whole body crayfish samples were also collected from the downtown reach. Copper was detected at concentrations of 17 and 18 mg/kg (between RM 12 and 12.3; Map 5.6-7d).

Epibenthic Invertebrates

Two composite samples of epibenthic invertebrates (mixed taxa) were collected from the study area and analyzed for copper, with detected concentrations of 3.01 J and 6 J mg/kg (between RM 2 and 3; Map 5.6-9a).

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory-reared *Lumbriculus* worms to study area sediments, followed by analysis of whole body worms for copper. Copper was detected in all of the samples, with concentrations in these laboratory-exposed samples ranging from 1.83 to 20.2 mg/kg (maximum concentration from sediments collected between RM 8 and 9; Map 5.6-14e).

One result was generated by exposing laboratory-reared *Lumbriculus* worms to downstream reach sediments, followed by analysis of whole body worms for copper. Copper was detected at a concentration of 2.88 mg/kg (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for copper analysis. Copper was detected in each sample, with concentrations ranging from 1.01 to 1.82 mg/kg (maximum concentration between RM 3 and 4; Map 5.6-9a).

5.6.13 Zinc in Biota

This section presents a summary of the distribution of zinc in fish and invertebrate tissue. Scatter plots showing the distribution of zinc concentrations in select biota tissue collected from the study area are provided on Figures 5.6-13a-e. A box-whisker plot

showing the distribution of zinc concentrations in whole body tissue samples collected of each species across the study area is provided on Figure 5.6-27.

5.6.13.1 Zinc in Fish Tissue

Zinc was detected in all fish samples collected from the study area that were analyzed for this contaminant (Table 5.6-1). Selected fish species were also collected from the downstream reach (Table 5.6-2) and the downtown and upriver reaches (Table 5.6-4) for zinc analysis. Species-specific data are summarized below by tissue type.

Black Crappie

Individual black crappie samples were collected within the study area and were composited for laboratory analysis. A total of four fillet (with skin) composite samples were submitted for laboratory analysis of zinc. Zinc was detected in all four samples, with concentrations ranging from 7.45 to 9.03 mg/kg (maximum concentration between RM 3 and 6; Map 5.6-1a).

A total of four whole body composite samples were submitted for laboratory analysis of zinc. Zinc was detected in all four samples, with concentrations ranging from 14.2 to 16.8 mg/kg (maximum concentration between RM 6 and 9; Map 5.6-1b).

Brown Bullhead

Brown bullhead samples were collected within the study area and were composited for laboratory analysis. A total of six skin-off fillet composite samples were submitted for laboratory analysis of zinc. Zinc was detected in all six samples, with concentrations ranging from 3.96 J to 6.49 J mg/kg (maximum concentration between RM 3 and 6; Map 5.6-2a).

A total of six whole body composite samples were submitted for laboratory analysis of zinc. Zinc was detected in all six samples, with concentrations ranging from 12.7 to 15.6 mg/kg (maximum concentration between RM 6 and 9; Map 5.6-2b).

Two whole body brown bullhead samples were collected from the upriver reach. Zinc was detected in each sample, with concentrations ranging from 13.9 to 14.45 mg/kg (maximum concentration between RM 28 and 33; Map 5.6-15b).

Carp

Twelve skin-on fillet composite samples of carp were collected within the study area and submitted for laboratory analysis of zinc. Zinc was detected in each sample, with concentrations ranging from 17.4 J to 31 mg/kg (maximum concentration between RM 4 and 8; Map 5.6-3b).

Six whole body composite carp samples were submitted for zinc analysis, which was detected in each sample at concentrations ranging from 87.1 to 112 mg/kg (maximum concentration between RM 4 and 8; Map 5.6-3b). Six whole body composite samples of carp based on combined fillet and body without fillet fractions were also submitted for

laboratory analysis of zinc. Zinc was detected in each sample, with concentrations ranging from 71.2 to 113 mg/kg (maximum concentration between RM 4 and 8; Map 5.6-3b). Additionally, six carp body without fillet samples were collected from the study area. Zinc was detected in each sample, with concentrations ranging from 89.9 to 147 mg/kg (maximum concentration between RM 4 and 8; Map 5.6-3b).

Nine composite carp samples were collected within the downstream reach (between RM 0 and 1; Map 5.6-3a) and submitted for analysis of zinc, which was detected in all nine samples. Zinc concentrations for the skin-on fillet composite samples ranged from 24.8 to 30.6 mg/kg. Zinc concentrations for three body without fillet composite samples ranged from 88 to 111 mg/kg. Zinc concentrations for three composite samples of combined fillet and body without fillet fractions ranged from 72 to 89.9 mg/kg.

Chinook Salmon

Fifteen juvenile whole body Chinook salmon samples were collected within the study area and were composited for laboratory analysis of zinc. Zinc was detected in each sample, with concentrations ranging from 24 to 33.3 mg/kg (maximum concentration between RM 2 and 3; Map 5.6-4a).

Eight juvenile whole body composite samples were also collected from the Clackamas River Fish Hatchery for zinc analysis. Zinc was detected in each sample, with concentrations ranging from 22 to 37.5 mg/kg (between RM 17 and 18; Map 5.6-16).

Three fillet composite samples were collected from the Clackamas River Fish Hatchery and submitted for laboratory analysis of zinc. Zinc was detected in each sample, with concentrations ranging from 4.56 to 4.6 mg/kg.

Lamprey Ammocoetes and Macropthalmia

Four juvenile (ammocoetes and macropthalmia) lamprey samples were collected from the study area for zinc analysis. Zinc was detected in each sample, with concentrations in ammocoete ranging from 19 to 26.7 mg/kg (maximum concentration with RM 10 and 11.8; Map 5.6-8).

Four juvenile lamprey samples were also collected from the upriver reach for zinc analysis. Zinc was detected in each sample, with concentrations in macropthalmia ranging from 25.8 to 29.1 mg/kg (maximum concentration between RM 18 and 19; Map 5.6-16).

Largescale Sucker

Six whole body composites of largescale sucker were collected from the study area and submitted to the laboratory for zinc analysis. Zinc was detected in each sample, with concentrations ranging from 17.1 to 19.7 mg/kg (maximum concentration between RM 7 and 9; Map 5.6-10a).

Northern Pikeminnow

Six whole body composites of northern pikeminnow were collected from the study area and submitted to the laboratory for zinc analysis. Zinc was detected in all six samples, with concentrations ranging from 16.4 to 20 mg/kg (maximum concentration between RM 8 and 10; Map 5.6-10b).

Peamouth

Four whole body composites of peamouth were collected from the study area and submitted to the laboratory for zinc analysis. Zinc was detected in all four samples, with concentrations ranging from 23.1 to 25.2 mg/kg (maximum concentration between RM 8 and 10; Map 5.6-10b).

Sculpin

Forty-two whole body composite samples of sculpin were collected and submitted to the laboratory for zinc analysis. Thirty-eight of these samples were collected from the study area. Zinc was detected in each of the samples collected from the study area, with concentrations ranging from 11.7 to 18 mg/kg (maximum concentration between RM 4 and 5; Map 5.6-11c).

Two whole body composites were collected from the downstream reach, with detected concentrations of 13.1 and 16.8 mg/kg (near RM 1.5; Map 5.6-11a). Two whole body sculpin composites were also collected from the downtown reach for zinc analysis, which was detected at concentrations of 15 and 15.3 mg/kg (between RM 11.8 and 12.3; Map 5.6-11f).

Smallmouth Bass

Sixty-one smallmouth bass samples were collected and submitted to the laboratory for zinc analysis. All but 6 of these samples were collected from the study area. Study area samples included 18 composites of body without fillet, 23 fillet composites, and 14 whole body composites. In addition, concentrations were derived for 18 composites by calculating concentrations for fillet and body without fillet fractions.

Zinc was detected in all of the samples collected from the study area. Detected zinc concentrations of these study area smallmouth bass samples, as presented on Maps 5.6-12a-e, ranged as follows:

- Fillet—7.12 to 10.9 J mg/kg (RM 5 to 6)
- Combined fillet and body without fillet fractions—10.8 to 13 mg/kg (RM 6 to 8)
- Body without fillet—11.5 to 15 mg/kg (RM 8 to 9)
- Whole body—13.4 to 16.3 mg/kg (RM 2 to 5).

Zinc was detected in the six whole body samples collected from above the downtown and upstream reaches, with concentrations ranging from 12.8 to 16.8 mg/kg (maximum concentration between RM 28 and 33, Map 5.6-15b).

Sturgeon

Twenty-three sturgeon samples were collected from the study area and submitted to the laboratory for zinc analysis. These included 5 composite skin-off fillet samples, 15 whole body samples, and 3 samples of stomach contents.

As presented on Maps 5.6-13a-b, zinc was detected in all of the samples. Detected zinc concentrations of skin-off fillet samples ranged from 2.08 to 2.93 mg/kg (maximum concentration between RM 5 and 6). Whole body zinc concentrations ranged from 7.39 to 11.9 mg/kg (maximum concentration between RM 3 and 5). The zinc concentrations in the three stomach contents samples ranged from 9.56 to 19.1 mg/kg (maximum concentration between RM 2 and 3).

5.6.13.2 Zinc in Invertebrate Tissue

As shown in Table 5.6-5, zinc was detected in all invertebrate species and tissue types collected from the study area for which zinc analysis was conducted. Selected invertebrate species were also collected from the downstream reach and from the downtown and upriver reaches (Tables 5.6-6 and 5.6-7, respectively). Taxon-specific data are summarized below.

Clams (Resident)

All clam samples consisted of soft parts only (body without shell). Thirty-seven composite samples of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for zinc analysis. Zinc was detected in all of the samples, with concentrations ranging from 19.6 to 54 mg/kg (RM 8 to 9; Map 5.6-5e). Three additional depurated samples were collected within the study area for zinc analysis. Zinc was detected in each sample, with concentrations ranging from 19.3 to 27.9 mg/kg (RM 10 to 11; Map 5.6-5f).

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. Zinc was detected in the depurated sample at a concentration of 21.3 mg/kg (near RM 1.6; Map 5.6-5a) and in the non-depurated samples at concentrations of 25.4 and 30.5 mg/kg (near RM 1.6 and Multnomah Channel; Maps 5.6-5a-b).

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. Zinc was detected in the depurated sample at a concentration of 23.7 mg/kg and in the non-depurated samples at concentrations of 27.8 and 30.4 mg/kg (between RM 11.9 and 12.3; Map 5.6-5f).

Clams (Laboratory-Exposed)

Thirty-four additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by analysis of soft body parts for zinc. Zinc was detected in all of the samples, with concentrations ranging from 10.8 to 16.8 mg/kg (maximum concentration from sediments collected between RM 8 and 9; Map 5.6-6e).

One clam result was generated by exposing laboratory-reared clams to downstream reach sediments, followed by analysis of soft body parts for zinc. Zinc was detected at a concentration of 12.2 mg/kg (Multnomah Channel; Map 5.6-6b).

Crayfish

Thirty-two whole body crayfish composites were collected within the study area and submitted to the laboratory for zinc analysis. Zinc was detected in all of the samples, with concentrations ranging from 13.7 J to 20.3 J mg/kg (RM 6 to 7; Map 5.6-7c).

Two composite whole body crayfish samples were collected from the downstream reach. Zinc was detected at concentrations of 15.3 and 15.9 mg/kg (between RM 1 and 1.5; Map 5.6-7a).

Two composite whole body crayfish samples were also collected from the downtown reach. Zinc was detected at concentrations of 18.9 and 19.4 mg/kg (between RM 12 and 12.3; Map 5.6-7d).

Epibenthic Invertebrates

Two composite samples of epibenthic invertebrates (mixed taxa) were collected from the study area and analyzed for zinc, with detected concentrations of 12.6 J and 24.8 J mg/kg (between RM 9 and 10; Map 5.6-9b).

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory-reared *Lumbriculus* worms to study area sediments, followed by analysis of whole body worms for zinc. Zinc was detected in all of the samples, with concentrations in these laboratory exposed samples ranging from 18.2 to 31.5 mg/kg (maximum concentration from sediments collected between RM 4 and 5; Map 5.6-14b).

One result was generated by exposing laboratory reared *Lumbriculus* worms to downstream reach sediments, followed by analysis of whole body worms for zinc. Zinc was detected at a concentration of 26.1 mg/kg (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for zinc analysis. Zinc was detected in each sample, with concentrations ranging from 15.7 to 41.5 mg/kg (maximum concentration between RM 7 and 8; Map 5.6-9b).

5.6.14 Tributyltin Ion in Biota

Species-specific data are for TBT in biota are summarized below by tissue type. Scatter plots showing the distribution of TBT concentrations in select biota tissue collected from the study area are provided on Figures 5.6-14a-e. A box-whisker plot showing the distribution of TBT concentrations in whole body tissue samples collected of each species across the study area is provided on Figure 5.6-28.

5.6.14.1 TBT in Fish Tissue

As shown in Table 5.6-1, TBT was detected in all fish samples collected from the study area that were analyzed for this contaminant. Selected fish species were also collected from the downstream reach (Table 5.6-2) and above the study area (Table 5.6-4) for TBT analysis. Species-specific data are summarized below by tissue type.

Black Crappie

Black crappie samples collected from the study area were not analyzed for TBT.

Brown Bullhead

Brown bullhead samples collected from the study area and from locations above and from the downstream reach were not analyzed for TBT.

Carp

Six skin-on fillet composite samples of carp were collected within the study area and submitted for laboratory analysis of TBT. TBT was detected in five samples out of six, with detected concentrations ranging from 3.7 J to 11 J µg/kg (maximum concentration between RM 8 and 12; Map 5.6-3c).

Six whole body composite samples of carp based on combined fillet and body without fillet fractions were also submitted for laboratory analysis of TBT. TBT was detected in each sample, with concentrations ranging from 3.4 J to 8.6 µg/kg (maximum concentration between RM 8 and 12; Map 5.6-3c). Additionally, six carp body without fillet samples were collected from the study area. TBT was detected in each sample, with concentrations ranging from 4.3 J to 9.8 µg/kg (RM 8 to 11; Map 5.6-3c).

Nine composite carp samples were collected within the downstream reach (between RM 0 and 1; Map 5.6-3a) and submitted for analysis of TBT, which was detected in all nine samples. TBT concentrations for the skin-on fillet composite samples ranged from 2.6 J to 7 µg/kg. TBT concentrations for three body without fillet composite samples ranged from 2.8 J to 8.4 µg/kg. TBT concentrations for three composite samples of combined fillet and body without fillet fractions ranged from 2.7 J to 7.5 µg/kg.

Chinook Salmon

Eight juvenile whole body Chinook salmon samples were collected within the study area and were composited for laboratory analysis of TBT. TBT was detected in each sample, with concentrations ranging from 1.3 J to 4.1 J µg/kg (maximum concentration between RM 6 and 7; Map 5.6-4b).

Three juvenile whole body composite samples were also collected from the upriver reach for TBT analysis. TBT was detected in each sample, with concentrations ranging from 0.37 J to 0.45 J µg/kg (maximum concentration between RM 17 and 18; Map 5.6-16).

Lamprey Ammocoetes and Macropthalmia

One juvenile (ammocoete) lamprey sample was collected from the study area for TBT analysis. TBT was detected at a concentration of 4.1 µg/kg (between RM 1 and 10; Map 5.6-8).

Largescale Sucker

Largescale sucker samples collected within the study area and from locations in the downstream and upriver reaches were not analyzed for TBT.

Northern Pikeminnow

Northern pikeminnow samples collected within the study area and from locations in the downstream and upriver reaches were not analyzed for TBT.

Peamouth

Peamouth samples collected within the study area and from locations in the downstream and upriver reaches were not analyzed for TBT.

Sculpin

Sixteen whole body composite samples of sculpin were collected and submitted to the laboratory for TBT analysis. Twelve of these samples were collected from the study area. TBT was detected in four of the samples collected from the study area. Detected TBT concentrations ranged from 2.3 J to 4 J µg/kg (RM 4 to 8; Maps 5.6-11c-d).

Two whole body composites were collected from the downstream reach, with no detected TBT concentrations in both samples. Two whole body sculpin composites were also collected from the downtown reach for TBT analysis. TBT was detected in one of the samples at a concentration of 6.2 µg/kg (near RM 1.5; Map 5.6-11a).

Smallmouth Bass

Thirty-six smallmouth bass samples were collected and submitted to the laboratory for TBT analysis. All of these samples were collected from the study area and included 18 composites of body without fillet and 18 fillet without skin composites. In addition, concentrations were derived for 18 composites by calculating concentrations for fillet and body without fillet fractions.

TBT was only detected in four of the composite samples of combined fillet and body without fillet fractions and four fillet samples. Detected concentrations of these study area smallmouth bass samples, as presented on Maps 5.6-12a-b, ranged as follows:

- Fillet—0.48 J to 0.92 J µg/kg (maximum concentration between RM 3 and 5)
- Combined fillet and body without fillet fractions—0.78 J to 1.6 J µg/kg (maximum concentration between RM 3 and 5).

Sturgeon

Fifteen whole body sturgeon samples were collected from the study area and submitted to the laboratory for TBT analysis. As presented on Map 5.6-13b, TBT was detected in four of the samples. Detected TBT concentrations ranged from 0.61 J to 1.1 µg/kg (maximum concentration between RM 9 and 10).

5.6.14.2 TBT in Invertebrate Tissue

As shown in Table 5.6-5, TBT was detected in all invertebrate species and tissue types collected from the study area for which analysis was conducted. Selected invertebrate species were also collected from the downstream reach and from the downtown and upriver reaches (Tables 5.6-6 and 5.6-7, respectively).

Clams (Resident)

All clam samples consisted of soft parts only (body without shell). Thirty-three composites of resident clams (non-depurated) were collected within the study area and submitted to the laboratory for TBT analysis. TBT was detected in 21 samples, with concentrations ranging from 2.5 to 530 µg/kg (RM 8 to 9; Map 5.6-5d). Two additional depurated samples were collected within the study area; however, TBT was not detected above laboratory reporting limits.

Three composite clam samples, one depurated and two not depurated, were collected from the downstream reach. TBT was detected in one non-depurated sample at a concentration of 4.7 µg/kg (Multnomah Channel; Map 5.6-5b). TBT was not detected above laboratory reporting limits for the depurated sample.

Three composite clam samples, one depurated and two not depurated, were also collected from the downtown reach. TBT was not detected in any of the samples.

Clams (Laboratory-Exposed)

Thirty-four additional clam results were generated by exposing laboratory-reared clams to study area sediments, followed by analysis of soft body parts for TBT. TBT was detected in nine of the samples, with concentrations ranging from 1.1 to 680 µg/kg (maximum concentration from sediments collected between RM 8 and 9; Map 5.6-6e).

One clam sample was analyzed by exposing laboratory-reared clams to downstream reach sediments, followed by analysis of soft body parts for TBT. TBT was not detected above laboratory reporting limits.

Crayfish

Five whole body crayfish composites were collected within the study area and submitted to the laboratory for TBT analysis. TBT was detected in three of the samples, with detected concentrations ranging from 0.56 J to 2.3 µg/kg (RM 6 to 7; Map 5.6-7c).

Two composite whole body crayfish samples were collected from the downstream reach. TBT was detected in one of these two samples at a concentration of 1.3 J µg/kg (near RM 1; Map 5.6-7a).

Two composite whole body crayfish samples were also collected from the downtown reach. TBT was detected in one of these two samples at a concentration of 1.6 µg/kg (near RM 12; Map 5.6-7d).

Epibenthic Invertebrates

Epibenthic invertebrates (mixed taxa) collected from the study area were not analyzed for TBT.

Laboratory-Exposed *Lumbriculus* Worms

Thirty-four results were generated by exposing laboratory-reared *Lumbriculus* worms to study area sediments, followed by analysis of whole body worms for TBT. TBT was detected in 14 samples, with detected concentrations in these laboratory-exposed samples ranging from 2.1 to 1,700 µg/kg (maximum concentration from sediments collected between RM 8 and 9; Map 5.6-14e).

One result was generated by exposing laboratory-reared *Lumbriculus* worms to downstream reach sediments, followed by analysis of whole body worms for TBT. TBT was detected at a concentration of 2.6 µg/kg (Multnomah Channel; Map 5.6-14b).

Mussels

Seven composites of resident mussels were collected within the study area and submitted to the laboratory for TBT analysis. TBT was detected in each sample, with concentrations ranging from 2.2 J to 16 J µg/kg (between RM 3 and 4; Map 5.6-9a).

6.0 LOADING, FATE, AND TRANSPORT FOR SELECT CONTAMINANTS

This section presents an assessment of contaminant loading mechanisms to the study area from external sources as well as in-river processes affecting the concentration, transport, and fate of select contaminants within the study area. Section 6.1 assesses contaminant inputs (external loading) to the study area. Section 6.2 describes fate and transport processes that act on contaminants in abiotic and biotic media within the study area. The discussion of fate and transport processes is grouped by sediment and pore water, surface water, and biotic processes. Section 6.3 provides an evaluation of sedimentation in the upper study area utilizing three sediment core profiles in the navigation channel; two in borrow pits, which are natural sediment traps, and one in a shoal area.

Contaminants evaluated in this assessment are presented in Table 6.0-1. There are separate lists for surface water, stormwater, upland groundwater plumes, atmospheric deposition, and equilibrium partitioning (advective loading from subsurface sediment to surface sediment and from surface sediment to surface water). These lists reflect data availability by media and relevance of the contaminant to the loading mechanism. For example, equilibrium partitioning primarily focuses on hydrophobic contaminants and metals, stormwater and atmospheric deposition contaminants reflect the limited available data sets, and upland plume loading contaminants reflect individual upland plumes.

6.1 EXTERNAL CONTAMINANT LOADING

Loading is a quantity of mass that passes a boundary over a given time frame. The boundaries for determining external loads include the upstream and downstream river mile designations (RM 1.9 and 11.8), the surface of the river, the river bank, and the surface sediment/subsurface sediment boundary at 30 cm bml. Contaminant masses passing through these boundaries are external loads.

These loading mechanisms represent the combined estimated load from all study area sources for the corresponding pathway. A simplified conceptualization of the external loading pathways (loading terms) and internal transport processes is presented on Figure 6.1-1. Numerical loading estimates were generated for the following external contaminant loads:

- Upstream loading via surface water, including suspended sediment load
- Stormwater runoff
- Permitted non-stormwater point source discharges
- Upland groundwater plume transport to the river

- Atmospheric deposition to the river surface

Loading estimates for upland riverbank erosion, sediment bedload, and overwater releases were not quantified. Contaminant releases from overwater activities, such as sandblasting, painting, material transfer, maintenance, repair, and operations at riverside docks, wharfs, or piers; discharges from vessels; fuel releases; and spills are not considered quantifiable and are not addressed in this section. Releases of this nature are expected to have been more significant historically, prior to improved BMPs. While improved BMPs are likely to have reduced the occurrence of overwater releases significantly, although current and future releases could occur. Due to insufficient available information, no attempt is made in this report to predict and quantify such releases as a current loading term.

Quantification of sediment bedload (rolling, sliding, and saltating of sediment grains) into the study area and associated contaminant transport is not quantified in the HST model because it was assumed that bedload represents a relatively small fraction of the total sediment load entering the study area at RM 11.8. This is because of the lower Willamette River's morphology and the fact that its flows are regulated by upstream control structures. As noted in Section 3, the study area occupies the lower portion of the lower Willamette River where the river widens and has been deepened by dredging. The reach upstream of the study area, from Willamette Falls through downtown Portland, is generally narrower with high velocities, so suspended loads tend to be transported into the study area before settling out. In addition, dams at Willamette Falls (RM 26) and further upstream trap bedload moving downstream from the middle Willamette River to the lower Willamette River. The only significant tributary to the lower Willamette River below RM 26 is the Clackamas River at RM 24.7 and it is a gravel-bed stream.

Due to insufficient chemistry data at multiple shoreline sites, it is not possible at this time to estimate riverbank loading to the river. Further, is not possible to estimate typical erosion rates or a range of rates that might apply to riverbanks in the study area given the wide range of conditions present. Since contaminant loading from bank erosion is an area-specific condition dependent on both the erodibility and contaminant concentrations at any given bank area, the contaminant loading is more important on a more localized scale rather than as a load to the study area as a whole.

A range of estimates (central estimate and upper- and lower-bounds) is provided for all loading terms for which numerical estimates were generated to give perspective on the uncertainty associated with a given pathway for each contaminant. The estimation approach for each term varies in nature and approach depending on the degree to which loading associated with a given transport pathway could be evaluated using available information. Most, if not all, of the attributes utilized in the loading estimations are based on site-specific measurements and monitoring results. If attributes were either not measurable or site-specific data are not available, literature data or empirical data collected outside of the study area are used. Some assumptions and modeling or calculation techniques may be used in these assessments.

The assessments of external loading terms are intended to illustrate the estimated magnitude and variability in contaminant loads to the study area under typical conditions in an average water year. Assessment of year-to-year temporal variability was not the intent of this analysis. Because every water year is slightly different from the theoretical "average water year," the analyses include data collected during a range of environmental conditions. This variability is taken into account in the analyses to the extent possible. The approach to assess each term is discussed in Appendix E.

The target scale of assessment of current loading rates is mass per year; however, in many cases, the data set supports calculation of loading estimates at smaller temporal and/or spatial resolution. Where possible and relevant to understanding the system for the purposes of the RI, these more refined loading estimates were generated and are presented and discussed.

6.1.1 Upstream Contaminant Load

Upstream contaminant load is defined as the mass transport over time of a given contaminant across the upriver study area boundary at RM 11.8. Upstream contaminant loading is subdivided into dissolved and suspended solids fractions. Surface water loading is assessed in this section for typical flow conditions, as well as extreme observed and modeled high-flow conditions.

While upstream loading terms are presented here as dissolved surface water and suspended particulate loads, these loads represent the combined input to the study area from a variety of loading processes in the upstream watershed. These inputs include upstream point sources, upstream stormwater runoff, upstream CSOs, upstream atmospheric deposition, and upstream in-river sources. Distinguishing these individual contributions to the combined upstream load is beyond the scope of this document.

Concentration and flow rate data from the site were used to generate a range of estimates of annual upstream loading rates. Estimates for dissolved, particulate, and total loading rates are presented. Upstream surface water loading at RM 11.8 was estimated based on analytical data collected from sampling transects at RM 16 and 11.

6.1.1.1 Data Sets and Approach

Upriver surface water loading rates were estimated based on Round 2A and 3A surface water contaminant concentration data from the RM 16 transect sampling location and USGS flow information from RM 12.8 (Morrison Bridge Station 14211720). The annual flow regimes (Section 3) for the site have two distinct periods of flow: a high-flow and a low-flow condition. The approach discussed here, and described in more detail in Appendix E2, describes how the data was apportioned to represent a single external load.

To differentiate loads associated with high-flow and low-flow conditions during a typical flow year, the fraction of a typical water year that is described by each flow regime was determined. Since the USGS gage station and flow conditions during data

collection compared well, the 28-year hydrograph was considered adequately representative for use as the basis for defining the high-flow:low-flow volume ratio of 1.07 for a typical year.

The surface water analytical data set was apportioned to estimate representative concentration ranges for high-flow and low-flow conditions. Three surface water sampling events from the Round 2A sampling effort and four surface water sampling events from the Round 3A sampling effort provided the analytical data for the surface water loading calculations. Of these seven sampling events, four occurred during low-flow conditions (<50,000 cfs), two were during high-flow conditions (>50,000 cfs), and one was during a low-flow stormwater event (active runoff to the study area with river flow rate <50,000 cfs). Individual data points associated with the RM 16 transect were averaged to represent a single concentration per transect per sampling event (see Appendix E, Section 2.2.2 for details), and minimum, mean, and maximum concentrations at each transect was calculated for both high-flow and low-flow conditions.

Upriver loading rates were estimated as the product of the contaminant concentrations and the flow volumes associated with the high-flow and low-flow portions of the hydrograph. Lower, central, and upper estimates of high-flow loading were estimated for each transect by multiplying the minimum, mean, and maximum concentrations, respectively, by the total annual flow volume estimated for high-flow conditions. Low-flow rate loading estimates for each transect was estimated using the minimum, mean, and maximum of averaged concentrations and the estimated flow volume for low-flow conditions. The range of annual mass loading rate estimates were generated by summing the fractional loading contributions estimated for high-flow and low-flow conditions at the given transect.

There are no surface water sample results available from RM 11.8, which represents the upstream boundary of the study area. Therefore, high-flow and low-flow concentrations at RM 11.8 were estimated by combining data from RM 16 with selected data from RM 11. Because the surface water samples collected on the east side of RM 11 appear to have been influenced by one or more source areas of contaminants, these results are considered not representative of water quality entering the Site at the upstream boundary. Prior to combining the data, the RM 11 data set was assessed for each contaminant to determine whether the data represented the same population of upstream data as that sampled at RM 16. This approach assumes that the surface water concentrations at RM 11.8 would be similar to those at RM 16 than those at RM 11, recognizing that although there are additional sources between RM 11.8 and 16, the proximity of likely sources to the RM 11 transect are expected to have the larger effect. A graphical and statistical comparison of the contaminant data from RM 16 and 11 was conducted for each selected contaminant and is described in Appendix E, Section 2.2.2.1.

6.1.1.2 Uncertainty Associated with Surface Water Loading Estimates

Uncertainty associated with the surface water loading estimates is related primarily to the adequacy and representativeness of the analytical data set. The data sets are derived from grab samples, not time-weighted composites. Further, a limited number of samples were collected under a limited number of flow conditions. This prohibits a thorough understanding of temporal and flow variability in surface water quality and is an important source of uncertainty. The magnitude and direction of bias on loading estimates is unknown.

6.1.1.3 Annual Upstream Loading

Table 6.1-1 presents the range of total (dissolved plus particulate) annual upstream loading estimates for each contaminant evaluated. Figure 6.1-2 presents total upriver surface water loading estimates for total PCB congeners and selected individual PCB congeners. The total PCBs loading estimates show higher aggregate loads during the low-flow period of the year as compared to the high-flow period. Total PCBs show significant contributions of particulate-associated concentrations to the total surface water PCB loads for most flow conditions (Figure 6.1-3). These patterns in flow conditions and particulate/dissolved ratios are also generally apparent in the individual congener data sets.

Upriver loads for total PCDD/Fs and TCDD TEQ (Figures 6.1-4 and 6.1-5) are primarily associated with particulate matter. The relative contributions to the annual load from high-flow and low-flow periods are comparable (Figure 6.1-4).

The upriver loads for DDx compounds (Figures 6.1-6 and 6.1-7) indicate the loads are generally higher in the particulate fraction, as typically seen for the other hydrophobic contaminants, but the patterns with surface water flow regime differ. The annual aggregate upstream load of DDx compounds associated with the high-flow period is consistently higher than that associated with the low-flow period of the year. Further, the 4,4′-isomers of the DDx components compose the majority of the DDx upstream load, with DDT being the greatest fraction, and DDD being the smallest fraction of the DDx.

Upstream surface water loads of total PAHs are greater (approximately an order of magnitude) than total cPAHs (Figure 6.1-8). LPAHs generally exhibit greater solubility than HPAHs; cPAHs are primarily classified as HPAH compounds. The annual aggregate load of LPAHs and HPAHs associated with the high-flow period is higher than that associated with the low-flow period of the year. On a daily basis, total PAHs loads are higher during the high-flow period than during the low-flow period. LPAHs show higher fractions of dissolved as compared to particulate load (Figure 6.1-9). In contrast, HPAHs are generally more hydrophobic, and show higher fractions in the particulate load as compared to dissolved load.

Upstream loading rate ranges for BEHP and hexachlorobenzene are presented on Figures 6.1-10 and 6.1-11. The total annual BEHP load is almost exclusively associated

with high-flow periods. The high-flow contribution for hexachlorobenzene is also higher than the low-flow contribution. Hexachlorobenzene shows consistent fractions of particulate and dissolved contributions to the total load under all flow conditions, with the particulate fraction making up roughly 15 to 20 percent of the total load.

Upstream surface water loading rate estimates for other indicator pesticides are presented on Figures 6.1-12 and 6.1-13. Dieldrin exhibits the highest annual upstream loads, whereas loads for aldrin are comparatively low. This difference may reflect the fact that aldrin degrades relatively rapidly in surface water by photochemical or microbial processes (discussed further in Section 6.2). Upstream loading of these pesticides typically exhibit higher loads during high-flow conditions, with the exception of gamma-HCH where approximately 60 percent of the annual load occurs during low-flow conditions. Total surface water loads for these pesticides are dominated by the dissolved fraction (Figure 6.1-13).

Figures 6.1-14 and 6.1-15 present the upstream surface water loading rate estimates for selected metals. The highest overall loading rates are observed for zinc and copper, followed by nickel, chromium, lead and arsenic. Loading rates for mercury, which was infrequently detected (23 percent; see Table E2-5 in Appendix E), are the lowest. Loading rates during high-flow conditions for all of these metals are greater than loading rates during low-flow conditions. Further, the particulate fraction contributes more than the dissolved fraction to the total loading estimates for the majority of the metals, especially under high-flow conditions (Figure 6.1-15).

Estimated upstream total surface water loads for TBT are presented on Figure 6.1-16. There is no presentation of dissolved versus particulate fractions for TBT because the surface water data set only includes measurements of total concentrations. TBT in upstream surface water was detected only once during a low-flow sampling event. Therefore, no meaningful comparisons could be made regarding the relative loading of TBT with regard to low-flow versus high-flow conditions.

In summary, with the exception of PCBs and gamma-HCH, surface water contaminants exhibit higher upstream loading rates during high-flow conditions than during low-flow conditions. On a daily basis, loads for all of the contaminants are generally higher during high flows than during low flows. The particulate fraction represents the larger component for PCBs, PCDD/Fs, DDx, and metals. The dissolved fraction is the larger component for LPAHs, other pesticides, and hexachlorobenzene. In general, the ratios of particulate to dissolved mass loading for all surface water loading contaminants do not show large or consistent variations under different flow conditions, indicating possible conditions of equilibrium or near equilibrium, as discussed further in Section 6.2.2.

6.1.2 Stormwater Runoff

Stormwater loading estimates are presented in the following sections. Appendix E, Section 3.0 describes the detailed steps taken to calculate these loading estimates.

6.1.2.1 Data Sources and Calculation Approach

The stormwater composite water and sediment trap data were collected in accordance with the Round 3A Stormwater FSP and Addendum (Anchor and Integral 2007b,c) and the Round 3A Stormwater Sampling Rationale (Anchor and Integral 2007d) and analyzed in accordance with the QAPP Addendum 8 (Integral 2007m).

The stormwater sampling location rationale was developed in accordance with the approach of applying representative estimates of stormwater contaminant concentrations from various land use types as described in Scheuler (1987). A land-use-based contaminant load modeling approach was used to estimate loads across the entire study area. Contaminant loading models use site characteristics (land use and percent impervious area) and land-use-specific loading rates to estimate overall loading into the receiving waters. This approach has been modified to better fit the data needs and land use characteristics of the study area, as well as the practical constraints for this sampling effort.

Samples were collected from a subset of drainage basins/outfalls within each land use category in the study area. These locations were sampled by the LWG and Port of Portland (Terminal 4) during two sampling efforts in the spring/summer of 2007 (Round 3A) and the fall/winter of 2007-2008 (Round 3B). One additional site (GE Decommissioning) was sampled by GE during the same time frame. Results from the GE investigation are also included in the overall LWG stormwater data set. In early 2008, the City of Portland collected three additional samples to supplement the residential data set, and these samples are included as well.

Loads to the study area are calculated based on composite water and sediment trap data collected from heavy industrial, light industrial, residential, parks/open space, and major transportation land use locations. Where measured contaminant concentrations fell well outside the ranges observed in the of these land use locations, the locations were defined as non-representative sites. Twenty-seven stormwater outfalls were sampled within the study area to estimate stormwater loads. In general, three to five composite water samples and one sediment trap sample were collected at each stormwater sample site. Pesticides were analyzed at a small subset of locations (8 stations) in composite water samples, but they were analyzed at nearly all locations (22 stations) in sediment trap samples.

Due to the lack of representative composite water samples for pesticides, sediment trap data were substituted for composite water results for light industrial, parks/open space, residential, and transportation land uses, as well as for 1 of 3 non-representative locations that did not have composite water data (WR-147). Additionally, composite water data were substituted for sediment trap statistics for 2 of 3 non-representative locations that did not have sediment trap data (OF-22B and WR-96).

Contaminant load estimates were generally based on approximately 100 stormwater samples across all land uses and sites. A range of 27 to 72 composite water samples

were available for heavy industrial, 10 to 16 for light industrial, 9 to 10 for residential, 2 to 3 for parks/open space, 7 to 9 for major transportation, and 3 to 5 for each non-representative location. Load estimates for pesticides were based on 26 composite water samples (from 8 stations) and 19 sediment trap samples across all land uses and sites. The number of composite water samples available for pesticide loading estimates is 12 for heavy industrial, 4 for light industrial (from one station), 3 for residential (from 1 station), zero for parks/open space, zero for major transportation, and 3 to 4 for each non-representative location. Composite sample water data were only used for loading estimates for the heavy industrial and non-representative locations. The number of sediment trap samples available for pesticide loading estimates is 11 for heavy industrial, 3 for light industrial, 2 for residential, 1 for parks/open space, and 1 for major transportation, and 1 for non-representative locations.

The stormwater analytical data set was used to generate concentration ranges for each land use and non-representative site. Both stormwater composite water samples and sediment trap chemistry data were used to provide two independent means of estimating stormwater contaminant loads. Stormwater runoff volumes draining to each model cell were then calculated for each land use and non-representative location using the City of Portland's GRID model. It was not possible to develop runoff volumes and stormwater load estimates for individual outfalls due to uncertainty of stormwater basin boundaries for many outfalls.

Loads were estimated as a product of the calculated concentration estimates and the flow rate from the 50^{th} percentile flow year to represent a central tendency estimate of flow conditions. The annual mass loads were generated by adding the loading contributions from each land use and non-representative site for each fate and transport model segment.

6.1.2.2 Uncertainty Associated with Stormwater Loading Estimates

The primary sources of uncertainty in the stormwater loading estimates are the sample size and sampling period extrapolated to represent the composite conditions of a typical water year over the entire lower Willamette River runoff area. Specifically, data used to estimate the stormwater loads were collected during a total of 15 storm events, with each outfall sampled an average of three times. Sediment traps were left in place for 3 to 7 months during two separate sampling periods. Due to the limited time span of sampling and the known variability of stormwater, these data should be considered to represent a "snapshot" of stormwater entering the study area during the sampling period.

The methodology for calculating stormwater loading assumes that concentrations measured in individual sampled outfalls at non-representative sites are indicative of concentrations for all stormwater discharging from the site. This methodology has inherent uncertainty associated with it, as concentrations can vary significantly based on the physical characteristics of the drainage basins associated with the stormwater discharges. For example, if a drainage basin that was sampled drains a known upland

source area, the concentrations measured in this discharge may be significantly higher than stormwater discharges at the remainder of the site. Thus, this example could overestimate stormwater loading for this site. Overall, the direction of any bias in the estimates created by these uncertainties is unknown.

Other more specific factors within this particular study's methods that may contribute to the uncertainty of the stormwater loading estimates are discussed in Appendix E, Section 3.0.

6.1.2.3 Stormwater Loading

Table 6.1-2 presents the range of annual stormwater loads to the study area for each stormwater contaminant for both composite water and sediment trap data. These ranges are also presented on Figures 6.1-17 through 6.1-31 for each contaminant group, including ranges of the annual load estimated using both composite water and sediment trap data. Tables 6.1-3a–b present a percentage comparison of loads to the study area by land use and non-representative location for both composite water and sediment trap data.

Loads for total PCBs estimated using composite water data are slightly higher than the sediment trap estimated loads (Figure 6.1-17). The estimated loading rate for total PCBs is highest for the heavy industrial land use category as compared to other land uses, although one non-representative location contributes the greatest estimated load. A comparison of loads of individual PCB congeners is shown on Figure 6.1-18. Generally, composite water estimated loads for the various PCB components are slightly higher than the sediment trap estimated loads.

Stormwater loads for DDx pesticides are presented on Figure 6.1-20. These results indicate that the composite water estimated loads are generally within the range of loads calculated from the sediment trap data. The estimated annual loads for DDx is highest for the heavy industrial land use category as compared to other land uses; however, the highest estimated loading rates are from non-representative sites in Basin 20 (RM 6.8 to 7.4W). Loading rates from non-representative sites are based on the results from a single outfall (from the former DDT process area) that was included in summations of all land use types to represent stormwater runoff from the entire site.

Annual load estimates for total PAHs using composite water data compared well with estimates using sediment trap data (Figure 6.1-21). The estimated load for total PAHs is highest for the heavy industrial land use as compared to other land uses, with four non-representative locations contributing a substantial portion to the total stormwater load.

Stormwater loads for BEHP are presented on Figure 6.1-22. BEHP annual loads estimated using composite water data are higher than those generated using sediment trap data. BEHP estimated loading rates are highest from the heavy industrial land use areas.

Stormwater loads for hexachlorobenzene are presented on Figure 6.1-23. The results for hexachlorobenzene indicate that the sediment trap estimates are within the range of the composite water estimates. Hexachlorobenzene estimated annual loads are highest from the heavy industrial land use areas.

Stormwater loads for other organochlorine pesticides (aldrin, dieldrin, gamma-HCH, and total chlordanes) are presented on Figure 6.1-24. For each of these contaminants, the composite water annual load estimates were higher than estimates developed using sediment trap data. The estimated loads for other organochlorine pesticides are highest for the heavy industrial land use category.

Stormwater loads for metals are presented on Figure 6.1-25. Typically, the composite water load estimates for metals were slightly higher than estimates developed using sediment trap data. The highest overall estimated loads are observed for zinc, copper, and lead. Chromium, arsenic, and nickel have the next highest loads, and of the metals evaluated, mercury has the lowest. The highest estimated annual loads for metals are from the heavy industrial land use areas. Stormwater loads to the study area are presented by river mile for total PCBs, total PAHs, and DDx pesticides on Figures 6.1-26 through 6.1-31.

6.1.3 Permitted Point Source Discharges

Point source permitted non-stormwater discharges to the study area include NPDES-permitted discharges from commercial, industrial, private, and municipal outfalls or operations. This section presents the results of estimation of the current annual mass load of contaminants from these outfalls to the study area. The details of data compilation and loading estimation are presented in Appendix E, Section 4.0.

Both Oregon DEQ general and individual NPDES permits were considered in this evaluation. Active NPDES permits inside the study area were located using Oregon DEQ's Facility Profiler 2.0[1], and the DEQ Wastewater Permits Database[2] was used to query the permit file numbers. There are 14 NPDES wastewater permitted discharges in the study area listed as either Individual or GEN 15A Permits. Map 6.1-1 shows the facility locations for these 14 permits. This analysis is specifically limited to permitted wastewater discharges to the study area and does not represent stormwater discharges included in stormwater loading (see Section 6.1.2) or other types of point sources.

6.1.3.1 Data Sources and Calculation Approach

Permitted direct discharge loading analyses were based on water contaminant concentration data and discharge/flow data in discharge monitoring reports (DMRs), where available. These data were available for the following 10 of the 14 NPDES wastewater permitted discharges:

[1] Oregon DEQ's Facility Profiler 2.0: http://deq12.deq.state.or.us/fp20/
[2] DEQ Wastewater Permits Database: http://www.deq.state.or.us/wq/sisdata/sisdata.asp

- EOSM
- Kinder Morgan/Portland Bulk Terminal 4
- Koppers Inc.
- Starlink Logistics, Inc.
- Siltronic Corporation
- ARCO Products Company
- Kinder Morgan Liquid Terminals
- Equilon Enterprises
- Pinnacle Condominium Complex
- Univar USA.

The remaining four NPDES wastewater permitted discharges listed below were not included in the loading calculations due to insufficient data for calculations.

The facilities and the reasons they were not included are:

- Ash Grove – No flow or contaminant data reported
- Columbia River Sand and Gravel – No flow data reported and no contaminant analysis required (only TSS and turbidity monitored)
- Vigor (Cascade General) – No flow data reported on DMRs
- Hoyt Street Properties – No flow or concentration data reported.

The discharge information from these sites would be expected to increase the upper and lower end estimates of total loading to the study area for the contaminants included in their permits. However, the lack of data for these facilities is not expected to represent a significant loading data gap for any parameters.

Ranges of loading estimates were generated by considering the DMR discharge flow rates and contaminant concentration data for all the selected contaminants. Because of limited analyte lists in the DMRs and the permits, data for some parameters were not available for all facilities. Additionally, several of the selected contaminants were never monitored at any of the facilities. The results are summarized in Table 6.1-4 for the subset of selected contaminants for which data were available.

6.1.3.2 Uncertainty Associated with Permitted Point-Source Discharge Estimates

While there is uncertainty associated with the annual estimates for this loading term, the findings are expected to be reasonably representative of the relative significance of this pathway for current loading of contaminants to the study area. The primary source of

uncertainty in these estimates is the limited monitoring records available for many sites. There are four sites that could not be included in this assessment due to lack of information. If there is flow related to these permits, then discharge information from these sites would be expected to increase the upper and lower end estimates of total loading to the study area for the contaminant included in their permits.

6.1.3.3 Permitted Point Source Loading

Review of these results indicates that only a few of the analytes on the combined loading contaminant list are presented in the DMRs (for one or more permit, results are presented for DDT, select PAHs, TPH, select metals, select VOCs, and cyanide). For all of the parameters analyzed, the estimated range of results is narrow—ranging over a factor of 5. While flow volumes are relatively large for some dischargers (total permitted discharge volume is estimated to be only slightly less than stormwater runoff), the concentrations ranges are low, and the resulting loads are generally low. Because of limited volume and low contaminant concentrations, permitted point source discharges were not found to be a primary source of contaminants to the study area for those facilities and parameters for which data was available. Overall, it is expected that this loading term, as defined and assessed here, is not currently a primary source of contaminants to the study area since permitted discharges are regulated and monitored.

6.1.4 Atmospheric Deposition

Contaminant present in the atmosphere as a result of emissions from stationary, mobile, and non-point sources result in a load to the study area through the processes of dry and wet deposition. Further, persistent contaminants can travel long distances through the atmosphere from other parts of the world. Dry deposition refers to the deposition of air pollutants from atmospheric suspension in the absence of precipitation. Wet deposition refers to deposition of air pollutants from atmospheric suspension via rain or snow.

The following sections present the approach and data sources applied to generate estimates of the annual loading of selected analytes to the study area via dry and wet atmospheric deposition. Air deposition loading estimates presented here focus on dry and wet deposition directly onto the water surface of the lower Willamette River within the study area. Atmospheric deposition to land in the study area watershed which could subsequently be transported to the river via stormwater runoff is captured in the stormwater loading (Section 6.1.2).

Contaminants selected for evaluation atmospheric deposition loading are presented in Table 6.0-1. The detailed data sets, methodologies, and results for dry and wet deposition loading to the study area water surface are presented in Appendix E, Section 5.0.

6.1.4.1 Data Sets and Approach

Atmospheric deposition is the sum of both dry and wet deposition loads. Gases and particles are deposited to the ground or river surface in a process known as dry deposition, which is driven by the gravitational force on the particulate matter and the

gas aerosol. A review of studies performed to characterize dry deposition and concluded that both particulate matter and gases will contribute to the contaminant concentrations in soils and surface water bodies (USEPA 2005b). Wet deposition occurs when gases and particles are scavenged by rain droplets, freezing rain, snow, or fog droplets and are ultimately deposited to the surface.

6.1.4.1.1 Dry Deposition to the River Surface

Atmospheric dry deposition to the study area was estimated based on an assumed deposition velocity, study area-specific and non-local air concentration monitoring data, and the study area surface water extent. For a given analyte, dry deposition loading (kg/yr) to the study area can be calculated as the product of the air concentration (mass/volume), the deposition velocity (length/time), and the surface area of the study area (length^2). The rate of contaminant deposition to a surface (deposition velocity) is a function of atmospheric turbulence, properties of the contaminant species, and the relative reactivity of the species with the receiving surface (Seinfeld and Pandis 1998). Study area-specific or local ambient air concentration data were used, where available.

Concentration values from publicly available data sources, including DEQ and USEPA, were used for those contaminants for which local sampling data were not available. In summary, local information[3] was used in dry deposition calculations for all the metals, BaP, naphthalene, TPH (diesel), total PCBs, hexachlorobenzene, total PAHs, and cPAHs; exclusively external data sources were used for dry deposition estimates for the rest of the atmospheric deposition contaminants. A range of estimates was generated for the dry deposition loading fraction of the total atmospheric load. This range was based on the range of ambient air concentration results compiled.[4] Specific effort was made to analyze the local monitoring and modeling data for BaP and naphthalene to ensure the representativeness of the data values for dry deposition loading over the river surface (see Appendix E for details).

6.1.4.1.2 Wet Deposition to the River Surface

Although wet deposition flux can be modeled, the most reliable estimation method is to collect precipitation in suitable samplers, measure the contaminant concentrations, and calculate the deposition flux corresponding to the sampling period (Reinfelder et al. 2004). Unfortunately, such data are limited; study area-specific wet deposition monitoring results were only found for total PCBs (MWH 2008) and mercury. In the MWH study, wet deposition data were collected from three monitoring stations within the study area for a 2-month sampling period spanning May through June of 2007. This

[3] Local is defined here as monitoring data or modeling results for Portland, Oregon or Multnomah County, Oregon.

[4] The maximum value of 0.32 μg/m^3 BaP was determined to be an outlying value among the values from the LASAR data based on statistical analysis and was excluded from the calculation; an average value of 0.19 μg/m^3 was also excluded for the same reason. The following values for naphthalene were excluded from calculations based on statistical analysis: 2.16 μg/m^3 as one of the maximum values, 1.87 μg/m^3 as an average value, and 1.55 μg/m^3 as a minimum value. See Appendix E for more details.

study reported wet deposition loading rates calculated from the monitoring concentration data (taking into consideration the field blank values). Mercury findings from Hope (2005) were considered for comparison with estimates based on the New Jersey Atmospheric Deposition Network (NJADN) data (Reinfelder et al. 2004). Briefly, the Hope study used precipitation monitoring data from Oregon Mercury Deposition Network sites (one site near Beaverton and one site near the southern end of the basin), and found wet deposition estimates comparable to those generated here by the NJADN ratio approach.[5] In summary, local information was used for mercury and total PCBs, and non-local/modeling data sources were used for all other contaminants.

With the exception of PCBs and mercury, for which study area-specific precipitation monitoring results were available, the monitoring results from NJADN (Reinfelder et al. 2004) were used, corrected by the ratios of 1) total atmospheric concentrations between Portland, Oregon, and Jersey City, New Jersey (where available in both), and 2) total annual precipitation between Portland and Jersey City. This approach of scaling NJADN data sets to develop wet deposition loading estimates generated only a single point estimate rather than a range because only average values were reported from the NJADN study.

6.1.4.1.3 Total Deposition to the River Surface

The total deposition loading to the study area for each selected contaminant was estimated simply by summing the dry deposition and wet deposition loading estimates. Since only central estimates could be generated for wet deposition loading, the ratio of the central estimate for wet deposition to the central estimate for dry deposition was assumed to be representative of the ratios across the range of wet deposition loading estimates. From this, upper and lower range estimates were generated for wet deposition for use in estimating the total deposition range. Where wet deposition data were inadequate to allow for estimation of even a central estimate, total loads were assigned based on the dry deposition estimates. Wet deposition estimates were unavailable for PCB TEQ, TCDD TEQ, 4,4′-DDE, 4,4′-DDT, naphthalene, total PAHs, TPH (diesel), hexachlorobenzene, aldrin, and dieldrin. The estimates are still considered to be useful based on the relatively low contribution of wet deposition to the total estimates for similar contaminants: DDx (<2 percent), BaP (~10 percent), total cPAHs (~21 percent), and total chlordanes (~16 percent).

6.1.4.2 Uncertainty Associated with Atmospheric Deposition Estimates

The lack of the study area-specific, analyte-specific, and temporally proximal data inputs for many of the contaminants places significant uncertainty on the estimates for the atmospheric deposition loading term. Specifically, local data were available only

[5]Hope (2005) calculated dry, wet, and total mercury loading rates to surface water for the entire Willamette River basin (398,000,000 m^2). When scaled down to the sub-area of the basin represented by the study area (8,791,735 m^2, 2 percent of the open water area estimated by Hope), Hope estimates a total atmospheric mercury load of 0.08 kg/yr. This result is slight lower than, but comparable to, the lower mercury load (0.11 kg/yr) presented here.

for metals, BaP, naphthalene, cPAHs (modeled), total PAHs (modeled; based on 16 individual PAHs), hexachlorobenzene, TPH (diesel), and total PCBs (modeled) for dry deposition calculations; for wet deposition calculations, local data were available only for mercury and total PCBs (limited sampling period). In the case of the atmospheric deposition loading estimates, the presented range of estimates is not expected to fully capture or represent the uncertainty associated with this term, due to significantly limited local empirical data.

The major uncertainties associated with dry deposition loading estimates are as follows:

- The limited available local atmospheric concentration data
- The simplified calculation methodology
- The uncertainty associated with selection and uniform application of a deposition velocity.

The major uncertainties associated with wet deposition loading estimates, are as follows:

- The limited local wet deposition monitoring data. Data were available only for mercury and PCBs.
- The uncertainty associated with application of precipitation correction factors to allow for use of NJADN data.

In summary, atmospheric deposition to the river surface is one of the most uncertain loading terms, primarily due to the limited availability of local atmospheric concentration and precipitation concentration monitoring data. The direction of any bias in the estimates created by these uncertainties is unknown. However, deposition to the watershed and subsequent runoff to the river is captured in the empirical stormwater runoff data set and stormwater loading estimates discussed in Section 6.1.2.

6.1.4.3 Atmospheric Deposition Loading

This section presents the findings of the estimation of atmospheric deposition loading to the river surface. A qualitative discussion of atmospheric deposition to the watershed is also provided.

6.1.4.3.1 Atmospheric Deposition to the River Surface

Table 6.1-5 presents the estimated ranges of annual total atmospheric deposition to the river surface for the entire study area. Figures 6.1-32 through 6.1-36 present the estimated ranges of annual loads for dry deposition, wet deposition, and total atmospheric deposition to the study area for each contaminant group.

PCBs and TCDD TEQ – The estimated ranges of dry, wet, and total deposition for total PCBs and TCDD TEQ are presented on Figure 6.1-32. The dry deposition fraction of the annual load represents the majority of the total annual loading estimate for total

PCBs, with only less than 0.5 percent of the load attributed to wet deposition. No wet deposition data were available for TCDD TEQ.

Pesticides – The estimated ranges of dry, wet, and total deposition for pesticides are presented on Figure 6.1-33. The total annual loads for pesticides are dominated by the dry deposition load estimates. However, wet deposition estimates were only available for DDx and total chlordanes, and wet deposition composed 2 and 16 percent of the total, respectively. Further, DDx estimates based on NJADN estimates are lower than the 4,4´-DDE and 4,4´-DDT estimates based on ATSDR ambient concentration estimates.

PAHs – The estimated ranges of dry, wet, and total deposition for PAHs are presented on Figure 6.1-34. The total annual loading estimates are significantly higher for naphthalene than BaP (10 times for upper value, 3 times for central, and about the same for lower value), suggesting dominance of the LPAH fraction. Further, for all PAHs, the dry deposition fraction of the annual load represents the majority of the total annual loading estimate, with only a very small fraction attributed to wet deposition.[6] (Total PAH atmospheric loads are based on 16 PAHs from Oregon USEPA National Air Toxics Assessment data [USEPA 1996], which includes all of the study area PAHs except for 2-methylnaphthalene.) The PAH loading estimates are considered to be highly uncertain based on comparison with other loading term estimates. Furthermore, statistical analysis USEPA LASAR data for BaP and naphthalene indicated some data values are out of the statistical ranges that are suitable for atmospheric loading calculations, and therefore, the total PAHs values could be affected by the outliers.

Total Petroleum Hydrocarbons (Diesel) and Hexachlorobenzene – The estimated ranges of dry and total deposition for TPH (diesel) and hexachlorobenzene are presented on Figure 6.1-35. No wet deposition data were available for these contaminants. Furthermore, no data to support estimates of dry, wet, or total atmospheric deposition rates were available for other TPH fractions.

Metals – The estimated ranges of dry, wet, and total deposition for metals are presented on Figure 6.1-36. Lead, zinc, and copper exhibited the greatest total annual loading estimates by atmospheric deposition. Dry deposition loading contribution to total annual deposition was greater than the wet deposition contribution with the exception of mercury, which exhibited 7 times greater annual deposition by wet deposition. While dry deposition estimates were greater than wet deposition for the other metals, dry

[6] Wet deposition data were not available for total PAHs based on Oregon USEPA NATA data (USEPA 1996) for direct calculation of wet loading estimates; however, a closer look at the NJADN data set suggests that wet deposition is not expected to be a significant fraction of the total deposition for this chemical set. Wet deposition data were available from the NJADN study for a total based on 36 PAHs. Analysis of that New Jersey data shows that wet deposition loads are 3 orders of magnitude lower than dry deposition loads. Similarly, analysis of the 13 study area PAHs included in the New Jersey data set of 36 also shows that wet deposition loads are 3 orders of magnitude lower than dry deposition loads.

deposition estimates were all within a factor of 10 of the wet deposition estimates, suggesting both mechanisms are important to the overall load.

6.1.4.3.2 Atmospheric Deposition to the Watershed

Contaminants that are deposited via atmospheric deposition to soils and impervious surfaces in the study area watershed may subsequently be transported to the study area via stormwater runoff. In general, for surface water bodies with relatively smaller watershed areas compared to water surface area, the total atmospheric deposition loading to the surface water is greater than the deposition loading to the watershed (Steuer 1995). But for a riverine system such as the lower Willamette River, with small surface water areas relative to the contributing watershed, atmospheric deposition to the watershed plays a greater role.

A review of available literature indicates that the relative importance of the atmospheric deposition loading term, relative to other loading terms, varies by site and by contaminant. Some studies found atmospheric deposition to the watershed to be a significant source to the surface water bodies. For instance, atmospheric deposition was found to be the dominant source term for total PCBs to the North and Baltic Seas (Struyf and Van Grieken 1993; Wania et al. 2001) and for HCH to the North Sea (Struyf and Van Grieken 1993). A recent study performed by Sun et al. (2007) in the Great Lakes region correlates average gas-phase atmospheric PCB concentrations with local population size, suggesting a strong urban source of atmospheric PCBs. Likewise, Motelay et al. (2006) found atmospheric deposition to impervious surfaces to be the most important source of PAHs to the urbanized Seine River basin near Le Havre, France. Further, one of the most recent systematic monitoring studies (the NJADN) found that direct (dry, wet, and gaseous air-water exchange) and indirect (runoff) atmospheric deposition are of major importance to the accumulation of certain elements such as mercury, and major nutrients in surface water ecosystems (Reinfelder et al. 2004). Findings from a separate, locally relevant study led by Hope (2005) of Oregon DEQ produced loading rate estimates for mercury comparable to those from the NJADN study.

Other studies found atmospheric deposition to the watershed to be less significant as a source of contaminants to surface water. A study of numerous urban U.S. streams (not including the Willamette River) evaluated the relative importance of different non-point sources of VOCs to total loading, finding that atmospheric deposition was of secondary importance for VOCs compared to the loading from urban land sources (Lopes and Bender 1998).

Contaminants deposited in the watershed surfaces are subject to a number of loss mechanisms outside of runoff transport, including leaching, degradation (biotic and abiotic), and volatilization (USEPA 2005b). Because of the complexity of the fate and transport of contaminants via stormwater runoff, a simple application of the flux rate is not appropriate for estimating loads to the study area from atmospheric deposition. Further, it is difficult to appropriately estimate the amount of deposited contaminant

mass that would be transported by runoff, and even more difficult to determine how much of that entrained contaminant mass would be transported to the study area surface water given the complexity of routing and settling along the pathway. Other studies (Deletic et al. 1997; Grottker 1987) highlight the complexity of quantitatively estimating the relative contribution of atmospheric deposition to surface water bodies. These studies note that such estimates require a detailed understanding of the geochemical process and transport fluxes specific to the urban watersheds.

The only empirical information available to assess the atmospheric contribution to the stormwater load is present in the stormwater data set. While many areas sampled as part of the LWG stormwater program have contaminant sources other than atmospheric sources, it could be assumed that samples collected from open space areas (and possibly residential areas, depending on the contaminant) represent primarily atmospheric deposition sources. Target contaminants for stormwater loading were detected in stormwater runoff in water and/or sediment trap samples in all sampled open space land-use type locations, except for 4,4′-DDD, total DDD, aldrin, dieldrin, gamma-HCH, hexachlorobenzene, naphthalene, PCB 081, PCB 126, PCB 169, and total chlordanes. PCDD/Fs and TPH were not sampled in stormwater runoff for any land-use type. Given the complexities/variables of runoff routing, adsorption of contaminants to varying surfaces, stormwater controls, a more rigorous assessment of the stormwater data set is not performed. These variables confound the utility of a direct comparison of open-space runoff to other land-use type runoff for the purposes of assessing atmospheric deposition contributions.

6.1.5 Upland Groundwater Plumes

Upland groundwater plumes flowing toward the river are a potential source of contaminants to the in-river sediments, TZW, and surface water in the study area. Seepage rate and TZW concentration data information from the nine GWPA study sites were applied to generate an estimated range of annual loads for the individual study sites. There may be additional sites that lack upland groundwater data but have complete groundwater pathways; however, such sites have not been identified or assessed.

In order to generate estimates for this loading term, observed TZW concentrations were assumed to be entirely attributable to upland groundwater as a simplifying assumption. In areas where there are both upland groundwater plume and sediment sources, contaminants detected in TZW samples may be partly or wholly attributable to contamination originating in sediment solids (partitioning into pore water). Differentiation of the origin of contaminants present in the pore water in areas with groundwater discharge and upland groundwater plumes was often not possible with the available information for certain contaminants (redox-sensitive metals, petroleum-related hydrocarbons). In such instances, the estimates of groundwater plume loading are expected to be redundant with advective loading estimates in the specific TZW study areas.

The fate and transport model addresses loading from upland groundwater plumes and from groundwater discharge through sediments somewhat differently. The model simulates the transport of contaminants within and out of the sediment bed via as advection due to movement of groundwater, diffusion, and dispersion this transport includes partitioning. In the specific areas where there are contributions from upland plumes, an upland plume loading term is specified based on available TZW concentrations and flux estimates from filtered trident and peeper data; this additional mass is subject to the same transport processes and partitioning within the bed.

A summary of the data sets and approach used in the upland groundwater plume loading calculations, as well as a presentation and discussion of the findings is presented here. Detailed presentations of the data sets, data treatment, calculations, assumptions, and results are presented in the supporting Appendix E, Section 6.1.

6.1.5.1 Data Sets and Approach

Estimates of groundwater plume contaminant loading to the study area are based on site-specific identification of potential plume discharge zones offshore of the nine TZW study sites, measured concentrations of contaminants in TZW, and measured groundwater discharge rates in potential plume discharge zones. The following data sources were used to determine these terms:

- Twenty-eight flow zone areas identified offshore of the nine TZW study sites were used to group data sets for the calculations. These flow zones are presented with discussions supporting the interpretations in Appendix C2.
- Measured shallow TZW contaminant concentrations from 150 sample locations at the nine study sites were applied to the calculations. These samples represent the complete TZW data set for the sample depth interval from 0 to 38 cm bml (see Maps 2.1-20a-l). The sampling methods used to produce this data set include small-volume peeper, Trident, and Geoprobe samplers. Both unfiltered and filtered (where available) results were included in the evaluation.
- Seventy-seven seepage meter measurements from the 28 flow zone areas were used to estimate groundwater flux for each zone. This seepage rate data is presented in Appendix C2.

As a first step, Thiessen polygons based on the TZW sampling locations were generated within each flow zone based on the TZW sampling locations to assign an area to each sample. Loading estimates were prepared for each flow zone area by summing the estimated loads for each of the sample polygons within the flow zone, using the following general equation:

$$Load_{flowzone} = \Sigma(C_{sample} \times A_{sample} \times UnitFluxRate)$$

Where,

$Load_{flowzone}$	=	the estimated annual mass load to surface water, µg/yr
C_{sample}	=	the contaminant concentration in the TZW, µg/L
A_{sample}	=	the area of the Thiessen polygon associated with the given sample, ft^2
UnitFluxRate	=	groundwater seepage flux rate for the given flow zone, $L/ft^2/yr$.

A range of load estimates for each flow zone was determined by applying both the filtered and unfiltered concentrations to the calculations, as well as the average and the maximum measured seepage flux for the given flow zone. From the resulting four estimates, the highest and lowest values were assigned to designate the range. The estimate based on the average measured flux and the unfiltered concentrations was assigned as the central estimate.

The range of estimated annual loads for a given study site was determined by summing the estimated ranges for each Thiessen polygon. The ranges of load estimates for the study area were, in turn, generated by summing the estimates for each of the nine study sites.

6.1.5.2 Uncertainty Associated with Groundwater Loading Estimates

The upland groundwater plume loading estimates are based on empirical, study area-specific TZW chemistry and groundwater flux data collected offshore from the nine upland sites included in the GWPA sampling program conducted as part of the RI. The range of results presented for this term is expected to be a reasonable approximation of the uncertainty in the loading estimates, though there are additional potential sources of uncertainty that may not be reflected in these ranges. Specifically, the following sources of uncertainty are acknowledged in the upland groundwater plume loading estimates:

- This assessment does not include loading from sites other than the nine study sites where empirical TZW data were collected. As described in the site selection process (Section 4.4.3.1 and Appendix C2), these nine sites represent those with a confirmed or reasonable likelihood for discharge of upland groundwater COIs to Portland Harbor. Eighty-three other upland sites reviewed during the site selection process lacked sufficient data to determine the completeness of the groundwater pathway. To the extent that a complete groundwater transport pathway to the lower Willamette River could be identified in the future at one or more of these 83 sites or other currently unidentified sites, total groundwater plume loading to the study area may be underestimated.

- The spatial resolution of the analysis is limited to the resolution of the sampling data sets, as reflected in the Thiessen polygon approach.
- There is no attempt made in these estimates to distinguish the origin of the contaminants in the TZW, and it is possible that the empirical TZW data set includes contaminants originating from sediment.
- The GWPA study design specifically targeted areas of higher seepage and higher TZW concentrations for sampling in the areas offshore of the study sites.
- The TZW concentration estimates do not account for any additional attenuation to sediments that may occur in the upper 38 cm bml.
- Sampling was conducted during the hydrologic season of highest expected groundwater flow rates to maximize the observed groundwater signal (plume concentration and flow rate). Consequently, the lower end of the groundwater signal in the discharge areas is not captured in the empirical data set.

6.1.5.3 Annual Groundwater Plume Loading

The estimated ranges of upland groundwater plume annual loads are presented in Table 6.1-6 at the study area scale (sum of all nine study sites) and in Table 6.1-7 for the individual study sites. Groundwater plume loads at the study area scale are also presented graphically by contaminant group on Figures 6.1-37 through 6.1-41. These group plots show the estimated loads based on filtered and unfiltered estimates to allow for comparison of these data sets. Load estimates for the individual study sites are presented graphically on Figures 6.1-42 and 6.1-43 for DDx and total PAHs only; PCBs and dioxin/furans were not sampled in TZW.

Figure 6.1-37 presents load estimates based on filtered and unfiltered TZW sampling data for DDx components. The unfiltered results are consistently higher than the filtered results for this group of hydrophobic contaminants. As discussed in Appendix D4.4, unfiltered results are likely biased high due to entrainment of sediments in the TZW samples. Figure 6.1-42 presents the DDx loading estimates for the two study sites where this contaminant was sampled in TZW.

Figure 6.1-38 presents the upland groundwater plume loading estimates for PAHs. The majority of the total PAHs load from upland groundwater plumes is from LPAHs, which is likely due their greater water solubility than HPAHs. Consistent with their hydrophobic properties, HPAHs and LPAHs show a pattern of higher unfiltered concentrations and lower filtered concentrations.

Estimates for upland groundwater plume loading of metals at the study area scale (sum of all nine study sites) are presented on Figure 6.1-39. These estimates cover a large range of values. Unfiltered/filtered loading ratios vary for different metals. The ratios for arsenic and manganese show little difference; barium, cadmium, nickel, and mercury unfiltered loading estimates are moderately greater than filtered estimates. Zinc, copper, and lead exhibit large disparities between unfiltered and filtered loading

estimates. Estimated metals loads associated with groundwater discharges at individual study sites are provided in Table 6.1-7.

Figures 6.1-40 and 6.1-41 present the upland groundwater VOC and SVOC loading estimates at the study area scale (sum of all nine study sites). These plots are broken into two groups of VOCs: Group 1 includes chlorinated, non-aromatic VOCs, Group 2 contains aromatic VOCs and carbon disulfide. Among the Group 1 VOCs (Figure 6.1-40), chloroform and methylene chloride dominate the loading scale. *cis*-1,2-Dichloroethene exhibits the highest loads among trichloroethene and its daughter products.[7] Chloroethane exhibits the highest loads among trichloroethane and its daughter products. Among Group 2 (Figure 6.1-41), benzene loads dominate the BTEX contaminants, chlorobenzene loads are higher than those for1,2-dichlorobenzene. Estimated VOC and SVOC annual loading are provided in Table 6.1-7.

6.1.6 External Loading Summary

Table 6.1-8 provides a summary of the central estimates of external current loading to the study area for upstream surface water, stormwater runoff, non-stormwater permitted discharge, atmospheric deposition, upland groundwater plumes, and advection through subsurface sediments. The estimated annual loads for the internal transport mechanism of advection through surface sediments to surface water is also shown in Table 6.1-8 for comparison.

6.2 FATE AND TRANSPORT

This section describes the physical, chemical, and biological processes that influence the fate and transport of contaminants within the study area. This discussion of fate and transport processes is organized in three main subsections, corresponding to the major environmental compartments of the study area: 1) surface mixed sediment layer and associated pore water, 2) surface water, and 3) biota. Figure 6.1-1 presents a conceptual drawing of these major environmental compartments.

6.2.1 Sediment Particle and Pore Water Fate and Transport Processes

The following subsections discuss fate and transport processes relevant to select contaminants in the sediment and pore water[8] environment. A general discussion of organic and inorganic contaminant behavior in sediment and pore water is presented, followed by discussion of physical transport processes for these media.

[7] Loading estimates for trichloroethene, *cis*-1,2-dichloroethene, and vinyl chloride are dominated by results from a single TZW sample offshore of the Siltronic site. The groundwater pathway for trichloroethene is discussed in detail in Appendix C2.

[8] The term "pore water" is the interstitial water in the sediment within the bioactive zone.

6.2.1.1 Contaminant Distribution between Sediment Solid and Aqueous Phases

In the sediment, the distribution of a contaminant between the solid and aqueous phases is among the most important physiochemical processes affecting its migration, bioavailability, and half-life. The equilibrium distribution of a contaminant between the dissolved aqueous phase and sorbed to sediment particles or associated organic matter is generally described by the distribution coefficient, K_d. This coefficient varies in response to environmental conditions such as pH, temperature, and salinity. Major processes and environmental factors that control this distribution are discussed below in general terms for organic and inorganic analytes. Observed partitioning ratios are compared to published literature values for relevant analyte groups for additional perspective. Finally, degradation and transformation mechanisms for contaminants in the sediment/pore water environment are also discussed.

6.2.1.1.1 Organic Contaminants

Equilibrium partitioning mechanisms for organic analytes include hydrophobic sorption onto organic matter associated with the sediment, electrostatic attractions of oppositely charged ionic functional groups, and covalent bonding or complexation of ionic organic molecules with reactive surface groups. For nonionic organic contaminants (PCBs, pesticides, PCDD/Fs, PAHs, SVOCs, and VOCs), the primary partitioning mechanism is hydrophobic sorption onto organic matter. Therefore, for nonionic organic contaminants, K_d describes two-phase partitioning to the organic matter on the solid surfaces and is a function of the tendency of the contaminant to sorb to organic carbon (K_{oc}) and the fractional organic matter content of the solids (f_{oc}).

In addition to temperature, several factors can affect equilibrium partitioning behavior for nonionic organic contaminants:

- **Salinity** – High-salinity environments can cause increased adsorption (decreased solubility and higher observed K_d than predicted at lower salinity). This may be relevant in the highly saline sediment and pore water environment local to offshore areas on the west side of the river, between roughly RM 7 and 7.5, where pore-water salinities in excess of typical seawater have been observed. It is unlikely to be a significant factor elsewhere in the river.
- **Co-solvents** – The presence of miscible organic liquids in solution with hydrophobic contaminants can result in increased solubility (and therefore decreased K_d) of the hydrophobic contaminant. However, this requires significant amounts of co-solvent contaminants in solution (more than 10 percent by volume [Yalkowsky et al. 1976]).
- **Colloids** – Colloids are organic and/or inorganic particles in the system defined by their behavior (tendency to remain dispersed in water, not settle rapidly, and not filter easily) and size (usually 1 nm to 1 µm in diameter [Lyklema 1991]). Colloids represent a portion of the surface area available for sorption of organic contaminants. Because colloids can be mobile in water within a sediment

matrix, they can increase the apparent concentration of the hydrophobic contaminant in the aqueous phase. Because colloids are <1 μm in diameter, they could be present in both filtered and unfiltered water samples.

- **Characteristics of natural organic matter** – The nature of the organic matter present in the sediment can also affect the extent of partitioning, making partitioning behavior variable across different environments.

TPH is defined as the measure of all hydrocarbons that can be quantified in the carbon range from C_6 to C_{40}. TPH (diesel), TPH (residual), and TPH (gasoline) are descriptive terms for the fractions of TPH, and represent a mixture of hydrocarbon contaminants, both of natural and anthropogenic origin, with an broad range of partitioning behaviors. As such, its behavior as a contaminant group cannot be accurately characterized by a single K_{oc} value. Because the components of TPH are unknown for all sampling results, the various fractions also cannot be accurately characterized by K_{oc} values.

The partitioning behavior of TBT is strongly affected by pH and the identity of anions in solution that pair with the TBT ion (Arnold et al. 1997). Measured log K_{oc} values are on the order of 4 at pH 10 to 7, and approximately 2 at pH 7 to 3. The mean surface water pH is 7.38 (10^{th} percentile is 6.98 and 90^{th} percentile is 7.76). The observed pore water pH values measured in the GWPA ranged from 5.6 to 8.1.

Literature equilibrium partitioning values were compiled for the advective loading analysis presented in Appendix E. The average range in the K_{oc} values for organic analytes is 1 order of magnitude, with PCDD/Fs, TBT, and BEHP exhibiting a range of more than 2 orders of magnitude, representing substantial variability in partitioning behavior.

Site-specific empirical information to assess sediment pore water partitioning of organic contaminants is limited to the filtered TZW data set with paired surface sediment samples. This data set is limited as it focuses only on the offshore area of the nine TZW study sites, and not all COIs in sediment were analyzed in TZW samples (for example, PCBs were not analyzed in any TZW samples, and DDx and PCDD/Fs were analyzed in only a small fraction of the samples). However, because they are the only available empirical data, observed partitioning values were plotted against corresponding literature partitioning values. Observed partitioning for PAHs and DDx between filtered TZW and sediment are shown on Figures 6.2-1 and 6.2-2, respectively.

Comparisons of the literature-derived partitioning values for DDx with observed behavior are limited by the small number of sample pairs (n=4) for which a given isomer was detected in both TZW and sediment. This limited set of observed partitioning values also spans a broad range. In contrast, the range of partitioning coefficients obtained from literature sources for individual PAHs (Figure 6.2-1) is relatively narrow, whereas the observed partitioning shows much wider ranges, especially for the LPAH constituents. The wide variability in observed partitioning may reflect multiple factors, including non-equilibrium conditions between TZW and

sediment, small-scale spatial variability (sediment and TZW sample pairs were not always collocated), and/or filtered samples not reflecting truly dissolved concentrations.

6.2.1.1.2 Inorganic Contaminants

The fate and transport of inorganic species in pore water is defined by the distribution between the aqueous and solid phases. A wide range of mechanisms control the distribution of metals between these phases, most commonly precipitation/dissolution reactions and sorption/ion-exchange processes. Precipitation and dissolution are controlled by the concentration of species present both in solution and as mineral phases. Sorption and ion exchange are controlled by a variety of factors, including electrostatic attraction, covalent bonding, and weak intermolecular attractions such as van der Waals forces.

The distribution of inorganic species between the aqueous and solid phases is controlled by a number of mechanisms that are a function of the physical, chemical, and biological characteristics of the solid-aqueous system. The characteristics most important for the aqueous solution phase include the following:

- pH
- Oxidation-reduction potential (Eh)
- Presence of competing ions
- Aqueous complexation reactions
- Ionic strength and the specific ions in solution.

The solid phase characteristics of importance include the following:

- Grain size
- Composition/mineralogy
- Sorbed organic carbon content and type
- Surface characteristics such as charge, coatings, and area.

In addition, there is a range of factors that cannot easily be assigned to one phase, such as temperature and the fugacity of gases such as oxygen and carbon dioxide.

The aqueous-solid chemistry of the sediment can be strongly influenced by microbial processes. Microbial oxidation of labile organic carbon frequently depletes dissolved oxygen in pore water, resulting in chemically reduced conditions and the production of alkalinity. Further, under anaerobic conditions, microbial processes can induce numerous environmentally relevant changes to the chemical environment, such as dissolution of iron and manganese oxide minerals and production of sulfides.

Sorption and ion-exchange mechanisms for metals can empirically be described by K_d. Unlike organic contaminants, the appropriate K_d value is not a function of f_{oc}, although organic matter can also sequester inorganic contaminants, thereby affecting the K_d value. Literature K_d values were compiled arsenic, copper, lead, and mercury. These values were used in the calculation of pore water concentrations for estimation of loading to surface water from surface sediment via groundwater advection. This analysis and the significant uncertainty associated with the inherent assumptions are presented in Section 6.2.1.4, and the range of literature K_d values is presented in Appendix E, Table E6-6. These values show ranges of 1 to 3 orders of magnitude. The wide range in literature K_d values for metals reflects the strong, highly variable geochemical factors described above that influence partitioning behavior in environmental systems. Considering this, literature K_d values should be considered site-specific estimates resulting from the geochemical conditions particular to individual studies. Limited site-specific empirical information, consisting of the filtered TZW data set with paired surface sediment samples for arsenic, copper, lead, and mercury, is presented for general comparison purposes on Figure 6.2-3.

6.2.1.2 Degradation and Transformation Processes

A variety of abiotic degradation and transformation reactions, including hydrolysis, dehalogenation, oxidation, and reduction, can occur in aqueous systems. Hydrolysis is a reaction by which alkyl halides, esters, or ester analogs are converted to alcohols or organic acids. Dehalogenation is a reaction in which halogen atoms (such as chlorine) are removed from halogenated hydrocarbons. Oxidation and reduction are complementary reactions that involve the loss of one or more electrons (oxidation) by one chemical and the gain of one or more electrons (reduction) by another. Metals in environmental systems are subject to both oxidation and reduction reactions, depending on the particular metal, its speciation in the environment, and other geochemical conditions. Organic contaminants are subject to degradation/transformation by abiotic processes in the sediment/pore water environment, though the degradation rates are relatively slow for PCBs, BEHP, hexachlorobenzene, 1,2-dichlorobenzene, chlordanes, dieldrin, and dioxins.

Biodegradation can be a significant process for various organic contaminants found in sediments and pore water in the study area. It involves the metabolic oxidation or reduction of organic compounds and is carried out predominantly by bacteria in aqueous environments, though yeasts and fungi may also contribute to biodegradation. In general, oxidation of organic compounds occurs under aerobic conditions and reduction under anaerobic conditions, although both processes can occur under both conditions. Microbial mediated transformation of metals is only significant for mercury and lead organocompounds.

Biodegradation rates depend on chemical structure and concentration, the concentration of bacteria responsible for the biodegradation, the availability of organic matter to serve as food and energy sources for bacterial growth, and physical and chemical conditions at the site, such as temperature and oxygen level. The extent to which the organic

compound is bound to particles may also affect the biodegradation rate as the bound organic compounds may be biologically less available for microbial uptake.

A wide variety of microbial species that utilize different biochemical pathways to metabolize anthropogenic contaminants have been identified. Biodegradation can proceed to full mineralization with end products of carbon dioxide and water, or an intermediate compound may be formed that is not easily further biodegraded. For example, DDT is relatively readily biodegraded to DDE, but DDE is more persistent. The susceptibility of organic compounds to biodegradation depends on several factors, such as the presence and type of functional groups, the size and chemical structure of the organic compound, and solubility. A literature review has been completed to find appropriate biodegradation rate constants for use in the fate and transport model.

6.2.1.3 Sediment Physical Transport Processes

Hydrophobic contaminants are strongly associated with sediment particles, in particular cohesive or fine-grained particles (silts and clays). As a result, the physical transport of sediments, especially silts and clays, will affect the distribution and fate of hydrophobic contaminants within the study area. Hydrophobic contaminants found in Portland Harbor include PCBs, PCDD/Fs, organochlorine pesticides, and PAHs.

Sediment movement into, within, and through the study area occurs as suspended load in the water column and as bedload along the riverbed. Cohesive or fine-grained sediments generally move as suspended load, which is defined as transport in the water column. Non-cohesive sediments (sands and coarser) typically move as bedload transport, which refers to sediment transported along or very close to the riverbed. However, a variable fraction of non-cohesive sediments moves as suspended load as a function of the flow regime, as flows increase, a larger fraction of non-cohesive sediment will move in suspension.

The movement of sediments in the lower Willamette River is controlled by both natural and anthropogenic forces that affect water movement and bottom shear stresses. As discussed in Section 3, natural flow regimes exhibit a wide range between the dry summers and rainy winters in Portland Harbor. Based on site-specific erosion velocities measured with Sedflume and modeled bottom shear stress, significant natural resuspension and movement of sediments does not generally occur at river flows below approximately 40–50,000 cfs (Section 3.1.5.2.3). Late spring through fall lower Willamette River flows are typically well below this level (see Figure 3.1-8), whereas late fall and winter flows exceed this threshold for variable lengths of time, depending on the intensity of winter precipitation events in the Willamette Basin. This strong seasonal pattern applies to the deep channel environment in the lower Willamette River which, on an areal basis, makes up much of the riverbed. Flows in nearshore, off-channel areas are severely dampened by nearshore structures, bottom drag, and shoreline configuration (such as sheltered embayments and slips). As shown on Map 3.1-11, modeled bottom shear in many off-channel areas remains relatively low

even during a river flow event of 160,000 cfs. This pattern is important because most of the areas of relatively high sediment contaminant concentrations in Portland Harbor are located in off-channel areas.

In contrast to the channel environment, sediment disturbance, resuspension, and scour in nearshore areas, particularly around working piers, berths, marine terminals, and others areas with significant boat traffic, may be largely a function of anthropogenic factors, such a prop wash and boat induced waves, rather than natural factors alone. This effect may be accentuated during low flow portions of the year (late summer/fall) when river stage is low, reducing vessel drafts. This anthropogenic influence is suggested by the time-series bathymetric measurements (Map 3.1-6), which reveal scour patterns in sheltered areas, such as Swan Island Lagoon and the International Slip, as well as very close to shore in portions of the main stem that do not experience high bottom shear forces even during high river flows.

As described in Section 3, the physical character of the lower Willamette River transitions rather abruptly near the upstream end of the study area (about RM 10) from a relatively narrow, high velocity river characterized by coarse-grained riverbed channel sediments upstream to a broader, slower river dominated by fine-grained sediments downstream. This relatively wide, fine-grained character extends to the lower end of the RI study area at RM 1.9, with the exceptions of a distinct, narrow, higher energy reach between RM 5 and 7 and a small area at the head of the Multnomah Channel; both of these areas are dominated by sands (Map 3.1-3). Measured areas of sediment scour and deposition from 2002 to 2009 (time-series bathymetry) and modeled predicted bed change during a major flood events are shown on Map 3.1-12, and depict consistent areas of erosion and deposition in the lower Willamette River during both typical (observed) and extreme (modeled) flow conditions. These areas correspond to sand-dominated (erosion) and silt-dominated (deposition) reaches. Again, this pattern applies to the deeper, in-channel portions of the river and appears to reflect the influences of natural forces. Nearshore areas are subject to a more complex mix of natural forces and smaller-scale, anthropogenic factors, such as vessel traffic, river stage variations, and in-water construction/dredging and fill activities that affect localized sediment texture and resuspension/transport patterns.

The major transport and fate processes relevant to sediment-bound contaminants are sediment transport into the study area from upstream, downstream sediment migration out of the study area (either in the main stem or Multnomah Channel), and the fate and transport of sediments within the study area, such as surface sediment mixing and resuspension, permanent burial at depth in the sediment column, and biological uptake. These processes are addressed below.

6.2.1.3.1 Sediment Flux into/out of the Study Area

Sediment enters Portland Harbor as suspended and bedload. Suspended and bedload sediment fluxes are discussed separately below.

Suspended Sediments

Suspended sediment data have been collected in the lower Willamette River across a range of hydrologic conditions. These data are described in Section 3.1.5.2.4 and show that suspended loads are strongly correlated with flow and vary from approximately 5 to 50 mg/L seasonally and annually (see Figures 3.1-26 and 3.1-25a–h). Higher suspended loads are observed on the rising limbs of the hydrographic events than on the falling limbs. Finally, a series of *in-situ* suspended particle size measurements conducted for the hydrodynamic modeling data collection effort indicate that suspended sediment particles sizes are comparable throughout the study area, with a median percentile particle diameter between 15 and 30 μm (silt). In contrast, the median grain-size diameter at an upriver location (RM 18) was 78 μm (fine sand), reflecting the higher energy environment in the upper portion of the lower Willamette River (Figure 3.1-29).

The modeled HST suspended load fluxes into and out of the study area are included in Table 6.2-1. Across the modeled flow years (5th, 25th, 50th, 75th, and 95th percentiles), average total suspended sediment flux into the study area from upstream equals about 1.53 billion kg/yr, and the average total suspended sediment flux out of the study area equals about 1.26 billion kg/yr, indicating a net accumulation of about 0.28 billion kg/yr in the study area. Averaged over time, about 18 percent of the suspended material entering the harbor accumulates somewhere between RM 11.8 and 1.2. The average annual net sediment accumulation rate calculated from empirical bathymetric survey data collected between 2003 and 2009 was 0.20 billion kg/year, which is in very good agreement with the model estimates which correspond to a net accumulation of 0.19 billion kg/year. Net sediment accumulation represents a combination of new material entering the study area from upstream and some percentage of bedded sediment that is resuspended from the riverbed within the study area and then redeposited further downstream, but before exiting the study area.

Bedload Sediments

Bedload sediments move downstream along or just above the riverbed whenever near-bottom shear stresses exceed the threshold for sediment movement. Sediment entrained from the river bottom as bedload may be redeposited on the river bottom downstream, which may disperse contaminants in the sediment as they are transported downstream with the bedload. No direct measurements of bedload have been made as it is extremely difficult to measure in the field. Consequently, bedload processes are not quantified in the fate and transport evaluation.

6.2.1.3.2 Sediment Fate and Transport in the Study Area

The spatial pattern and extent of deposition and erosion in the study area was inferred from the time-series of bathymetric surveys conducted from 2002 to 2004 (described in Section 3.1.5.2.2). Based on surface and subsurface grain-size (percent fines) distribution (Maps 3.1-3 and 3.1-5) and bathymetric features (Map 3.1-9), areas of fine-grained sediment accretion appear to be dominant from RM 8 to 10, along the channel edge from RM 4 to 5, and from RM 1.5 to 3. These areas are known to be long-term

sediment accumulation areas based on historical dredging needs. Upstream depressions (borrow pits) between RM 9.5 and 11, that in combination span the navigation channel, likely capture some suspended and much of the bedload sediments that are entering the system. The study area reaches between RM 5 and 7 and RM 10 and 11.8, where the river is relatively narrow, are dominated by areas of small-scale net erosion, as is the western off-channel area from RM 0 to 3 (outside bend of the lower Willamette River as it turns toward the Columbia).

Analysis of the time-series bathymetric change data presented in Section 3.1.5.2.2 indicates that during typical flow conditions only about 10 percent of the riverbed exhibited net bathymetric changes (erosion or accretion) greater than 30 cm, but that relatively small-scale scour or accretion from about 8 cm (the limit of bathymetric resolution) to 30 cm in extent was widespread, possibly indicating that the top 30 cm of the sediment column is relatively unconsolidated and more susceptible to resuspension and erosion than deeper sediments.

The HST model prediction of bed elevation change for the high-flow flood scenario depicted on Figure 3.1-30 indicates that the spatial pattern of erosion predicted by the model for the extreme event is generally consistent with measured bathymetric change from 2002 to 2009 under more typical hydrologic conditions. However, in some areas, the magnitude of bed changes during the extreme event is dramatically greater, with erosion or deposition predicted to occur to one or more meters over observed changes (Map 3.1-12).

6.2.1.3.3 Surface Sediment Dynamics

Particles that settle out or move along the bottom are subjected to a wide range of physical, biological, and chemical processes:

- **Sediment mixed-layer turbation** – Biogenic mixing by benthic infauna or bottom-foraging fish can preclude or slow consolidation of surface sediments, as can natural (such as wind waves) and anthropogenic (such as prop wash) forces. These factors can greatly complicate the spatial and temporal degree of bed erodibility. The SPI survey conducted throughout the lower Willamette River in the late fall of 2001 revealed a complex mosaic of surface sediment processes in the top 22 cm of the sediment column (the maximum depth of the SPI images) across the study area (SEA 2002b). Areas of fine-grained, low-shear sediments contrasted with coarse-grained, more compacted bottom areas. In the channel environment, these large-scale gradients in gross characteristics coincided with and helped first define the hydrodynamic reaches described in Section 3.

  In some fine-grained areas, infaunal feeding pockets and worm tubes indicated that biogenic activity approached 20 cm depth. In other areas, minimal biogenic mixing activity was apparent. A well-mixed, biologically active zone appears to be on the order of 5 cm in many images, although this varied widely across the study area. Many nearshore areas showed steep onshore-offshore gradients in physical and biological conditions as a function of water depth, riverbed slope,

and/or the degree of shoreline protection (embayments, structures). In some areas, layers of freshly deposited sediments exceeding 10 to 15 cm in extent were apparent. This survey was conducted during the onset of the rainy season in late November.

Overall, the SPI survey in combination with the bathymetric change data point to a dynamic surface sediment bed in much of Portland Harbor that is subjected to physical disturbance in the form of deposition or scour (on a multi-centimeter scale) due to natural and anthropogenic forces, biogenic mixing, and geochemical disturbance factors, such a methane bubble ebullition. Under typical flow conditions, these disturbance factors appear to be limited to a maximum extent of the top 30 cm harbor-wide. Thus, frequent widespread physical and biological surface sediment mixing is likely restricted to much shallower depths over much of the study area.

- **Long-term sediment burial beneath the mixed layer** – Particles and associated contaminants that are advectively transported or buried below the mixed layer are permanently removed from the active transport system throughout most of the study area. In portions of the navigation channel upstream of RM 10.5 and between RM 5 to 7, erosion of bedded sediments to about 2 m is predicted to occur during 100-yr flood events, but this deep erosion is limited in areal extent (see Map 3.1-8b).
- **Sediment ingestion/uptake by biota** – Filter and deposit feeder organisms may actively or passively ingest particles in suspension or on the sediment bed. High densities of filter feeders can biologically enhance transfer of suspended particles to the sediment bed. Also, contaminants associated with ingested particles can enter the food web.

6.2.1.4 Pore Water Physical Transport Processes

Contaminants in pore water are subject to diffusive and advective physical transport processes. These mechanisms are discussed in the following subsections.

6.2.1.4.1 Diffusive Transport

Diffusion is the movement of particles or dissolved contaminants from higher to lower potential energy as represented by a difference in concentration in the case of diffusion from the pore water to the overlying water column. This is a spontaneous physical process that requires no additional energy inputs or expenditure. It is distinguished from advective transport in that it only requires a concentration gradient. Diffusive transport acts on any contaminants in solution and is therefore potentially relevant to all of the combined loading list contaminants.

6.2.1.4.2 Advective Transport

Advective transport of contaminants in the sediment/pore water environment refers to the aggregate movement of contaminants by flow of pore water through the sediments to the water column in the form of groundwater discharge. It represents a transport

pathway for contaminants in surface sediment/pore water to migrate to the water column, and is distinguished from the upland groundwater plume loading term described in Section 6.1.5. In certain parts of the study area, both mechanisms are likely occurring simultaneously for contaminants present in upland plumes and in sediments from other sources.

The surface and subsurface advective loading terms were assessed for the contaminants presented in Table 6.0-1. These were selected because they are likely to sorb to sediment solids and are subject to the chemical partitioning processes relevant to this loading mechanism. Loading estimates for each term were generated in units of mass loading per year and presented for the entire study area and by river mile. Detailed presentation of data sources and approaches for advective loading is provided in Appendix E, Section 6.2.

In areas where concentrations in pore water are attributable to both upland groundwater plumes and in-river sediment sources, the plume loading and advective loading assessments may overlap, resulting in some double-counting of loads. The extent of this overlap depends on the relative magnitude of the groundwater plume concentrations versus the sediment-derived pore water concentrations based on equilibrium partitioning. The TZW plume study areas account for less than 5 percent of the study area.

Study Area Annual Loading Estimates

Study area-wide loading estimates for the subsurface and surface sediment advective loading terms are presented in Table 6.2-2. These results are also presented graphically on Figures 6.2-4 through 6.2-16, showing both surface and subsurface annual loading estimate ranges. Patterns and other observations for each of the contaminants groups are discussed in the following paragraphs.

The central estimated ranges of annual loads for total PCBs (Figure 6.2-4) are slightly higher for surface sediment to surface water than for subsurface to surface sediment. However, the difference for total PCBs (subsurface sediment advection versus surface sediment advection) is only a factor of 1.5 for the central estimates. This observation is expected due to the study area-wide higher average PCB concentrations in subsurface as compared to surface sediments. For the individual congeners, estimated load ranges were generally higher for subsurface sediment loading to surface sediments when compared to advective loading from surface sediment to surface water (Figure 6.2-5). Of the individual congeners analyzed, PCB 118 and PCB 105 exhibit the highest annual loads, whereas PCB 169 is the smallest contributor.

Advective loading estimates for PCDD/Fs (Figure 6.2-6) show a slightly greater loading from surface sediment to surface water compared to subsurface- to surface sediments. Estimates of advective loading from surface sediment to surface water are higher by a factor of 2.5 for PCDD/Fs compared to rates of subsurface partitioning to surface sediments. The OC-normalized PCDD/Fs concentrations used in the load calculations

are generally similar in surface sediment and subsurface sediment, with 54 percent of the subsurface concentrations being greater than concentrations in surface sediment (Table E6-4). However, the study area-wide loading estimates are dominated by individual high surface sediment concentration values, resulting in the greater study area-wide total PCDD/Fs advective loading from surface sediment as compared to subsurface sediment.

DDD isomers comprise the largest share of the central estimate DDx advection load estimates for both surface and subsurface sediment, followed by DDT, and then DDE (Figure 6.2-7). The study area-wide subsurface loading to surface sediment is slightly greater than the loading to surface water for each of the DDx compounds.

Advective loading estimates for other organochlorine pesticides are presented on Figure 6.2-10. Among these, gamma-HCH exhibits the highest mass loading while aldrin exhibits the lowest, possibly due to a tendency for aldrin to degrade to dieldrin in environmental systems. The subsurface to surface advective loading ratios are 0.9 for aldrin, 1.15 for dieldrin, 0.6 for gamma-HCH, and 2.5 for total chlordanes.

Total PAHs annual load from both the surface and subsurface sediments is dominated by LPAHs (Figure 6.2-8). HPAHs exhibit slightly higher surface sediment loading to surface water relative to subsurface loading to surface sediments. In contrast, naphthalene and total PAHs loading from subsurface to surface sediment is greater than to surface water. The estimated PAH loading from subsurface to surface sediment is greater than loading to surface water by a factor of 3 for the central estimate.

The range of advective load estimates for BEHP are presented on Figure 6.2-9. The 5 orders of magnitude range in the estimated loads is a direct reflection of the large range in the literature K_{ow} (octanol-water partitioning coefficient) values. These estimates show slightly more surface sediment loading (by a factor of approximately 2 for the central estimates).

Advective loading rate estimates for arsenic, copper, lead, and mercury are presented on Figure 6.2-11. Arsenic and copper show the highest study area-wide loading, followed by lead. Mercury exhibits the lowest loading estimates, with central estimates 4 orders of magnitude less than the corresponding estimates for arsenic and copper. Copper, mercury, and lead surface and subsurface loadings were essentially equal (ratios of 0.8 to 1.1, respectively), and representative of the fairly even distribution of surface and subsurface sediment concentrations over approximately 60 to 70 percent of the study area (Table E6-4). The arsenic surface sediment to surface water loading estimate is 2.2 times greater than the subsurface loading to surface sediment estimated loading.

Estimated TBT advective loads (Figure 6.2-12) vary over 3 orders of magnitude from the lower to upper estimates. The subsurface-to-surface sediment loading estimate is 3.7 times higher than the surface sediment loading to surface water for the central estimates.

In summary, study area-wide advective annual loads from subsurface sediment to surface sediment were higher than advective loading from surface sediment to surface water for PCBs, DDx, LPAHs (and total PAHs, which are dominated by LPAHs), BEHP, arsenic, total chlordanes, and TBT. The opposite was true for PCDD/Fs, gamma-HCH, and HPAHs. There was little difference between the surface and subsurface advective loading estimates for aldrin, dieldrin, copper, mercury, and lead. These differences are a direct reflection of the patterns of relative OC-normalized concentration of each contaminant in surface as compared to subsurface sediment.

Annual Loading by River Mile

Figures 6.2-13 through 6.2-16 present annual surface sediment and subsurface sediment advective loading for each river mile in the study area for total PCBs, total PCDD/Fs, DDx, and total PAHs. Given the nature of the analysis, variations in river-mile-scale annual load estimates are indicative of variations in sediment contaminant concentrations and organic carbon content. Groundwater flux rates and assumptions of equilibrium behavior were held constant over the entire study area in advective loading calculations.

The sediment advective loading pattern for total PCBs is fairly complex. As shown on Figure 6.2-13, the highest central estimates of advective loading from subsurface sediment to surface sediment are observed at RM 8 to 9. The highest annual surface sediment loading estimates to surface water are observed at RM 9 to 9.9.

Subsurface sediment advective annual loading to surface sediment, and surface sediment advection to surface water for total PCDD/Fs (Figure 6.2-14) are fairly consistent across the study area, with the exception of higher annual loading estimates to surface water from RM 7 to 7.9.

The highest surface and subsurface sediment advective loads for DDx are predicted at RM 7 to 7.9 (Figure 6.2-15). Subsurface-to-surface sediment advective loading annual estimates are comparable or greater than the estimates of surface sediment advection to surface water in all river miles except RM 9 to 10 and RM 11 to 12, where the load from advection to surface water is somewhat greater.

The highest subsurface advective loading to surface sediment for PAHs (Figure 6.2-16) is observed at RM 6 to 6.9. The maximum load estimates for surface sediment advection to surface water are observed at RM 5 to 5.9. Subsurface-to-surface sediment advective loading estimates are comparable to or greater than the load estimates for surface sediment advection to surface water in all river miles except RM 5 to 6 and RM 9 to 10, where the load from advection to surface water is somewhat greater.

6.2.1.4.3 Uncertainty Associated with Advective Transport Estimates

There is uncertainty associated with the advective annual load estimates related to applied assumptions (including equilibrium behavior of all contaminants and uniform groundwater discharge rates), as well as the data sets used in the calculations (literature

equilibrium partitioning coefficients, and roughly estimated groundwater discharge rates).

The primary uncertainty related to equilibrium is the assumption of equilibrium in all parts of the complex sediment/pore water environment. This calculation fails to capture reaction kinetics and the sorption-desorption-resorption dynamics that occur in advective transport through sediment. For example, to the extent that non-equilibrium conditions may exist in the pore water environment as a result of kinetic limitations on desorption from contaminated sediments, the assumption of equilibrium will overstate pore water concentrations and advective loading rates. Beyond the assumption of equilibrium, the study area organic carbon associated with sediments may differ in character from that defined by the range of literature K_{oc} values. Likewise, the location-specific chemical and geochemical conditions (redox, pH, ionic strength and composition, sediment matrix composition, etc.) likely differ in character from those associated with the applied specific literature values. Further, this assessment ignores any chemical or biological transformation processes that may occur in the migration process.

There are a number of significant uncertainties related to the groundwater flux rate estimates. First, they are based on the limited available upland data and not on groundwater modeling of the area or direct measurement of seepage rates representative of the entire study area. Second, the groundwater advection rate estimates rely on a simple and conservatively high cross-sectional area. Third, the advection rate estimates apply a projection of the sediment surface area to represent the actual sediment surface area (thereby increasing the unit discharge estimate). Finally, the assumption of a uniform groundwater discharge rate for the entire study area does not capture the spatial variability that likely exists throughout the study area. The discharge rates are assumed to be constant in time and do not account for variability caused by seasonal recharge patterns, changes in river flow rates and stages, and tidal fluctuations (tidal pumping).

Among all seepage meter locations where net positive average advective groundwater fluxes were measured, the largest net negative recharge rate during a rising tide was offshore of the Siltronic site (Appendix C2). At this location, the negative recharge period covered roughly 9.5 hours, with an average seepage rate of –6.7 cm/day. This corresponds to a net negative seepage flux of 2.65 cm into the sediment bed over the 9.5-hour tidal recharge period. Assuming sediment porosity of 25 percent, the maximum depth of influence for this period of negative seepage would be approximately 10.6 cm before the direction reversed to positive discharge with the tidal change. Although tidal pumping may in some instances lead to increased loading of contaminants from the sediment bed to the water column by introducing relatively clean surface water into the uppermost several centimeters of the sediment bed with each tidal cycle, uncertainty in the loading estimates due to this effect is expected to be minor compared to the other sources of uncertainty inherent in these calculations.

The large range in most of the estimates presented in the following subsection reflects the range in literature equilibrium partitioning coefficients. These large-scale estimates of advective annual loads are considered to be uncertain, but useful for general comparison to other loading terms for each contaminant.

6.2.2 Surface Water Fate and Transport Processes

Fate and transport processes for contaminants present in the dissolved phase and sorbed to suspended solids include partitioning between surface water, air, and suspended sediment, physical transport of surface water and suspended solids, and physiochemical and biological processes are described below.

6.2.2.1 Contaminant Distribution between Surface Water and Suspended Sediment

The observed partitioning between surface water (filtered) and suspended sediment for surface water samples for PAHs, PCDD/Fs, PCB homologs, DDx, and other pesticides is presented on Figures 6.2-17 through 6.2-21. Limited site-specific information for arsenic, copper, lead, and mercury is presented for general comparison purposes on Figure 6.2-22. These figures also show the literature K_{oc} and K_d values compiled for use in the advective loading assessment. For most contaminants, the observed partitioning between suspended sediment and filtered surface water spans a wider range than the literature K_{oc} values. The source of this variability is unknown, but may be attributable to non-equilibrium conditions between surface water and suspended sediment, errors introduced by the estimation method for the f_{oc} content of suspended sediment (see Appendix E, Section 2.4), filtered surface water samples not reflecting truly dissolved concentrations, or a combination of these factors.

Based on visual inspection of the information presented on Figures 6.2-17 through 6.2-22, the central part of the range of observed partitioning values corresponds with the CT in the literature values for PCB homologs, PCDD/Fs, and pesticides (excluding DDx). In contrast, the observed partitioning in the data set generally appears to be biased high relative to literature K_{oc}/K_d for PAHs and, to a lesser degree, DDx pesticides and metals. McGroddy et al. (1995, 1996) noted that only a small fraction of PAHs present in bulk sediment from Boston Harbor appeared available for equilibrium partitioning; empirically derived log K_{oc} values were significantly greater than literature values, specifically for phenanthrene and pyrene. They concluded that PAH compounds associated with soot particles typical in many coastal and estuarine areas may be less available to exchange with the pore water than suggested by the literature, and that equilibrium partitioning models overestimated the pore water and desorption aqueous-phase PAH concentrations by as much as a factor of 100. Thus, modeled PAHs concentrations may be overestimated when based on literature values for K_{oc} and an assumption of equilibrium partitioning.

6.2.2.2 Physical Transport of Contaminants in Surface Water

Advection is the flow of river water in response to gravitational forces, and is the primary mechanism for transport of surface water and its load of dissolved and particle-bound contaminants. River flow is quantified using water velocity and discharge. Water velocity is dependent on the slope, shape, and physical characteristics of the riverbed and has the dimensional units of length/time (ft/s). Discharge represents the quantity of water passing a specific location within a specific time interval. It is calculated as the average velocity times the cross-sectional area of the river, and has the dimensional units of volume/time (cfs or L/yr). The surface water mass flux of a contaminant is the product of the concentration and the volumetric flow rate of the river, producing dimensional units of mass/time (kg/yr), as calculated in Section 6.1.1.1 for surface water load estimates.

The dominant direction of water flow in the lower Willamette River is downstream along the hydraulic gradient. However, the flow direction reverses on flood tides during low-flow periods (see Section 3.1.4.3). Upstream flow has been identified as far upstream as RM 12.8 during low-flow conditions (Figures 3.1-22a–h; Caldwell and Doyle 1995).

Lateral and vertical movement of contaminants in surface water occurs primarily as a result of turbulent dispersion, and to a lesser extent as a result of mixing and diffusion resulting from concentration, thermal, and density gradients. The velocity of river water is greatest near the center of the river and decreases toward the sides and bottom. These differences in velocity result in velocity shear, which gives rise to eddies. These may also be caused by channel irregularities, including structures in the water. These processes serve to mix the water and dilute contaminant concentrations as they move away from the source. The suspended load of particle-sorbed contaminants can also decrease due to settling of particles to the riverbed sediment surface.

Sources of contaminants to surface water, such as industrial point discharges or groundwater plume discharge areas, can result in plume formation as the contaminants mix with and diffuse into river water flowing downstream. Mixing patterns and plume sizes depend on differences in density between the effluent and river water, the depth, velocity, and turbulence of the river, and any density stratification of the river itself. Density is a function of the temperature and salinity of the water.

Suspended particles provide an important vehicle for exchange of contaminants between the sediment bed and surface water. Suspended particles can be derived from mineral sources, including eroded and weathered rock, or from organic sources, such as decaying plant material or plankton. The density of mineral particles is generally 2 to 3 g/cm^3, whereas the density of organic particles is close to the density of water (1 g/cm^3). The entrainment and settling of suspended particles are functions of river flow rate, particle size, particle shape, and particle density. The sediment-carrying capacity of river water increases with increasing stream flow and turbulence, which vary spatially as well as temporally. Stream flow, turbulence, and TSS loads are greater

in areas where the river is narrower, and throughout the river during high-flow events. Within the water column, suspended particle concentrations generally decrease from the riverbed to the water surface. TSS in surface water across the study area increases with increasing flow rate. The range of TSS as a function of flow rates decreases by RM 2, where river turbulence decreases.

6.2.2.3 Physiochemical and Biological Attenuation Processes in Surface Water

In addition to equilibrium partitioning, several physical, chemical, and biological processes can result in transfer of contaminants found in surface water between abiotic media, or in degradation/transformation reactions. These include chemical precipitation, volatilization, abiotic degradation (chemical reaction or photolysis), and biodegradation. With the exception of volatilization and photolysis, these processes also generally pertain to sediment aqueous and particle interactions previously discussed in Section 6.2.1.2.

Volatilization is the transfer of contaminants dissolved in surface water to the atmosphere, and is most important for small organic molecules such as VOCs. It is dependent on water and air temperature, dissolved concentration, and vapor pressure. Water turbulence and wind velocity at the air/water interface will also affect volatilization rates. Volatilization typically decreases with increasing molecular weight. Additionally, various forms of mercury and organolead compounds may also volatilize from the water column. Equilibrium partitioning between dissolved volatilized phases is defined by the Henry's law constant (H).

Photolysis degradation or transformation reactions occur in response to absorption of solar energy, and can occur either directly or indirectly. Direct photolysis is the breaking of molecular bonds by electromagnetic radiation, particularly high-energy ultraviolet radiation. Indirect photolysis involves formation of a reactive species such as a hydroxyl radical or oxygen singlet, which subsequently reacts with an organic molecule. Examples of indirect photolysis include cleavage of aromatic rings, hydrolysis, hydroxylation, or dechlorination reactions. The degree to which photolysis occurs is affected by the depth and turbidity of the water, and by the intensity and angle of incidence of light. It can be significant for aldrin, PAHs (especially LPAHs), PCP, TBT, and organolead compounds. Additionally, contaminants sorbed to labile organic carbon can be released to the water column through degradation of the dissolved/suspended organic matter. PCBs and PCDD/Fs are also subject to photolysis in surface water, though the process is considered to be minor for PCBs and is only relevant to PCDD/Fs near the water surface (USEPA 1994).

6.2.3 Biota-Related Fate and Transport Processes

A number of processes govern how organisms living in the lower Willamette River are exposed to contaminants and how contaminants are transformed, excreted, or stored in tissue. Organisms living in the lower Willamette River take up contaminants through physical, chemically- and biologically-mediated processes, including transfer of

waterborne contaminants across gill structures or other tissues, consumption of prey, or ingestion of sediment. Organisms can modify the contaminant burden in their tissues through growth, reproduction, excretion, metabolic transformation, or sequestration. Some contaminants are transferred among organisms through trophic interactions, resulting in increases in concentrations of some contaminants at higher trophic levels.

PCBs, pesticides, PCDD/Fs, and PAHs, and similar hydrophobic contaminants, are likely to be associated with organic materials (lipids in tissues, dissolved or particulate carbon in the surface water, pore water, and sediment). However, some metals (lead and zinc) also tend to associate with organic and inorganic solids because the geochemical properties, such as ionic charge, governing their behavior tend to promote sorption.

Once released to the aquatic environment, contaminants enter the food web in a number of ways; the process is not sequential in that all trophic levels can interact with abiotic media. The behavior of contaminants within an aquatic food web is briefly described below.

Primary producers such as phytoplankton and plants take up contaminants primarily through diffusion from water. The lipid content of phytoplankton also serves as a substrate for the partitioning of organic compounds. Metabolic byproducts of phytoplankton contribute to the colloidal material in the water column, which can also serve as a binding substrate for dissolved contaminants. These colloidal materials can be directly utilized by bacteria, other phytoplankton, and zooplankton, serving as an additional uptake and transfer mechanism for recycling contaminants within the water column food chain. Zooplankton prey upon phytoplankton and other zooplankton, further recycling contaminants within the water column. More complex aquatic organisms (invertebrates and fish) can take up dissolved- or colloidal-bound contaminants from surface water and pore water across gill membranes, skin, and other permeable tissues, such as the mantle in clams (shells, exoskeletons, and scales are less permeable). Sediment surfaces may be coated with bacteria and bacterial slimes, natural organic polymers, and other amorphous organic molecules that serve as binding sites. Finer-grained sediments have a greater surface area-to-volume ratio and thus have a greater organic carbon content and contaminant concentrations.

Once sediment or prey is ingested by invertebrates and fish, the rate of contaminant absorption across gut membranes is affected by the size of the molecule (larger molecules are more difficult to transfer across membranes), concentration gradients between gut content and surrounding tissues, acidity of the gut, and other physical/chemical conditions in the gut. Absorbed contaminants may undergo various metabolic processes that change the chemical structure and properties.

Once absorbed, metals that are not excreted may be stored in calcium carbonate matrices (invertebrates) or bone (vertebrates), which tend to reduce the reactivity of the metal. Organic contaminants that are not metabolized tend to be stored in organs or

fatty tissues, including gametes. These stores can be released within the aquatic and terrestrial food webs when these organisms are ingested by others, upon their death and decomposition, or by transfer to their offspring.

6.3 UPPER STUDY AREA SEDIMENT CORES

This section details contaminant concentration with depth from cores collected in known depositional areas at the upper end of the study area. Three cores were collected in Round 3A in three different known depositional areas based on the time-series bathymetric data (Figure 6.3-1). This sampling effort is detailed in the Round 3A FSP (Integral 2006q), and the full data sets are presented in the corresponding data report (Integral 2007g,h).

The objectives of this sampling effort were to analyze both radioisotopes and conventional/contaminant chemistry at uniform and continuous depth intervals in long-term depositional areas expected to act as natural sediment traps. Because of the location of these cores, these data allow inferences to be made about deposition rates and the chemical composition of sediments settling out in the upper study area. Two of the three stations sampled, RC02-2 at RM 10.9 and RC01-2 at RM 10.5, are situated in formerly excavated borrow pits with mudline depths well below the authorized channel depth of -40 ft CRD. The third station, RC483-2 at RM 9.6, is located in the main channel on the large shoal that occurs along the western half of the channel in this area.

Detailed evaluation of the radioisotope data from these cores is provided in Anchor (2007e). Because of the heterogeneous origins of the sediments making up the deposits, the radiochemical data did not support the assignment of a timeline to the sediment profiles. However, empirical data on the history of the borrow pits as well as the shorter-term LWG time-series bathymetric data support overall sedimentation rates of approximately 1.5 ft/yr (45 cm/yr) at RC02-2 and 1 ft/yr (30 cm/yr) at RC01-2 (Anchor 2007e). These rates represent a long-term average over multiple years. The actual sedimentation in any given year is likely variable and may be higher or lower than this net long-term average.

The remainder of this section focuses on the conventional and contaminant chemical data measured in these cores with depth. These core samples were sectioned and sampled in 30-cm segments from the mudline to the bottom of each core. This allows inferences to be made about the quality of material entering and settling in the upper portion of the study area over time.

6.3.1 Upper Study Area Depositional Core Sediment Quality

The locations of the three depositional cores in the upper study area are presented on Figure 6.3-1. As noted above, RC483 is a shoal area on the western side of the channel at RM 9.6. RC01 and RC02 are located in dredged borrow pits on the western side of the channel at RM 10.5 and RM 10.9, respectively. Summary statistics for all core segments for all three cores combined are provided in Table 6.3-1 and for each core

individually in Tables 6.3-2 through 6.3-4. A range of contaminants plus grain size and percent TOC are included in these tables. The upper study area depositional core data evaluation that follows focuses on the physical nature of the cores and the measured concentrations of four contaminants, total PCBs (Aroclors)[9], TCDD TEQ, DDx, and total PAHs.

6.3.1.1 Physical Texture

Figure 6.3-2 shows the core log physical description for each core. Core recovery ranged about 260 cm at RC01 to 330 cm at RC02. All three cores show a general pattern of an upper silt layer deposited over a distinct sand interval, which is approximately 40 cm thick at RC01 and approximately 15 cm at RC483 and RC02. This subsurface sand layer may represent coarse-grained material deposited during the most significant, recent high-flow event on the lower Willamette River (approaching 200,000 cfs; see Figure 3.1-8) that occurred in December 2005/January 2006. The overlying 30 to 40 cm of silt would be consistent with an approximate 1-year time frame from cores collected in February 2007. Both the estimated long-term sedimentation rate of 30 to 45 cm/yr based on the borrow pit in-filling data noted above and the measured 2002 bathymetric change at stations RC01 and RC02 which averaged 38 cm/yr and 34 cm/yr, respectively, over the 7-year period from 2002 to 2009. Below this sand layer in each core, there is a thick silt layer that varies somewhat in character between the three cores. The silt layer is interbedded with fine sand lenses in RC483, the shoal location at RM 9.6, and RC02, the borrow pit at RM 10.9. In RC02 the texture becomes increasingly sandy below 240 cm down to another distinct sand layer at 315 cm. It is very possible that this deep sand layer reflects the high-flow event (approaching 250,000 cfs; see Figure 3.1-8) that occurred in the lower Willamette River during the winter of 1998/1999. The 315 cm of accumulation over the 8-year period from this horizon to 2007 equals an average sedimentation rate of 39 cm/yr. This is consistent with the long-term sedimentation rates estimated for this area. At RC01, the subsurface silt layer exhibits thick organic beds below 90 cm, suggesting some heterogeneity in the quality of material settling out within this portion of the river.

Figure 6.3-3 shows the 30-cm composite interval results for grain size and TOC with depth for each core. Grain size with depth is consistent with visual core log information at RC483 and RC02 with fine-grained sediments (60 to 80 percent fines) dominant throughout the core except for where distinct sand layers are evident. RC01 is more variable in texture with depth but does show the distinct shallow subsurface sand lenses. Consistent with the organic debris observed at depth in RC01, TOC values are somewhat higher in this core below 90 cm (exceeding 3 percent in most intervals) than in the other cores.

[9] PCB congeners were not analyzed in these core samples, so total PCBs concentrations are based on Aroclor data only.

6.3.1.2 Contaminant Vertical Profiles

Figures 6.3-4 through 6.3-7 present vertical profiles of the bulk sediment chemistry concentrations on both a dry-weight and TOC-normalized basis for total PCBs, TCDD-TEQ, DDx, and total PAHs in each core. Non-detects are plotted at the full detection limit with an open symbol. Selected summary statistics (using detected values only) for the data from all three depositional cores combined, as well as each individual core, are provided in Table 6.3-5.

The vertical profile data across the four analytes show some general trends. Dry-weight contaminant concentrations in all three cores vary with sediment grain size and TOC, with lower concentrations for all contaminants measured in the sand layers. the measured values for all analytes is generally low measured values for all of these analytes across all cores, with corresponding minimal vertical gradients within and between cores. Some exceptions to these general trends include a dioxin and PCB spike in the 180-to-210 cm interval in RC01, which may correlate with organic-rich beds in the silt layer. Assuming average sedimentation rates, this horizon may correspond to the atypically low-flow water year in 2001 (Figure 3.1-8). Another exception is the notably higher total PCBs levels at RC02 (RM 10.9) compared with RC01 (RM 10.5) and RC483 (RM 9.6). While the levels in RC02 average less than 20 µg/kg, this compares with mostly undetected values in the cores farther downstream. This difference appears to reflect the influence of the proximal source or sources of PCBs on the east side of the river at RM 11.5 (see Section 5.2). Finally, slight vertical trends with concentrations increasing with depth are evident in the TOC-normalized PCB and possibly the TOC-normalized PAH data at RC02.

The vertical profiles of the four indicator contaminants measured in three cores from known depositional areas in the upper portion of the study area show relatively low concentrations for all contaminants and minimal gradients with depth within each core and between cores. The farthest upriver core at RM 10.9 exhibits slightly elevated PCB concentrations compared with the other cores, and this may reflect the influence of the elevated PCB concentrations detected just upstream at RM 11.5E. Otherwise, the relatively low contaminant concentrations measured in these known depositional area cores appear to reflect the quality of sediments entering and settling out in the upstream portion of the study area over approximately the last 10 years. This trend may be representative of the periods of significant sediment deposition and accumulation in the lower Willamette River associated with conditions (higher flows, precipitation) that bring large volumes of sediment to the river, and this would act to dilute the relatively localized sources of contamination in bulk sediment deposits.

6.3.2 Upper Study Area Deposition Rates

Based on the harbor-wide measured riverbed elevation changes over the 7-year period from 2002 to 2009 (see Map 3.1-6), the net sediment accumulation rates in these upstream borrow pits at RM 10.9 and 10.5 are estimated to be approximately 41 and 31 cm/yr at RM 10.9 and 10.5, respectively. This is consistent with the 19 year estimates noted previously in Section 6.2. The borrow pits themselves, spanning the channel in

this reach and presenting a relatively larger channel cross-sectional area (because of their greater depth) than in reaches immediately upstream, provide conditions that promote sedimentation. However, based on the bathymetric survey data, sedimentation rates in this portion of the lower Willamette River outside the borrow pits, such as the large shoal that occupies the western portion of the navigation channel from RM 8 to 10, are comparable in scale (31 cm/yr at the maximum shoaling point at RM 9.6, see Map 3.1-10). This shoal area has historically required regular maintenance dredging (see Section 3.2.3.1.13).

The long-term sedimentation rate observations noted above apply to the study area channel environment. Based on bathymetric change, SPI data, and limited radioisotope sampling for MNR assessment (Anchor 2005b), nearshore and off-channel areas do not appear to accumulate sediment at these rates. Short-term active sediment deposition and resuspension are indicated by these data sets, likely due in many areas to anthropogenic activity. Seasonal (rainy season) inputs of fine-grained sediments in areas adjacent to the channel are also evident. However, seasonal comparison of surface sediment textures at similar locations in the spring versus the fall suggests that some nearshore deposits can be remobilized over time and dispersed (WEST and Tetra Tech 2009), minimizing net accumulation rates. These observations are supported by the radioisotope data from four nearshore areas in 2004 (Anchor 2005b), which show well-mixed surface sediment layers and calculated net sedimentation rates of approximately 1 cm/yr.

7.0 DETERMINATION OF BACKGROUND CONCENTRATIONS FOR INDICATOR CONTAMINANTS

Contaminant concentrations at a CERCLA site may be due to releases from the site itself, as well as natural and/or anthropogenic sources that are not site-related. Thus, site-specific background concentrations are needed as a means to distinguish site-related contamination from non-site-related chemical concentrations, as well as for developing remedial goals, and for characterizing risk from contaminants that may also be attributed to background sources. EPA policy (USEPA 2002b) provides the framework by which background concentrations should be considered at CERCLA sites.

An understanding of background conditions is important in the case of Portland Harbor because of the urbanized and industrialized setting of the region, and the fact that the lower portion of the river is influenced by many human activities occurring upstream throughout the broader watershed. This section describes the identification of the relevant background sediment data set for the RI/FS, discusses the evaluation of those data for use in the RI/FS, presents a statistical analysis, and provides the complete, final RI background data in an electronic format.

The approach used to determine background sediment concentrations reported here is documented in a series of RI technical memoranda and associated EPA comment letters (Kennedy/Jenks, Anchor, Integral, and Windward 2006; USEPA 2006m; USEPA 2008c,d; LWG 2008a,b; USEPA 2013a).

The discussion presented in this section is organized as follows:

- Section 7.1 presents definitions based on EPA guidance that are relevant to the determination of background in the RI.
- Section 7.2 describes the process that was employed to generate appropriate data sets for characterizing background concentrations in surface sediments, identification of chemicals for which background estimates are needed, reference area selection, data quality requirements, and data evaluation.
- Section 7.3 presents the background analysis for surface sediments including outlier identification and development of estimates of CT and background threshold values (BTVs) estimates using ProUCL.

7.1 DEFINITIONS AND USES OF BACKGROUND IN THE RI/FS PROCESS

The following EPA documents were reviewed to assist in providing a consistent set of definitions, as well as recommended uses, of background data in the Portland Harbor RI/FS:

- *Role of Background in the CERCLA Cleanup Program* (USEPA 2002b)

- *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (USEPA 2002c)
- *Determination of Background Concentrations of Inorganics in Soils and Sediments at Hazardous Waste Sites* (USEPA 1995b)
- *ProUCL Version 5.0 Technical Guide* (USEPA 2013b).

The following definition provided in USEPA (2002b) was adopted for the Portland Harbor RI/FS:

- **Background**—Substances present in the environment that are not influenced by releases from a site and are usually described as naturally occurring or anthropogenic.
    1. ***Naturally occurring*** – substances present in the environment in forms that have not been influenced by human activity; and,
    2. ***Anthropogenic* –** natural and human-made substances present in the environment as a result of human activities (not specifically related to the CERCLA release in question).

The term "reference area" is defined here as where background samples were collected for comparison with samples collected on-site. The reference area should have the same physical, chemical, geological, and biological characteristics as the site being investigated, but have not been affected by activities on the site. Background reference areas are normally selected from off-site areas, but are not limited to natural areas undisturbed by human activities.

7.2 BACKGROUND DATA SET IDENTIFICATION

Identification of an appropriate background data set is a critical element of a CERCLA background evaluation and involves the overlapping considerations of which contaminants are relevant for background determination, the selection of a suitable reference area(s), and the data quality requirements. These elements are discussed in Sections 7.2.1 through 7.2.4. Data management and evaluation is discussed in Section 7.2.5. Identification and treatment of outlying data points that may reflect the influence of point sources of contamination or may not be representative of the dominant background population is addressed in Section 7.3. Appendix H contains the background data set in electronic format and outputs from ProUCL 5.0 for the indicator contaminants.

7.2.1 Contaminants Considered in the Background Analysis

The selection of indicator contaminants for which background was established is based primarily on the contaminants of concern identified in the BHHRA and BERA. These include naturally occurring chemicals (primarily metals) as well as man-made chemicals whose use and environmental persistence has resulted in a widespread,

anthropogenic background concentration unrelated to specific Portland Harbor sources. The determination of indicator contaminants is discussed further in Section 5.

For the RI, background concentrations were either established or attempted for the following indicator contaminants:

- Aldrin
- Arsenic
- Bis(2-ethylhexyl) phthalate
- Chlordanes
- Chromium
- Copper
- DDx
- Dieldrin
- Mercury
- Total PAHs
- PCBs as Aroclors
- PCBs as congeners
- Total PCDFs/PCDDs
- Tributyltin
- Zinc

Background concentrations were also either established or attempted for an additional 19 contaminants, and those results are presented in Appendix H.

7.2.2 Reference Area Selection

In consultation with EPA, DEQ, and the Tribes, the upriver reach of the lower Willamette River extending from RM 15.3 to 28.4 was selected as the reference area for determining background sediment concentrations (Maps 7.2-1a–b). This area, which extends from the upstream end of Ross Island (just upstream of the downtown Portland area) to approximately 2.5 miles above Willamette Falls, was chosen because it is considered broadly representative of the upstream sediment loading to Portland Harbor. Although much of the upriver reach is characterized by an exposed natural bedrock bottom and swifter currents than generally found in the study area, there are pockets of reworked sand and finer-grained sediments along the margins and in backwaters. The area is representative of the urban and suburban upland conditions along the banks of the lower Willamette River as it flows into Portland through its suburbs, but is upstream and uninfluenced by releases from the Portland Harbor Site. Because of the urbanized

and developed setting, the reference area may be influenced by historical or current local point sources such as shoreline industrial facilities and overwater structures, as well as non-point sources.

7.2.3 Data Quality Requirements

Contaminant concentrations in sediment in the reference area have been the subject of both LWG and non-LWG characterization efforts. Because an accurate background data set is of importance to project stakeholders, only those data meeting the stringent Category 1, QA Level 2 data quality requirements established for the baseline risk assessments were considered for inclusion in the background data set.

Data that meet these criteria for surface sediments in the reference area are available from the following investigations:

- LWG Round 2A Sediment Sampling, 2004
- LWG Round 3B Sediment Sampling, 2007
- 2005 Portland District O&M Sediment Characterization
- Corps Dredged Materials O&M Sediment Characterization, 2004
- McCormick & Baxter RI Phase 3, 1999
- EPA Blue Heron & West Linn Paper Mill Site Investigations, 2007.

Individual sample locations from these investigations and within the reference area are shown on Maps 7.2-1a–b.

Samples from the EPA 2007 investigation were analyzed using Method SOM01.2, and comprise the bulk of the available sampling conducted upstream of RM 23.2. The results for Arcolors, aldrin, chlordane, dieldrin, and DDx compounds were consistently non-detect. An initial conclusion from these results would be that the potential for recontamination by ambient organochlorine compounds from this reach of the river is nonexistent. However, samples from these locations also analyzed for PCBs as congeners display a consistent pattern of detections. The SOM01.2 data were further reviewed with respect to the results for persistent organochlorine compounds, and the results for aldrin, Aroclors, chlordane, and dieldrin consistently display a pattern of high detection limits relative to the detection limits reported for these analytes in other reference area investigations. For this reason, data for Aroclors, aldrin, chlordane, dieldrin, and DDx obtained by Method SOM01.2 were excluded from the calculation of background. The results for all other indicator contaminants appear generally consistent with the results from other investigations, and these data were retained in the background calculations.

Appendix D1.4 presents an analysis of the comparability of PCB Aroclor data analyzed by Method SW8082 to congener data analyzed using Method 1668A. This analysis concluded that the data are “fairly comparable between methods in most cases.”

However, their comparability is less certain at the lower concentrations associated with the regional anthropogenic contribution. A total of 33 samples in the background reference area were analyzed for both PCBs as Aroclors and congeners. Although there are several exceptions, the Aroclor results are generally greater than the corresponding congener data, often by a factor of two or more. The calculated correlation between these two data sets is presented on Figure 7.2-1, and a scatter plot of these results by river mile is presented on Figure 7.2-2. Because the two data sets are not well correlated in the concentration range associated for this background analysis, they were not combined into a single PCB data set, and separate background statistics were calculated for PCBs measured as Aroclors and as congeners.

7.2.4 Measurement Basis for Surface Sediment Background Estimates

Background values for surface sediment were estimated on a dry weight basis. Dry-weight background values were adjusted to reflect the differences between the mean organic carbon content of surface sediments in the reference area and the study area. These estimates, termed OC-equivalent dry-weight values, were calculated as follows:

$$C_{dw,eq} = C_{dw,bgrnd} \times \frac{TOC_{SA}}{TOC_{bgrnd}}$$

Where,

$C_{dw,eq}$ = OC-equivalent dry-weight sediment concentration
$C_{dw,\ bgrnd}$ = Dry-weight background sediment concentration
TOC_{SA} = study area surface sediment mean TOC (1.71 percent)
TOC_{bgrnd} = Background surface sediment mean TOC (1.11 percent).

7.2.5 Data Management and Evaluation

The background data sets were evaluated to address field replicates, remove high-biasing non-detect results, and incorporate non-detect values in the calculation of results presented as totals.

Field replicates reported in the sediment data set were averaged to provide a single reported value to avoid introducing spatial bias into the data set by "double-counting" replicates from the same station.

Consistent with EPA guidance (USEPA 1989) and EPA comments on the Round 2 Report (USEPA 2008b), non-detect results with a reporting limit higher than the highest detected result for a given analyte in the surface sediment background data were flagged as high-biasing non-detects and were excluded.

Chemical concentrations for multiple-constituent analytical totals were calculated using the rules established for the baseline risk assessments. Specifically, detected values

were included at their reported concentrations, non-detects were included at one-half of the reporting limit for those analytes that were detected at least once in the background data set. Chemicals that were never detected in a given background data set were excluded from the analytical totals. Finally, if all analytes contributing to a sum were not detected in a given sample, then the highest reporting limit for any of the individual analytes within the given sample was reported for the total and qualified with a non-detect flag (U-qualified).

7.3 SURFACE SEDIMENT BACKGROUND OUTLIER DISPOSITION AND STATISTICAL ANALYSIS

A key element of developing appropriate background is to ensure that the data set is as free as possible of data points that are not representative of the background conditions. While it is important to obtain samples from a reference area that has not been influenced by releases from the site or other known point sources of contamination, in practice, background conditions may no longer exist and cannot be known with certainty. As a result, the reference area data may also contain high-biasing outliers that are either not representative of the dominant background population or are representative of specific contaminant sources. EPA guidance (USEPA 2013b) notes that when present, the presence of a few high outliers can mask the normality of a data set, and that a lognormal distribution tends to accommodate outliers. Additionally, the presence of outliers tends to distort decision statistics of interest such as upper prediction limits (UPLs). While the actual origin of high-biasing outliers is not always clear, EPA recommends that to provide a proper balance between false positives and false negatives, methods to calculate upper limits to describe background should only be used when the background data set represents a single environmental population without outliers, and that "*upper limits computed by including a few low probability high outliers tend to represent locations with those elevated concentrations rather than representing the main dominant background population"* (emphasis in original). Thus, BTVs should be estimated by statistics representing the dominant background population represented by the majority of the data set.

To assess the influence of outliers on the various statistics of interest, EPA guidance (USEPA 2013b) recommends calculating all relevant statistics using data sets both with and without outliers. This step provides for a direct comparison of the influence of outliers on the various statistics of interest, such as the mean and UPL, needed to inform the decision on the disposition of specific outliers. Table 7.3-1 presents the calculated values of the upper threshold and CT statistics for background sediments on a dry weight basis for two cases—with potential outliers included (all data), and with the identified potential outliers removed. The table also includes the OC-equivalent concentrations for the same statistics based on the OC-correction factor described above. An analogous table containing background statistics on a dry weight and OC-equivalent basis for an additional 19 sediment contaminants is provided in Appendix H.

Classical statistical tests were used to in conjunction with visual and graphical evaluations to aid in identifying potential outliers. The statistical evaluation utilized the

either Dixon's or Rosner's tests, depending on the size of the specific data set. Dixon's Extreme Value test is used to test for outliers when the sample size is 25 values or less. The test is capable of determining whether individual values represent outliers at a specified significance. Rosner's test can be used to identify up to k=10 outliers in data sets of 25 or greater. The details of these tests are described in USEPA 2013b.

Although it is not necessary for the data to be normally distributed to apply either Dixon's or Rosner's test, the resulting data after the potential outliers are removed should follow a normal distribution (USEPA 2013b). However, this condition was not met in all instances, and thus greater emphasis was given to the visual examination of the data to supplant the results of the statistical tests alone. Because the intent here is to identify outliers at the right tail of the data distribution, treatment of non-detect results in outlier identification is less critical than when calculating descriptive statistical moments. Hence, non-detect values may be replaced by their respective detection limits, one-half the detection limit (DL/2), or ignored altogether. For these evaluations, non-detects were included at one-half the detection limit. Graphical review of the data was conducted using box-whisker plots, normal Q-Q plots with non-detects set at the reporting limit, and river mile concentration plots shown in Figures 7.3-1 through 7.3-15 and in Appendix H contaminants .

Estimates of central tendency (the 95 percent upper confidence limit on the arithmetic mean, or 95 UCL) and an upper limit, defined as the 95 percent upper prediction limit (95 UPL) were generated using ProUCL Version 5.0. The 95 UPL represents a statistic such that an independently collected new observation from the same population will be less than or equal to the UPL with a confidence coefficient of 0.95.

The data analysis for each of the indicator contaminants is described in the following subsections. Outliers that were not considered representative of background were excluded from the calculation of background as described below.

7.3.1 Aldrin

No background value was calculated because the detection frequency was only 12.5 percent, even after excluding the Method SOM01.2 data. Background for aldrin is considered to be the method detection limit.

7.3.2 Arsenic

Three samples were identified as potential outliers in both the graphical data evaluation and Rosner's test: U6TOC-2, U6TOC-2, and WR085D. After excluding these potential outliers, the remaining data follow a normal distribution.

7.3.3 Bis(2-ethylhexyl) phthalate

Four samples were identified as potential outliers in both the graphical data evaluation and Rosner's test: U1C-3, UG11C, UG03B, and UG03C. Because the highest detected result is an order of magnitude greater than any other detection, it tended to mask the

presence of the other potential outliers. Thus, the data were examined visually without the result at U1C-3 to confirm the conclusion from Rosner's test. Although the resulting data set without these samples did not meet the condition of following a normal distribution, these results appear sufficiently distinct from the remaining dominant population to warrant their exclusion from the background calculation.

7.3.4 Chlordanes

Only U6TOC-2 was identified as a potential outlier. The resulting data follow a normal distribution.

7.3.5 Chromium

No potential outliers were identified and the full background data set follows a normal distribution.

7.3.6 Copper

No potential outliers were identified and the full background data set follows a normal distribution.

7.3.7 DDx

Two samples were identified as potential outliers in both the graphical data evaluation and Rosner's test: U12GA and U6TOC-2. The data followed a normal distribution both prior to and after removal of the potential outliers. However, visual examination of the data indicates that the two potential outliers appear sufficiently distinct from the remaining dominant population to warrant their exclusion from the background calculation.

7.3.8 Dieldrin

No background value was calculated because the detection frequency was only 5 percent, even after excluding the Method SOM01.2 data. Background for dieldrin is considered to be the method detection limit.

7.3.9 Mercury

No potential outliers were identified and the full background data set follows a normal distribution.

7.3.10 Total PAHs

Three samples were identified as potential outliers in both the graphical data evaluation and Rosner's test: UGO4B, SED099-42, and UG12C. After excluding these potential outliers, the data follow a normal distribution.

7.3.11 PCBs as Aroclors

As discussed in Section 7.2.3, data analyzed as Aroclors by Method SOM01.2 were removed from the background data. A review of the graphical data evaluation indicated four values that appeared to clearly represent outliers. Rosner's test identified a total of five samples as potential outliers: UG02C, U2C2, UG03C, UG03B, and UG02A. The data do not follow a normal distribution after elimination of the potential outliers. However, they are all located between RM 16 and 17, and appear sufficiently distinct from the remaining dominant population to warrant their exclusion from the background calculation.

7.3.12 PCBs as Congeners

Four samples were identified as potential outliers in both the graphical data evaluation and Rosner's test: WR08SD, U2C-2, WR04SD, and TR01SD. Although the resulting data set without these samples did not meet the condition of following a normal distribution, these results appear clearly distinct from the remaining dominant population to warrant their exclusion from the background calculation.

7.3.13 Total PCDFs/PCDDs

Only U1C1 was identified as a potential outlier. Although the condition of following a normal distribution was not met after excluding this result, this value appears clearly distinct from the remaining dominant population in the graphical data evaluation.

7.3.14 Tributyltin

Only three samples were collected and analyzed for tributyltin in the upstream data set; this is not sufficient data to establish a background concentration.

7.3.15 Zinc

A single potential outlier (U2C-2) was identified. The data follow a normal distribution both with and without the potential outlier. While this result appears sufficiently distinct from the rest of the data, the resulting calculated BTV and UCL are similar with and without incorporating this potential outlier.

8.0 BASELINE HUMAN HEALTH RISK ASSESSMENT SUMMARY

The BHHRA presents an evaluation of risks to human health at the Portland Harbor Superfund Site. It is intended to provide an analysis of baseline risks and help determine the need for action at the Site, and to provide risk managers with an understanding of the actual and potential risks to human health posed by the Site and any uncertainties associated with the assessment.

Consistent with USEPA guidance (USEPA 1989), the BHHRA incorporates assumptions to provide a health protective assessment of risks associated with contaminants present at the Site. The risk assessment for Portland Harbor is a baseline risk assessment in that it evaluates human health risks and hazards associated with contamination in the absence of remedial actions or institutional controls. The BHHRA follows the approach that was documented in the Programmatic Work Plan (Integral, Windward, Kennedy/Jenks, Anchor, and GSI 2004) and subsequent interim documents. It also reflects numerous discussions and agreements on appropriate risk assessment techniques for the Site among interested parties, including the USEPA, DEQ, ODHS, and Native American Tribes.

Potential exposure pathways, populations, and exposure assumptions were originally identified in the Programmatic Work Plan and in subsequent direction from USEPA. Additional assumptions for estimating the extent of exposure were provided in the Exposure Point Concentration Calculation Approach and Summary of Exposure Factors Technical Memorandum (Kennedy/Jenks 2006) and the Human Health Toxicity Values Interim Deliverable (Kennedy/Jenks 2004). The BHHRA is based on USEPA (1989, 1991, 2001a, 2004c, 2005c) and USEPA Region 10 (2000b) guidance, and is also consistent with DEQ guidance (DEQ 2000, 2010c).

The remainder of this section presents a summary of the methods used and results of the BHHRA, including the data evaluation, exposure assessment, toxicity assessment, risk characterization, uncertainty analysis, and conclusions. The complete BHHRA is presented in Appendix F to this RI report.

8.1 DATA EVALUATION

The sources of data available for use in the BHHRA are described in Section 2 of this RI report. The use and evaluation of those data for purposes of the BHHRA are described in Section 2 of Appendix F. Data from LWG and non-LWG sampling events were included in the SCRA database, a subset of which was used for the BHHRA. Only data that meet QA2Cat1 data quality objectives were used in the BHHRA. Data collected between RM 1.0, including Multnomah Channel and upstream to RM 12.2 were included in the risk assessment. Samples collected between RM 1.9 and RM 11.8 were considered to be within the study area, which was the focus of the BHHRA. The following summarizes the data used in the BHHRA by medium:

- **Beach Sediment:** Composite beach sediment samples that were collected from designated human use areas within the study area.
- **In-water Sediment:** In-water sediment (i.e., not beach sediment) samples that were collected from the top 30.5 cm in depth between the bank and the navigation channel.
- **Surface Water:** All Round 2 and Round 3 surface water data collected from the study area, as well as Multnomah Channel.
- **Groundwater Seep:** Data from Outfall 22B, which discharges in a potential human use area. However, samples collected from this outfall as part of a stormwater sampling event were excluded.
- **Fish Tissue:** Composite samples, both whole body and fillet with skin (fillet without skin samples were analyzed for mercury only), of target resident fish species (smallmouth bass, brown bullhead, black crappie, and common carp). Composite samples of adult Chinook salmon (whole body, fillet with skin, and fillet without skin), adult lamprey (whole body only), and sturgeon (fillet without skin only) were also included in for evaluation of consumption by tribal members.
- **Shellfish Tissue:** Composite samples of crayfish and clam tissue, depurated and undepurated.

Because of the large number of chemicals detected in environmental media, a risk-based screening approach was used to focus the risk assessment on those contaminants most likely to significantly contribute to the overall risk. Contaminants of potential concern (COPCs) were selected for quantitative evaluation in the BHHRA by comparing the SCRA analytical data to risk-based screening values. If the maximum detected concentration of a chemical exceeded its appropriate risk-based screening level, or if a risk-based screening level was not available, the contaminant was selected as a COPC.

8.2 EXPOSURE ASSESSMENT

The exposure assessment consists of three primary tasks:

- Characterization of the exposure setting. This step includes identifying the characteristics of populations that can influence their potential for exposure, including their location and activity patterns, current and future land use considerations, and the possible presence of any sensitive subpopulations.
- Identification of exposure pathways. Exposure pathways are identified for each population by which they may be exposed to chemicals originating from the site.

- Quantification of exposure. The magnitude, frequency, and duration of exposure for each pathway is determined. This step consists of the estimating of exposure point concentrations and calculation of chemical intakes.

8.2.1 Conceptual Site Model

The CSM describes potential contaminant sources, transport mechanisms, potentially exposed populations, exposure pathways, and routes of exposure. The CSM is presented on Figure 8.2-1. Currently or potentially exposed populations were identified based on consideration of both current and potential future uses of the study area, and include populations who may be exposed to contamination though a variety of activities. Exposure pathways are defined as the physical ways in which chemicals may enter the human body. A complete exposure pathway consists of the following four elements:

- A source of chemical release
- A release or transport mechanism (or media in cases involving media transfer)
- An exposure point (a point of potential human contact with the contaminated exposure medium)
- An exposure route at the exposure point.

If any of the above elements is missing, the pathway is considered incomplete and exposure does not occur. The relevant potential exposure pathways to human populations at the study area include:

- Incidental ingestion and dermal contact with beach sediment
- Incidental ingestion and dermal contact with in-water sediment
- Incidental ingestion and dermal contact with surface water
- Incidental ingestion and dermal contact with surface water from seeps
- Consumption of fish and shellfish
- Infant consumption of human milk

8.2.2 Identification of Potentially Exposed Populations

The specific populations and exposure pathways evaluated in the BHHRA were as follows:

- Dockside workers — direct exposure via incidental ingestion and dermal contact with beach sediments
- In-water workers — direct exposures to in-water sediment
- Transients — direct exposure to beach sediment, surface water for bathing and drinking water scenarios, and groundwater seeps

- Recreational beach users — direct exposure to beach sediment and surface water while for swimming
- Tribal fishers — direct exposure to beach or in-water sediments, and consumption of migratory and resident fish
- Recreational and subsistence fishers — direct exposure to beach or in-water sediments, consumption of resident fish, and consumption of shellfish
- Divers — direct exposure to in-water sediment and surface water
- Domestic water user — direct exposure to untreated surface water potentially used as a drinking water source in the future
- Infant consumption of human breast milk — exposure to certain persistent and bioaccumulative contaminants (PCBs, DDx compounds, dioxins and furans, and PBDEs) via nursing infants of dockside and in-water workers, divers, and recreational, subsistence, and tribal fishers.

Exposures were evaluated on a study area-wide basis, as well as on more localized spatial scales as appropriate for each exposure scenario. Exposure to beach sediment was assessed per beach, and exposure to groundwater seeps was assessed per seep. Exposure to in-water sediment, surface water, and fish and shellfish tissue was assessed on both localized and study area-wide scales. Except where specifically noted, the exposure assumptions used in the BHHRA were applied uniformly to all of the study area, and may or may not be applicable at specific locations within the study area depending on factors not specifically addressed in the BHHRA.

Consistent with USEPA policy, the exposure assessment evaluated a reasonable maximum exposure (RME), which is defined as the maximum exposure that is reasonably expected to occur. In addition, estimates of CT, which are intended to represent average exposures, were also evaluated. Assumptions about each population were used to select exposure parameters to calculate the pathway-specific chemical intakes. As site-specific values are not available to describe potential exposures for each population and pathway, default values representative of the larger U.S. population were used. Where default values are not available, best professional judgment was used based on likely activity patterns.

8.2.3 Exposure Point Concentrations

Exposure point concentrations were calculated to represent the average concentration contacted over the duration of the exposure. The average is used to represent "a reasonable estimate of the concentration likely to be contacted over time" (USEPA 1989). USEPA guidance (USEPA 1989, 1992) recommends that the 95 percent upper confidence limit (UCL) on the arithmetic mean should be used to represent the average because of the uncertainty associated with estimating the true average concentration at a site. The maximum reported concentration was used in instances where there were insufficient data to calculate a UCL, or the calculated UCL was greater than the

maximum reported value. The simple mean was used as the exposure point concentration in sediment and surface water for the CT evaluations.

8.2.4 Estimation of Chemical Intakes

The amount of each chemical incorporated into the body is defined as the dose and is expressed in units of milligrams per kilogram per day (mg/kg-day). The dose is calculated differently when evaluating carcinogenic effects than when evaluating noncarcinogenic effects.

For non-occupational scenarios where exposures to children are considered likely, exposures to both adult and child were evaluated. Children often exhibit behavior such as outdoor play activities and greater hand-to-mouth contact that can result in greater exposure than for a typical adult. In addition, children have a lower overall body weight relative to the predicted intake. As cancer risks are averaged over a lifetime, they are directly proportional to the exposure duration. Accordingly, a combined exposure from childhood through adult years was evaluated where appropriate, to account for the increased relative exposure and susceptibility associated with childhood exposures.

In general, Superfund exposure assessments assess RME by using a combination of 90^{th} or 95^{th} percentile values for contact rate, exposure frequency, and duration, and 50^{th} percentile values for other variables. CT estimates are done using average or median values for all variables.

For example, a range of fish consumption rates was evaluated using information from studies conducted in the Willamette and Columbia river basins, as well as from data representing the general U.S. population. A consumption rate of 17.5 g/day (approximately two 8-oz meals per month) was considered representative of a CT value for recreational fishers, 49 g/day and 142 g/day per day (approximately seven and 19 8-oz meals per month) were selected as the RME values representing the higher-end consumption practices of recreational and subsistence fishers, respectively.

The rates of 17.5 g/day and 142 g/day represent the 90^{th} and 99^{th} percentiles, respectively, of per capita consumption of uncooked freshwater/estuarine finfish and shellfish by individuals (consumers and non-consumers) 18 or older, as reported in the Continuing Survey of Food Intakes by Individuals and described in USEPA's Estimated Per Capita Fish Consumption in the United States (USEPA 2002d). The consumption rate of 49 g/day is from a creel study conducted in the Columbia Slough (Adolfson 1996), and represents the 95 percent UCL on the mean, where 50 percent of the mass of the total fish is consumed. Tribal consumption of a mixed diet consisting of both resident and anadromous fish was evaluated using a consumption rate of 175 g/day (approximately twenty-three 8-oz meals per month), representing the 95^{th} percentile of consumption rates from the CRITFC (1994) survey.

8.3 TOXICITY ASSESSMENT

The toxicity assessment is composed of two steps: hazard identification and dose-response assessment. Hazard identification is a determination of whether exposure to a chemical may result in an adverse health effect in humans, consisting of characterizing the nature of the effect and the strength of the evidence that the chemical will cause the observed effect. The dose-response assessment characterizes the relationship between the dose and the incidence and/or severity of the adverse health effect. For risk assessment purposes, chemicals are generally separated into categories based on whether a chemical exhibits carcinogenic or noncarcinogenic health effects. As appropriate, a chemical may be evaluated separately for both effects. Noncancer effects are evaluated using a reference dose (RfD). The RfD, expressed in units of mg of substance/kg body weight-day (mg/kg-day) is defined as an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population, including sensitive subgroups, that is likely to be without an appreciable risk of adverse effects resulting from a lifetime exposure. RfDs are based on the concept that exposures less than the critical value are without adverse health effects. Carcinogenic effects are assessed using the cancer slope factor, which is typically expressed in units of per mg of substance/kg body weight-day [$(mg/kg\text{-}day)^{-1}$]. The slope factor represents an upper bound estimate on the increased cancer risk. Slope factors are generally accompanied by a weight of evidence descriptor, which expresses the confidence as to whether a specific chemical is known or suspected to cause cancer in humans.

The recommended hierarchy of toxicity values for use in Superfund risk assessment is as follows (USEPA 2003b):

- Tier 1 – USEPA's Integrated Risk Information System (IRIS) database (USEPA 2010).
- Tier 2 – USEPA's Provisional Peer Reviewed Toxicity Values derived for use in the Superfund Program when values are not available in IRIS.
- Tier 3 – USEPA and non-USEPA sources of toxicity information, with priority given to those sources of information that are the most current, transparent, and publicly available, and which have been peer reviewed. Tier 3 sources may include, but are not be limited to, the following sources:
  - The California Environmental Protection Agency Toxicity Criteria Database (Cal EPA 2008)
  - ATSDR Minimal Risk Levels
  - USEPA's Health Effects Assessment Summary Tables.

8.4 RISK CHARACTERIZATION

Risk characterization integrates the information from the exposure assessment and toxicity assessment, using a combination of qualitative and quantitative information.

Risk characterization is performed separately for carcinogenic and noncarcinogenic effects. Carcinogenic risk is expressed as the incremental increased probability that an individual will develop cancer over a lifetime as a result of exposure to a potential carcinogen. Noncarcinogenic hazards are evaluated by comparing an estimated exposure level, or dose, with the RfD that is without appreciable risk of adverse health effects

8.4.1 Risk Characterization Methodology

Noncancer effects are addressed by comparing the estimated dose, as defined by the chronic daily intake, to the corresponding RfD to yield an HQ. HQs for multiple chemicals are summed across all relevant exposure pathways to calculate the cumulative hazard indices (HIs). Although an HI provides an overall indication of the potential for noncancer hazards, dose additivity is most appropriately applied to chemicals that induce the same effect via the same mechanism of action. When the HI is greater than 1 due to the sum of several HQs of similar value, it is appropriate to segregate the chemical-specific HQs by toxicological effect and mechanism of action. When either the cumulative or the effect-specific HI is less than 1, adverse health effects associated with the exposures are considered unlikely.

Potential cancer risks were assessed by multiplying the estimated dose by the appropriate cancer slope factor. This calculated risk is expressed as the probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen, and is a conservative, health-protective estimate of the incremental probability of excess individual lifetime cancer risk.

Response actions under CERCLA are generally warranted when the baseline risk assessment indicates a cumulative risk under either current or future exposure is greater than the upper end of the acceptable risk range of 1×10^{-4} to 1×10^{-6}, or when the HI is greater than 1. Accordingly, risk and hazard estimates are generally presented in terms of whether they are greater than 1×10^{-4} or greater than 1, respectively.

8.4.2 Risk Characterization Results

The ranges of estimated potential risks resulting from the different exposure scenarios are summarized in Tables 8.4-1 and 8.4-2. A summary of the risk characterization results is presented by exposure scenario in the following sections.

8.4.3 Dockside Workers

Risks to dockside workers were estimated separately for each of the eight beaches designated as a potential dockside worker use areas. The estimated cancer risks are less than 1×10^{-4} at all beach areas, and the HIs are less than 1 for adults and infants.

8.4.4 In-Water Workers

In-water sediment exposure by in-water workers was evaluated in half-mile increments along each side of the river. The estimated CT and RME cancer risks are less than

1×10^{-4} at all river mile segments, and the RME HIs for adults are less than 1 at all locations. The HI for infants at RM 7W is 2 due to dioxins and furans.

8.4.5 Transients

Risks to transients were estimated separately for each beach designated as a potential transient use area, as well as for the use of surface water as a source of drinking water and for bathing. Year-round exposure to surface water was evaluated for four individual transect stations, Willamette Cove, Multnomah Channel, and for four transects grouped together to represent study area-wide exposure. The CT and RME risk estimates for beach sediment are less than 1×10^{-4} for all locations, and the HIs are less than 1. Estimated CT and RME cancer risks associated with surface water exposures, including surface water from a groundwater seep at Outfall 22, are less than 1×10^{-4} at all locations, and the HIs are less than 1.

8.4.6 Divers

Commercial divers were evaluated for exposure to surface water and in-water sediment, assuming the diver was wearing either a wet or a dry suit. In-water sediment exposure by divers was evaluated in half-mile exposure areas for each side of the river, and on a study area-wide basis. Risks associated with exposure to surface water were evaluated for four individual transect stations, and at single-point sampling stations grouped together in one-half mile increments per side of river.

The estimated CT and RME cancer risks associated with exposure to in-water sediments by divers wearing wet suits are less than 1×10^{-4} at all half-mile river segments as well as for study area-wide exposure, and the HIs are also less than 1 for adults. The HI for indirect exposure to infants of adult divers is 2 at RM 8.5W for the RME evaluation, due to PCBs. The estimated CT and RME cancer risks associated with exposure to surface water are less than 1×10^{-4} for all half-mile river segments, and the HIs are less than 1.

The estimated RME cancer risk associated with exposure to in-water sediments and surface water by divers wearing dry suits is less than 1×10^{-4} at all half-mile river segments and for study area-wide exposure, and the HI is also less than 1 for adults and indirect exposures to infants via breastfeeding.

8.4.7 Recreational Beach Users

Risks associated with exposure to beach sediment were evaluated separately for each beach designated as a potential recreational use area, and exposure to surface water was evaluated using data collected from three transect locations and three single-point locations at Cathedral Park, Willamette Cove, and Swan Island Lagoon. Estimated CT and RME cancer risks associated with exposure to beach sediments and surface water are less than 1×10^{-4} at all recreational beach areas, and the HIs are also less than 1. Indirect exposures to infants via breastfeeding were not evaluated.

8.4.8 Recreational/Subsistence Fishers

Recreational and subsistence fishers were evaluated assuming direct exposure to contaminants in sediment and via consumption of fish and shellfish. Exposures associated with beach sediment were assessed at individual beaches designated as potential transient or recreational use areas; in-water sediment exposures were evaluated on a one-half river mile basis per side of the river and as an averaged, study area-wide evaluation. Sediment exposures were further assessed as CT and RME evaluations and assuming either a low- or a high-frequency rate of fishing.

Estimated CT and RME cancer risks associated with both low- and high-frequency fishing exposures to either beach or in-water sediments are less than 1×10^{-4} at all areas evaluated. HIs associated with adult exposures to beach sediment are less than 1 at all locations evaluated. The RME HI associated with adult exposures to in-water sediment is greater than 1 at RM 7W for high-frequency fishing; HIs for all other locations and fishing exposures are less than 1. The RME HI associated with indirect exposures of in-water sediment contamination to infants via breastfeeding is greater than 1 at RM 7W and 8.5W. Indirect exposure to contaminants in beach sediment to infants was not evaluated.

Consumption of resident fish species was evaluated on a river mile basis using smallmouth bass data as a surrogate for all fish consumed. Consumption of fish was also evaluated over the entire study area assuming a diet consisting of equal proportions of common carp, brown bullhead, back crappie, and smallmouth bass. Consumption on a river mile basis was evaluated only for recreational fishers; consumption averaged over the entire study area was evaluated for both recreational and subsistence fishers. With the exception of RM 5, RME risk estimates on a river mile basis are all greater than 1×10^{-4}. CT estimates are greater than 1×10^{-4} at RM 7, Swan Island Lagoon, and RM 11. River miles exhibiting the highest estimated RME risks are: RM 2 (2×10^{-4}), RM 4 (3×10^{-4}), RM 7 (6×10^{-4}), Swan Island Lagoon (6×10^{-4}), RM 9 (2×10^{-4}), and RM 11 (1×10^{-3}). Study area-wide RME risks for recreational and subsistence fishers are 4×10^{-3} and 1×10^{-2}, respectively; the study area-wide CT estimate for recreational fishers is 1×10^{-3}.

RME and CT HIs are greater than 1 at all river miles. River miles exhibiting the highest estimated HIs are RM 4, RM 7, Swan Island Lagoon, and RM 11. Study area-wide RME HIs for recreational and subsistence fishers are 300 and 1,000, respectively; the CT estimate for recreational fishers is 100.

RME HIs associated with indirect exposure to infants via breastfeeding range from 30 to 1,000, and CT estimates range from 10 to 500, when assessed on a river mile scale. Study area-wide, the HIs for recreational fishers are 2,000 and 4,000 for the CT and RME estimates, respectively, and the RME HI for subsistence fishers is 10,000. River miles exhibiting the greatest RME HIs are: RM 2 (200), RM 4 (200), RM 7 (200), Swan Island Lagoon (600), and RM 11 (1,000). The majority of the hazard estimate is attributable to PCBs.

exposure point concentrations on a river mile scale use data from smallmouth bass to represent contaminant concentrations in all resident fish species, and consumption was assumed to consist primarily of just the fillet rather than other parts of the fish. However, an evaluation of the data collected from Portland Harbor indicates that PCB concentrations in whole body smallmouth bass are typically an order of magnitude greater than those measured in just the fillet. By contrast, in common carp and brown bullhead, the observed ratio of whole body-to-fillet PCB concentrations is less than noted in smallmouth bass, meaning that given the same overall PCB concentration in whole body fish, the PCB concentration in smallmouth bass fillet tissue will be less than for carp and bullhead. These differences are reflected in the exposure concentrations such that the use of fillet smallmouth bass data on a river mile scale resulted in a greater relative reduction of PCB concentration than would be seen if fillet data from common carp and brown bullhead were included. A diet that consists of some portion of carp and bullhead could result in relatively greater intake of PCBs, and the associated risk and hazard would be correspondingly greater as well. In addition, at least some of the fishers in the Portland Harbor area consume more than just the fillet. Consumption of other portions of the fish in addition to the fillet can result in greater relative exposure to PCBs and other persistent bioaccumulative chemicals and thus, greater relative risks.

Risks from consumption of clams and crayfish were evaluated for subsistence fishers. Estimated RME cancer risks associated consumption of undepurated clams by subsistence fishers are greater than 1×10^{-4} at 10 of the 22 river mile sections evaluated. The estimated risk study area-wide is 4×10^{-4}. Carcinogenic PAHs pose the highest risks at RM 5W and 6W, while PCBs pose the highest risks in Swan Island Lagoon and RM 11. Carcinogenic PAHs and PCBs pose the highest risks on a study area-wide basis. Estimated CT cancer risks are all less than 1×10^{-4}. Risks based on depurated clams were estimated at RM 1E, 2W, 10W, 11E, and 12E, and none of the estimated CT or RME cancer risks are greater than 1×10^{-4}. The estimated RME HIs associated consumption of undepurated clams by subsistence fishers are greater than 1 at 20 of the 22 river mile sections evaluated, as well as when evaluated on a study area-wide basis. RME HIs associated with indirect exposure to infants via breastfeeding are greater than 1 at each river mile evaluated.

The estimated RME cancer risks associated consumption of crayfish by subsistence fishers are greater than 1×10^{-4} at RM 7W and RM 11E, as well as on study area-wide basis. All estimated CT cancer risks are less than 1×10^{-4}.

The estimated RME HIs associated consumption of crayfish by subsistence fishers are greater than 1 at 7 of the 32 individual stations; the estimated HI study area-wide is 10. RME HIs associated with indirect exposure to infants via breastfeeding are greater than 1 at 23 of the 32 stations evaluated; the HI is 200 when evaluated study area-wide.

8.4.9 Tribal Fishers

Exposures to tribal fishers were evaluated assuming direct contact with contaminants in sediment and via consumption of fish. Exposures associated with beach sediment were

assessed at individual beaches, and in-water sediment exposures were evaluated on a one-half river mile basis per side of the river and as an averaged, study area-wide evaluation. Fish consumption was evaluated assuming a multi-species diet consisting of anadromous and resident fish species, and fishing was evaluated on a study area-wide basis.

The estimated CT and RME cancer risks associated with direct contact to beach sediment is less than 1×10^{-4} at all beaches evaluated. RME cancer risk associated with exposure to in-water sediment is greater than 1×10^{-4} at RM 6W and 7W. With the exception of in-water sediment exposure at RM 7W, the estimated HIs are less than 1 at all beach and in-water locations evaluated. Noncancer CT and RME HIs associated with indirect exposure to infants via breastfeeding were evaluated assuming maternal exposure to in-water sediment. The estimated RME HI is greater than 1 at RM 7W, 8.5, and 11E.

The estimated RME cancer risk for tribal consumption of fish is 2×10^{-2} assuming whole body consumption, and 1×10^{-2} assuming consumption of fillets only. RME HI associated with childhood consumption of whole body fish is 800, and is 600 assuming consumption of fillets only. RME HI associated with indirect exposure of tribal infants via breastfeeding assuming maternal consumption of whole body fish is 9,000, and is 8,000 assuming maternal fillet-only consumption.

8.4.10 Domestic Water Use

Use of surface water as a source of household water for drinking and other domestic uses was evaluated using data from five transect and 15 single point sampling locations, as well as averaged over a study area-wide basis. The estimated cancer risk for combined child and adult exposures is greater than 1×10^{-4} at RM 6W.

The estimated HIs based on childhood exposure are equal to or greater than 1 at several sampling locations: W005 (1) at RM 4, W023 (1) at RM 11, W027 (2) near the mouth of Multnomah Channel, and W035 (2) in Swan Island Lagoon. In all instances, MCPP is the primary contributor to the estimated hazard.

8.4.11 Cumulative Risk Estimates

Cumulative risk and hazard estimates were calculated for those populations where concurrent exposure to more than one media was assumed to be plausible. Recreational/subsistence and tribal fishers were further evaluated on the basis of whether they were assumed to fish predominately from the shore or from a boat. Populations for which concurrent exposure to more than one medium was considered are as follows:

- Transients: Beach sediment, surface water
- Divers: In-water sediment, surface water
- Recreational beach users: Beach sediment, surface water

- Recreational fishers (beach): Beach sediment, fish tissue (fillet)
- Recreational fishers (boat): In-water sediment, fish tissue (fillet)
- Subsistence fishers (beach): Beach sediment, fish tissue (fillet), shellfish tissue
- Subsistence fishers (boat): In-water sediment, fish tissue (fillet), shellfish tissue
- Tribal fishers (beach): Beach sediment, fish tissue (fillet and whole body)
- Tribal fishers (boat): In-water sediment, fish tissue (fillet and whole body).

Cumulative risk estimates were generally calculated for each one-half river mile per side of the river, and the risk estimates for specific media appropriate to each one-half mile segment were used to calculate the total risk or hazard. For example, cumulative risks for recreational fishers who fish from a boat and consume smallmouth bass would include the risks associated with exposure to in-water sediment at the specific half-mile and smallmouth bass from the larger river mile assessment. Risks resulting from the consumption of fish or shellfish are generally orders of magnitude higher than risk resulting from direct contact with sediment, surface water, or seeps. PCBs are the primary contributor to risk from fish consumption harbor wide. When evaluated on a river mile scale, dioxins/furans are a secondary contributor to the overall risk and hazard estimates. PCBs are the primary contributors to the noncancer hazard to nursing infants, primarily because of the bioaccumulative properties of PCBs and the susceptibility of infants to the developmental effects associated with exposure to PCBs.

8.4.12 Identification of Contaminants Potentially Posing Unacceptable Risks

Contaminants were identified as potentially posing unacceptable risks if they resulted in a cancer risk greater than 1×10^{-6} or a HQ greater than 1 under any of the exposure scenarios for any of the exposure point concentrations evaluated in the BHHRA, regardless of the uncertainties. There were 33 contaminants identified as potentially posing unacceptable risks for the exposure scenarios listed above. Only a subset of these contaminants was associated with cancer risks exceeding 1×10^{-4} or HQs exceeding 1, and an even smaller number of contaminants contributed to most of the relative percentage of total risk. Four of the contaminants (alpha-, beta-, and gamma-HCH and heptachlor) were identified as potentially posing unacceptable risks on the basis of N-qualified data only. The use of an "N" qualifier indicates that the identity of the analyte is not definitive. These four chemicals are not recommended for further evaluation of potential risks to human health. The remaining 27 contaminants identified as potentially posing unacceptable risks to human health are presented in Table 8.4-3.

8.5 UNCERTAINTY ANALYSIS

The presence of uncertainty is inherent in the risk assessment process, and USEPA policy calls for numerical risk estimates to always be accompanied by descriptive information regarding the uncertainties of each step in the risk assessment to ensure an objective and balanced characterization of the true risks and hazards. The term

"uncertainty" is often used in risk assessment to describe what are, in reality, two conceptually different terms: uncertainty and variability. Uncertainty can be described as the lack of a precise knowledge resulting in a fundamental data gap. Variability describes the natural heterogeneity of a population. Uncertainty can sometimes be reduced or eliminated through further measurements or study. By contrast, variability is inherent in what is being observed. Although variability can be better understood, it cannot be reduced through further measurement or study, although it may be more precisely defined. However, the additional cost of further data collection may become disproportional to the reduction in uncertainty.

The risks and hazards presented are consistent with USEPA's stated goal of RME representing the high end of the possible risk distribution, which is generally considered to be greater than the 90^{th} percentile. However, these estimates are based on numerous and often conservative assumptions and, in the absence of definitive information, assumptions are used to ensure that actual sites risks are not underestimated. The cumulative effect of these assumptions can result in an analysis with an overall conservativeness greater than the individual components. Accordingly, it is important to note that the risks presented here are based on numerous conservative assumptions in order to be protective of human health and to ensure that the risks presented here are more likely to be overestimated rather than underestimated. A detailed analysis of the uncertainties associated with the BHHRA is found in Section 6 of Appendix F.

Exposure Parameters for Fish and Shellfish Consumption Scenarios. Site-specific information regarding fish consumption is not available for Portland Harbor prior to its listing as a Superfund site. In the absence of site-specific data, fish consumption data representative from several sources were considered and selected as being representative of the general population of the greater Portland area, as well as that portion of the population that actively fishes the lower Willamette and utilizes fish from the river as a partial source of food.

The rates presented in the Continuing Survey of Food Intakes by Individuals described in Section 8.2.4 represent per capita consumption rates rather than true long-term averaged consumption rates. In addition, the large range between the percentile values is indicative of substantial variability in the underlying data. In addition to the consumption rates, uncertainty also exists with respect to the relative percentage of the diet of obtained from the study area or within individual exposure areas versus other nearby sources of fish, and the degree to which different methods of preparation and cooking may reduce concentrations of persistent lipophilic contaminants.

Using the Maximum Concentration to Represent Exposure. In cases when there were fewer than five samples with a detected concentration for a given analyte for a given exposure area, the sample size was not sufficient to calculate a representative 95 percent UCL on the mean, so the maximum concentration detected was used as the exposure point concentration. Data sets with fewer than 10 samples generally provide poor estimates of the mean concentration, defined as a large difference between the sample

mean and the 95 percent UCL. In general, the UCL approaches the true mean as more samples are included in the calculation of the exposure concentration.

Regional Tissue Concentrations. PCBs and dioxins/furans have been detected in fish tissue collected in the Willamette and Columbia rivers, outside of the study area. In the Columbia River Basin Fish Contaminant Survey, the basin-wide average concentrations of total PCBs in resident fish ranged from 0.032 to 0.173 parts per million (ppm) for whole body samples and from 0.033 to 0.190 ppm for fillet with skin samples (USEPA 2002e). In the middle Willamette River (RM 26.5 to 72), the average concentrations of total PCBs in resident fish ranged from 0.086 to 0.146 ppm for whole body samples and from 0.026 to 0.071 ppm for fillet with skin samples (EVS 2000). The regional tissue concentrations may be associated with unacceptable risks from fish consumption, especially at higher consumption rates. However, these regional concentrations are lower than the concentrations detected in the study area, where average concentrations ranged from 0.16 to 2.8 ppm in whole body samples and from 0.17 to 2.5 ppm in fillet with skin samples (for PCBs as total congeners). The fish species included in the studies were different than those collected within the study area, so the concentrations may not be directly comparable. Sources contributing to the PCBs and dioxins/furans detected in fish collected outside of the study area are unknown and may not be relevant to the study area.

8.6 SUMMARY AND CONCLUSIONS

The following presents the major findings of the BHHRA[1]:

- Risks resulting from the consumption of fish or shellfish are generally orders of magnitude higher than risk resulting from direct contact with sediment, surface water, or seeps. Risks and hazards from fish and shellfish consumption exceed the USEPA point of departure for cancer risk of 1×10^{-4} and target HI of 1 when evaluated on a harbor-wide basis, and when evaluated on the smaller spatial scale by river mile.
- Consumption of resident fish species consistently results in the greatest risk estimates. Evaluated harbor-wide, the estimated RME cancer risks are 4×10^{-3} and 1×10^{-2} for recreational and subsistence fishers, respectively. Evaluated on a river mile scale, it is only at RM 5, where the estimated RME risk for recreational fishers is 9×10^{-5}, that the risk from consumption of resident fish is less than 1×10^{-4}. River miles associated with the highest estimated risk estimates are RM 4, 7, 11, and in Swan Island Lagoon. Evaluated harbor-wide and assuming a diet that consists of migratory fish in addition to resident fish species, the estimated RME cancer risk for tribal consumers is 1×10^{-2} assuming fillet-only consumption, and 2×10^{-2} assuming whole body consumption.

[1] However, the identification of the contaminants presenting the most significant risk in various areas of the site consistent with USEPA risk assessment guidance is not intended to suggest that other contaminants in those areas and at the site generally do not also present potentially unacceptable risk.

- Noncancer hazard estimates for consumption of resident fish species are greater than 1 at all river miles. Evaluated harbor wide, the estimated RME HI is 300 and 1,000 for recreational and subsistence fisher, respectively. The highest hazard estimates are at RM 4, 7, 11, and in Swan Island Lagoon. The highest noncancer hazards are associated with nursing infants of mothers who consume resident fish from Portland Harbor. When fish consumption is evaluated on a harbor-wide basis, the estimated RME HI is 4,000 and 10,000 for infants of recreational and subsistence fishers, respectively. Evaluated on a harbor-wide scale, the estimated RME hazard for tribal consumers of migratory and resident fish is 600 assuming fillet-only consumption, and 800 assuming whole-body consumption. The corresponding HI estimates for nursing infants of mothers who consume fish are 8,000 and 9,000 respectively, assuming maternal consumption of fillet or whole-body fish.
- PCBs are the primary contributor to risk from fish consumption harbor wide. When evaluated on a river mile scale, dioxins/furans are a secondary contributor to the overall risk and hazard estimates. PCBs are the primary contributors to the noncancer hazard to nursing infants, primarily because of the bioaccumulative properties of PCBs and the susceptibility of infants to the developmental effects associated with exposure to PCBs.
- The largest source of uncertainty in the risk and hazard estimates includes the lack of good site-specific information about consumption of resident fish from Portland Harbor. Because tribal fish consumption practices were evaluated assuming a combined diet consisting of both resident and migratory fish, it not clear to what degree contamination in Portland Harbor contributes to those estimated risks. In addition, it is important to remember that the noncancer hazard estimates presented in the BHHRA are not predictions of specific disease, and the cancer estimates represent upper-bound values, and the USEPA is reasonably confident that the actual cancer risks will not exceed the estimated risks presented in the BHHRA.

9.0 BASELINE ECOLOGICAL RISK ASSESSMENT SUMMARY

This section summarizes the BERA for aquatic and aquatic-dependent species exposed to hazardous substances associated with the in-water Willamette River portion of the Portland Harbor Superfund site. The BERA is provided as Appendix G of this RI report. For the purpose of the BERA, the Willamette River is defined as all areas lower in water surface elevation than the ordinary high water mark, including nearshore riparian zone areas not normally inundated by water.

9.1 PURPOSE

The specific overall objectives of the BERA are:

- Identify the risks posed by chemical contaminants to aquatic and aquatic-dependent ecological receptors associated with the Portland Harbor study area under baseline conditions.[1]

- In the event that unacceptable ecological risks require remedial actions at Portland Harbor, provide information that risk managers can use to make remedial action decisions that are protective of ecological receptors.

Given the large number and wide variety of historical and present-day contaminant sources; the multitude of chemicals and hazardous substances released; the differences in the composition, volume, and mass of hazardous substances released from the various sources; and the multiple locations within and outside of the study area from which contaminants have been released, some contaminants have elevated concentrations throughout much if not all of the study area while many more contaminants are only elevated in sections of the study area. This is reflected in the distribution and variability in the number of contaminants posing potentially unacceptable risks[2] in any specific section of the study area, as well as the areal extent and magnitude of ecological risks from exposure to each hazardous substance.

9.2 ECOLOGY

The numerous aquatic and aquatic-dependent organisms that use the lower Willamette River can be divided into the following general groups: invertebrates, fishes, birds, mammals, amphibians, reptiles, and aquatic plants. All organisms present within the study area contribute to the ecological functioning of the river. Riverine invertebrates are

[1] Baseline conditions are the conditions represented by the BERA data set, which is presented in Attachment 4 of the BERA in Appendix G, and includes samples collected between June 2002 and November 2007.

[2] The phrase "contaminant posing potentially unacceptable risk" is used throughout this BERA instead of the more commonly used phrase "contaminant of (ecological) concern.

predominantly benthic (living in or associated with river bottom substrates), using substrates such as fine-grained sediment, gravel and cobble, plant roots, and large woody debris. The benthic invertebrate community within the lower Willamette River is dominated by small benthic organisms, many of which feed on organic material imported from upstream areas.

The Willamette River is an important migration corridor for anadromous fishes, including Pacific lamprey and multiple salmon species, and provides habitat for approximately 50 resident fish species. Fish present in the river can be grouped into four major feeding guilds: omnivores/herbivores, invertivores, piscivores, and detritivores. Over 20 commonly occurring aquatic-dependent bird species use habitats and feed on aquatic species within the study area. The trophic representation of these birds is broad and includes herbivores, carnivores, and omnivores; sediment-probing invertivores and omnivores; and piscivores. Seven aquatic or semi-aquatic mammals use or may use the river within the study area, including herbivores, omnivores, and piscivores.

9.3 ECOLOGICAL RISK ASSESSMENT PROCEDURE

Procedures used in the BERA to evaluate the nature, severity, and areal extent of risks to ecological receptors in Portland Harbor were based on the guidance provided in the 8-step, iterative approach to ecological risk assessment (ERA) described in the USEPA (1997b) *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments – Interim Final*. The 8 steps identified in this guidance are as follows:

1. Screening Level Problem Formulation and Ecological Effects Evaluation 2. Screening Level Preliminary Exposure Estimate and Risk Calculation	Screening-level ERA (SLERA)
3. Baseline Risk Assessment Problem Formulation 4. Study Design and Data Quality Objectives 5. Field Verification of Sampling Design 6. Site Investigation and Analysis of Exposure and Effects 7. Risk Characterization	BERA
8. Risk Management	Risk management

Additional procedures, methodologies, memoranda, and intermediate data reports and analyses have been developed and presented in documents prepared include the *Portland Harbor Remedial Investigation/Feasibility Study (RI/FS) Programmatic Work Plan* (Integral, Windward, Kennedy/Jenks, Anchor, and GSI 2004), the draft *Portland Harbor RI/FS, Ecological Preliminary Risk Evaluation* (Windward 2005d), and the *Problem*

Formulation for the Baseline Ecological Risk Assessment at the Portland Harbor Site (USEPA 2008e).

9.4 CONTAMINANT AND TOXICITY DATA

The BERA data set is a subset of the complete RI data set and includes only those samples relevant to ecological exposure pathways. It does not contain sediment data from a depth greater than 30.5 cm, or 12 in., below the sediment surface; nor does it include TZW collected greater than 38 cm (15 in.) below the sediment surface. The deeper sediment and TZW samples were excluded from the BERA exposure assessment because the likelihood that any species present in Portland Harbor comes into contact with or ingests such material is extremely low.

Contaminant data available for use in the BERA were collected during three rounds of sampling. Round 1 sampling, which focused on the collection of biota (tissue) samples, was conducted in 2002. Round 2 sampling began with multiple field efforts in 2004 and focused on the characterization of surface and subsurface sediment quality. Round 3 sampling occurred between 2006 and early 2008 and included the collection of surface water, biota, sediment upstream and downstream of the study area, suspended sediment (in-river sediment traps), and stormwater samples. Round 3 sampling also filled data gaps related to site characterization, ecological and human health risks, upriver background contaminant concentrations, and the FS.

The Portland Harbor BERA is supported by a database that features the concentrations of numerous chemicals in multiple environmental media types (sediment, water, bird eggs, and tissues from multiple fish and invertebrate species). In addition to this chemical data set, sediment toxicity test results, which directly measured the effect of sediment constituents on the survival and growth of two benthic species, were available. The numbers of samples in the BERA data set are summarized in Table 9.4-1.

In addition, a study was conducted to address the question of whether the use of surrogate species in the risk assessment would be protective of lamprey ammocoetes. The study evaluated the acute toxicity of six chemicals representing six different toxic modes of action (Andersen et al. 2010). Results indicated that the use of surrogates was protective of lamprey at this life stage.

9.5 SCREENING-LEVEL ECOLOGICAL RISK ASSESSMENT FINDINGS

The screening-level ecological risk assessment (SLERA) identified numerous COPCs whose concentrations exceeded conservative screening-level effect thresholds in sediment, water, tissue, and ingested dietary doses. Because the possibility of ecological risks from hazardous substances within Portland Harbor could not be discounted based on the SLERA results, a more comprehensive ecological risk evaluation described in the BERA was conducted.

9.6 BERA PROBLEM FORMULATION

According to USEPA (1997b) guidance, a BERA problem formulation generally consists of the following tasks:

- Refinement of the preliminary list of COPCs for the site
- Further characterization of the potential ecological effects of COPCs on study area receptors
- Review and refinement of information on the fate and transport of COPCs, on potential exposure pathways, and on the receptors potentially at risk
- Selection of assessment endpoints (environmental values to be protected)
- Development of a CSM with testable hypotheses (or risk questions) that the BERA will address.

The products of the problem formulation are used to select measurement endpoints (what is actually measured at a site) and develop the ERA work plan and SAPs for the study area in Step 4 of the ERA process. In practice, Steps 3 and 4 are often performed concurrently.

9.6.1 Identification of COPCs

The refined screen, which resulted in the final COPC list evaluated in the BERA, is presented in Appendix G. Table 9.6-1 presents the number of COPCs carried forward from the refined screen to the risk characterization step for each environmental medium evaluated.

Table 9.6-1 also lists the number of contaminants within each medium for which screening-level or refined screen toxicity reference values (TRVs) could not be identified or derived. Risks associated with these contaminants were evaluated if alternative methods were available to derive TRVs in the BERA; otherwise, risks from these contaminants could not be quantified. Unquantified ecological risks from contaminants without baseline TRVs are likely the primary source of uncertainty in the BERA that could lead to underestimating ecological risks within Portland Harbor because most other types of uncertainty are handled by making conservative assumptions, which tends to build a margin of safety into ecological risk estimates.

The types or groups of contaminants identified as COPCs in the BERA are summarized in Table 9.6-2. Screening resulted in the identification of a combined 104 COPCs for benthic invertebrates across four media types (sediment, invertebrate tissue, surface water, and TZW). A combined 74 fish COPCs were identified when the results of the screening of all fish species analyzed were compiled, based on summing the COPCs across all media and for the dietary line of evidence (LOE). Twenty-three COPCs were identified for birds through two LOEs, and 12 COPCs were identified for mammals based on one LOE. Finally, 64 COPCs were identified for amphibians and aquatic plants

through two LOEs. More detailed information regarding the final COPC list for the various receptors is presented in Appendix G.

9.6.2 Ecological Effects Characterization

Ecological effects characterization within the BERA problem formulation resulted in the final list of TRVs and sediment quality values (SQVs) for the various environmental media and samples evaluated. TRVs and SQVs are contaminant concentrations in media, which if not exceeded, describe contaminant concentrations considered to pose no or only acceptable levels of ecological risk.

A floating percentile model and logistic regression model were both used to evaluate site-specific synoptic sediment toxicity chemistry data to develop SQVs that provide relatively reliable predictions of sediment toxicity test results at 293 sediment sampling locations for which sediment toxicity tests were conducted (269 sampling locations in the study area and 24 sampling locations in the lower Willamette River upstream from the study area). The SQVs were then used to predict sediment toxicity at Portland Harbor sediment sampling locations for which sediment toxicity tests were not conducted.

The tissue residue approach presented in the BERA is used to derive contaminant concentrations in fish and aquatic invertebrate tissue, which, if exceeded, would define tissue contaminant concentrations posing potentially unacceptable ecological risks. Although screening-level ecological risk benchmarks for contaminants in aquatic life tissue have been available for some time, the BERA represents perhaps the first effort to derive numerous baseline tissue TRVs.

The remaining TRVs used in the BERA were taken from either existing compendia of environmental quality guidelines or directly from the original scientific literature. The basis for selection of each TRV is presented in the BERA.

9.6.3 COPC Fate and Transport, Exposure Pathways, and Receptors at Risk

Contaminant sources and distribution within Portland Harbor and their environmental fate and transport (Sections 4, 5, and 6, respectively, of this RI), as well as exposure pathways and the identification of ecological receptors potentially at risk, had largely been defined prior to the development of the BERA problem formulation (USEPA 2008e). Therefore, this stage of the problem formulation focused on identifying a subset of species for which ecological risks would be evaluated in the BERA.

Given that Portland Harbor is inhabited by hundreds if not thousands of species, the majority of which are lower-trophic-level species, such as algae and benthic invertebrates, it is not feasible to quantify risks to every species within the study area. The primary selection criteria for ecological receptors were: 1) that they represent the feeding guilds present at Portland Harbor; 2) that the receptor use the same habitat as other similar species; 3) that the receptor be susceptible to contaminants; and 4) that the receptor be ecologically, culturally, or economically significant. The term feeding guild

refers to a group of species that share similar feeding strategies or diets, thus, resulting in a similar potential for contaminant exposure as other members of the guild.

9.6.4 Assessment Endpoint Selection

The development of the assessment endpoints, risk questions, measurement endpoints, and LOEs to be assessed in a BERA are as follows:

- **Assessment endpoints**—Explicit expressions of environmental values to be protected
- **Risk questions**—Proposed or suspected relationships between assessment endpoints and their predicted responses when exposed to contaminants
- **Measurement endpoints**—Measurable ecological characteristics, either measures of exposure or measures of ecological effect that are related to the valued characteristics chosen as assessment endpoints
- **Line of evidence**—A set of data and associated analyses that can be used, either alone or in combination with other LOEs, to estimate ecological risks.

For each assessment endpoint, risk questions and testable hypotheses are developed. Risk questions provide the basis for defining measurement endpoints that are evaluated with information collected during studies designed and performed as part of this RI. Each measurement endpoint is evaluated with one or more LOEs.

The Portland Harbor BERA evaluates 13 assessment endpoints. Twelve of the 13 assessment endpoints take the form of "survival, growth, and reproduction of" a group of species that share a habitat, taxonomic category, or feeding guild.

The 12 assessment endpoints with the form "survival, growth, and reproduction of…" are:

- Aquatic plants
- Benthic macroinvertebrates
- Bivalves
- Decapods
- Invertivorous fish
- Omnivorous fish
- Piscivorous fish
- Amphibians
- Piscivorous birds
- Omnivorous birds

- Invertivorous birds
- Aquatic-dependent mammals.

The 13th assessment endpoint is:

- Survival and growth of detritivorous fish (Pacific lamprey ammocoetes).

Reproduction is not evaluated for Pacific lamprey ammocoetes because this is not the reproducing life stage of the lamprey.

The full list of 24 target ecological receptors, 31 measurement endpoints, and 55 LOEs evaluated is presented in Attachment 2 of Appendix G.

9.6.5 Conceptual Site Model Development

Development of the CSM was largely completed prior to the commencement of work on the BERA problem formulation (USEPA 2008e). A simplified version of the refined ecological CSM is presented in Figure 9.6-1.

The routes of exposure are the means by which contaminants are transferred from a contaminated medium to an ecological receptor. The most significant pathways by which ecological receptors may be exposed to Portland Harbor COPCs are:

- **Aquatic plants—**Root uptake; direct contact with sediment, surface water, and TZW
- **Benthic invertebrates—**Direct contact with sediment, surface water, and TZW; ingestion of sediment and food
- **Fish—**Direct contact with sediment, surface water, and TZW; ingestion of sediment and food
- **Birds and mammals—**Ingestion of soil, sediment, and food
- **Amphibians—**Direct contact with surface water and TZW; ingestion of sediment and food.

9.7 STUDY DESIGN AND DATA QUALITY OBJECTIVE PROCESS

The study design and data quality objective process describes the individual sediment, water, and biota sampling events that were carried out during the BERA. All of the sampling and chemical analyses performed to obtain the data used in the BERA followed procedures defined in the ERA work plan (Integral, Windward, Kennedy/Jenks, Anchor, and GSI 2004) and the numerous SAPs for various tasks. The data management rules (including data reduction, data usability, and data quality) are described in detail in Appendix A.

The data quality objective process used during the development of the BERA SAPs describes a series of planning steps that were employed to ensure that the type, quantity,

and quality of environmental data collected for the BERA were adequate to support the intended uses of the data.

9.8 FIELD VERIFICATION OF SAMPLING DESIGN

Step 5 of the ERA process verifies that the selected assessment endpoints, testable hypotheses, exposure pathway model, measurement endpoints, and study design from Steps 3 and 4 are appropriate and implementable at the study area. By verifying the study design, alterations can be made to the study design and/or implementation if necessary. These changes ensure that the ERA meets its objectives.

The availability of radiotelemetry information on the movement of juvenile salmonids, smallmouth bass, and northern pikeminnow (Friesen 2005) in the study area allowed for the development of site-specific home range estimates for these species. Site-specific home range estimates for aquatic species are rare at Superfund sites, and the availability of such information for several target ecological receptors informed FSPs and also allowed for the definition of species-specific contaminant exposure concentrations for these species.

9.9 SITE INVESTIGATION AND ANALYSIS OF EXPOSURE AND EFFECTS

Information collected during the site investigation (Step 6 of the ERA process) was used to characterize exposures and ecological effects. The site investigation included all of the field sampling and surveys that were conducted as part of the ERA. The site investigation and analysis of exposure and effects followed the ERA work plan (Integral, Windward, Kennedy/Jenks, Anchor, and GSI 2004) and the numerous SAPs and FSPs developed and tested in Steps 4 and 5.

9.9.1 Ecological Exposure Assessment

To ensure conservatism protectiveness in the BERA, all COPCs are first evaluated on a sample-by-sample basis. The exposure of benthic invertebrates is assessed based on contaminant concentrations in individual samples of sediment, water, and TZW throughout the BERA, inasmuch as settled individuals of these species have little or no ability to move within the study area.

Because a sample-by-sample exposure area is not ecologically relevant for the mobile receptors evaluated in the BERA (such as fish, birds, and mammals), COPCs for mobile species are then evaluated at an exposure scale that is ecologically relevant for each specific receptor. The exposure area for mobile receptors is defined as the home range of each target ecological receptor evaluated. With the exception of the fish species for which site-specific movement and home range information was available, home ranges are derived from the published ecological literature. For dietary risks to fish and wildlife, exposure estimates are also determined for a diet consisting of multiple prey species using prey portions reported in the literature. Exposure concentrations are based both on measured contaminant concentrations, and for some LOEs (the tissue-residue LOE and the dietary LOE for shorebirds), on predicted values.

9.9.2 Ecological Effects Assessment

The effects assessment involves two general approaches. For most ecological receptors, the effects of COPCs are assessed by comparing contaminant concentrations in each environmental medium with contaminant- and medium-specific TRVs or site-specific SQVs. Consistent with the problem formulation, for all receptors and receptor groups evaluated at the community or population level, lowest-observed-adverse-effect level TRVs are used. No-observed-adverse-effect level TRVs are used for receptors evaluated at the organism level (juvenile Chinook salmon, Pacific lamprey ammocoetes).

The second effects assessment approach uses sediment toxicity bioassays as a direct measure of the effects of sediment contaminant mixtures on the survival and biomass of benthic invertebrates in the laboratory. Two predictive models (the floating percentile model and logistic regression model) are used to develop site-specific SQVs. The goals of both models are to predict benthic toxicity for locations at which there were no measured toxicity data and to define site-specific SQVs based on associations between measured sediment chemistry and measured sediment toxicity.

9.10 RISK CHARACTERIZATION

Risk characterization is the final phase of the BERA itself. During risk characterization, information from the exposure assessment and ecological effects assessment are combined into descriptions of the likelihood of unacceptable ecological risk to the assessment endpoints established in the problem formulation. The risk characterization includes information on the contaminants posing potentially unacceptable risk, which ecological receptors are at risk, the media and exposure pathways in which contaminants posing potentially unacceptable risks are found, the magnitude of the risks, and the location(s) of risks within the study area.

In addition to the quantitative calculations performed to estimate risks, the risk characterization also discusses the level of agreement among the multiple LOEs used to assess risks to the assessment endpoints, the relative strengths and weaknesses of each LOE, the ecological significance of identified risks, and the uncertainties associated with the risk assessment conclusions.

Direct evidence of causality, if available, provides the strongest LOE for a site posing potentially unacceptable ecological risks. Sediment toxicity tests were performed to evaluate adverse effects of Portland Harbor sediment on survival and biomass (a combined survival and growth endpoint) of larvae of the aquatic insect *Chironomus dilutus* and juveniles of the amphipod *Hyalella azteca*. Results are summarized in Table 9.10-1. These toxicity tests demonstrate that the exposure of these animals to sediment from some locations within Portland Harbor resulted in increased mortality and/or reduced biomass of these two species within 10 to 28 days—a direct measure of sediment toxicity to benthic invertebrates.

The moderate and severe levels of toxicity are not randomly scattered throughout the study area. Instead, most samples and locations eliciting multiple instances of moderate

and severe toxicity tend to be clustered in several areas, especially areas between RM 5.9 and 7.8 on the west side of the river. Other areas with "clusters" of benthic toxicity include:

- International Slip
- Between RM 3.7 and 4.2, west side of river
- Between RM 4.8 and 5.2, west side of river
- Willamette Cove
- Near the mouth of Swan Island Lagoon
- RM 8.7 to 8.8, west side of river.

Other individual samples and locations exhibited toxicity to *Chironomus* and *Hyalella*. However, the above areas are those within the study aea where the greatest toxicity was found. A weight-of-evidence analysis identified 17 benthic areas of concern within the study area. Combined, the above areas to cover between 4 and 8 percent of the total surface area of sediment within the study area.[3] Contaminants found at elevated concentrations relative to SQVs in these areas are those most likely to be posing ecological risks to benthic invertebrates.

Most risk characterizations in the BERA are made using the HQ. An HQ is calculated by dividing the exposure point concentration by the selected TRV. HQs can also be comparisons of ingested dietary doses of contaminants with dietary TRVs or comparisons of measured COPC concentrations in prey of target ecological receptors with threshold tissue concentrations in prey species.

COPCs for which the HQ was ≥ 1.0 at the conclusion of the BERA are identified as contaminants posing potentially unacceptable risk. The potential for unacceptable risk becomes increasingly large as the HQ value increases, although the increase is not necessarily linear (for example, an exposure area with an HQ = 2.0 does not necessarily have twice the risk of an exposure area with an HQ = 1.0 for the same LOE).[4]

The complete list of COPCs posing potentially unacceptable ecological risks to the BERA assessment endpoints, the exposure pathways by which COPCs pose potentially unacceptable risks, and sections of the BERA where additional details can be found

[3] Estimates of the proportion of the study area eliciting moderate or severe toxicity to benthic invertebrates are made using GIS models. Different GIS models make different extrapolations of contaminated areas between sample locations of known levels of contamination or toxicity, accounting for the range in the estimates of the percentage of the study area that elicits moderate or severe toxicity.

[4] The HQ scale is not necessarily the same for different LOEs or COPCs. For example, the potentially unacceptable risks for two LOEs with HQ = 2 for the same COPC and exposure area are not necessarily the same, nor are the potentially unacceptable risks for two COPCs with HQ = 2 for the same LOE and expousre area.

regarding the magnitude of risks, risks to specific target ecological receptor species, and locations within the study area where risks are found are presented in Table 9.10-2. Table 9.10-3 lists the measurement endpoints or LOEs for several assessment endpoints for which no ecological risks are identified.

9.11 ECOLOGICAL SIGNIFICANCE OF IDENTIFIED RISKS

The ecological significance of the identified risks is often determined by evaluating whether estimated risk will make a difference or be observed in light of other factors that are influencing the environment, such as habitat alteration. With the exception of species protected by law or regulation (threatened and endangered species) for which individual organisms are protected, EPA (1997b) guidance and policy state that BERAs should generally focus on the protection of local populations and communities of biota. Oregon's ERA guidance (DEQ 1998) defines a local population for a stream or river as follows, "For aquatic species in moving water such as streams and rivers (lotic habitats), the local population comprises all individuals of the endpoint species within the stream segment within the contaminated area."

Contaminant concentrations, which, if not exceeded, are protective of local populations and communities were largely estimated in this BERA by extrapolating from effects on individual organisms or groups of organisms using an LOE approach. Hazard quotients greater than 1 for a given LOE are considered to indicate potentially unacceptable risk to ecological receptors. For example, an $HQ \geq 1$ might indicate the potential for reduced or impaired reproduction or recruitment of new individuals. HQs provide insight into the potential for adverse effects on organisms in the local population resulting from contaminant exposure. Any COPC with an $HQ \geq 1$ in the final step of the risk characterization for at least one LOE in any location in the study area, or the risks of which could not be quantified in the BERA, was identified as a contaminant posing potentially unacceptable risk. The ecological significance of risk associated with each receptor-LOE-COPC combination posing potentially unacceptable risk was evaluated relative to the assessment endpoints to determine risk conclusions.

Ecological significance can be defined as the importance of an adverse effect on population, community, or ecosystem responses. Factors contributing to ecological significance considered in the BERA included the nature and magnitude of effects, the spatial and temporal extent of effects, uncertainties in the exposure assessment, uncertainties in the effects characterization, and concordance of the various LOEs used to assess risk to communities or populations. However, as there are no specific directions in EPA guidance (USEPA 1997b) describing how to quantify ecological significance, the guidance calls for the use of professional judgment when describing the ecological significance of identified risks. The specific procedures used to evaluate ecological significance are presented in Appendix G. Contaminants of ecological significance tended to meet the following criteria:

1. Had relatively high HQs in one or more environmental media.

2. Had potentially unacceptable ecological risks over extensive areas.
3. Spatial extent of potentially unacceptable risk encompassed many other contaminants that posed a risk at only one or a few locations in the study area.
4. Had potentially unacceptable risks to multiple ecological receptors.
5. Multiple LOEs indicated potentially unacceptable risks.
6. Known or has potential to biomagnify in food webs.

These criteria are used to make judgments about whether the potential adverse effects on organisms in the study area from exposure to contaminants pose risk to local populations, and whether those risks are ecologically significant.

The primary contaminants of ecological significance at Portland Harbor are PCBs, PAHs, dioxins and furans, and DDx[5] (Table 9.11-1). Five of the 16 contaminants (cyanide, ethylbenzene, perchlorate, manganese, and vanadium) are groundwater contaminants that only or primarily pose potentially unacceptable risks in TZW.

Contaminants posing potentially unacceptable risk listed in Table 9.10-2 but not in Table 9.11-1 fall within low ecological significance levels. All contaminants posing potentially unacceptable risk at the end of the BERA (Table 9.11-1) were recommended to be carried forward to the FS. All other contaminants listed in Table 9.10-2 are recommended for comparison with projected post-remedial action conditions to confirm that alternatives developed for the ecologically significant contaminants would also be protective of risks of low ecological significance.

9.12 ECOLOGICAL RISK ASSESSMENT UNCERTAINTIES

By design, risk assessments are conservative in the face of uncertainty. In this context, conservative means efforts were made to minimize the chances of underestimating exposure, effects, or risk. The uncertainty analysis portions of the BERA are intended to illustrate the degree of confidence in the BERA conclusions. An uncertainty analysis can help the risk manager focus on those aspects of ecological risk that can be reduced during site remediation with the greatest certainty that the selected remedy will result in benefit to and the protection of the environment.

Uncertainty in a BERA has four components: variation, model uncertainty, decision rule uncertainty, and true unknowns. Examples of these types of uncertainty are:

- Variation – A fish is exposed to a range of contaminant concentrations in water, not to a constant concentration of a contaminant

[5] Depending on the LOE, different TRVs are used for PCBs, PAHs, dioxins and furans, and DDx, so different names are used to describe these chemical groups at different places in the BERA. For example, DDx includes two individual chemical forms each of DDT, DDD, and DDE.

- Model uncertainty – Use of a single species or several target ecological receptors within a feeding guild to represent all species within that guild introduces uncertainty because of the considerable amount of interspecies variability in sensitivity to a contaminant
- Decision rule uncertainty – Use of standard EPA default values, such as assuming contaminants are 100 percent bioavailable, because such defaults are used as single-point values throughout the BERA, despite having both variation and model uncertainty associated with them
- True unknowns – The effects of titanium in water on smallmouth bass survival, growth, and reproduction has never been studied and is unknown.

Consistent with the methods of the problem formulation (USEPA 2008e), receptor-COPC pairs posing potentially unacceptable risk were identified using conservative methods and assumptions. Examples of conservatism include assumptions that environmental contaminant concentrations are 100 percent bioavailable and assumptions that resulted in low baseline TRVs, which, in the case of nutritionally essential metals such as copper, had to be adjusted upward because they were below nutritional requirements for some, but not all, fish species.

Not all uncertainties create a conservative bias. Some can lead to an underestimation of risk, such as unavailability of exposure or effects data, thresholds that do not account for untested sensitive species, uncertainty about whether multiple COPCs present at the site interact synergistically, and uncertainty about whether metabolic processes increase the toxicity of accumulated contaminants in ways that are not observed in toxicity tests.

9.13 PRIMARY CONCLUSIONS OF THE BERA

Combining the findings of the BERA as summarized in Tables 9.10-1, 9.10-2, 9.10-3, and 9.11-1 and as described in more detail in Appendix G, the following primary conclusions can be made.

- In total, 93 contaminants (as individual contaminants, sums, or totals)[6] with HQ $\geq$ 1 pose potentially unacceptable ecological risk. Differences in the specific TRVs used in different LOEs for total PCBs (total PCBs vs. specific Aroclor mixtures), DDx, and total PAHs (17 individually measured contaminants such as naphthalene, as well as several groupings by molecular weight), all of which describe individual contaminants or a group of multiple but related individual chemical compounds, can result in different counts of the number of contaminants posing potentially unacceptable risk. The list of contaminants posing potentially unacceptable risks can be condensed if all PCB, DDx, and PAH compounds or

[6] The five chemicals or chemical groups with concentrations that exceeded only the sediment probable effects concentration and/or probable effects level are not included in this count.

groups are condensed into three comprehensive groups: total PCBs, DDx, and total PAHs. Doing so reduces the number of contaminants with HQ ≥ 1 posing potentially unacceptable risks to 66.

- Risks to benthic invertebrates are clustered in 17 areas.
- Sediment and TZW samples with the highest HQs for many contaminants also tend to be clustered in areas with the greatest benthic invertebrate toxicity.
- The COPCs in sediment that are most commonly spatially associated with locations of potentially unacceptable risk to the benthic community or populations are PAHs and DDx compounds.
- Not all COPCs posing potentially unacceptable risk have equal ecological significance. The most ecologically significant COPCs are PCBs, PAHs, dioxins and furans, and DDT and its metabolites.
- The list of ecologically significant COPCs is not intended to suggest that other contaminants in the study area do not also present potentially unacceptable risk.
- The contaminants identified as posing potentially unacceptable risk in the largest numbers of LOEs are (in decreasing frequency of occurrence) total PCBs, copper, DDx, lead, TBT, zinc, total TEQ, PCB TEQ, benzo(a)pyrene, cadmium, 4,4′-DDT, dioxin/furan TEQ, BEHP, naphthalene, and benzo(a)anthracene. The remaining 78 contaminants posing potentially unacceptable risk were identified as posing potentially unacceptable risk by three or fewer LOEs.
- Of the three groups of contaminants (total PAHs, total PCBs, DDx) with the greatest areal extent of HQs ≥ 1.0 in the study area, PAH and DDx risks are largely limited to benthic invertebrates and other sediment-associated receptors. PCBs tend to pose their largest ecological risks to mammals and birds.
- The combined toxicity of dioxins/furans and dioxin-like PCBs, expressed as total TEQ, poses the potential risk of reduced reproductive success in mink, river otter, spotted sandpiper, bald eagle, and osprey. The PCB TEQ fraction of the total TEQ is responsible for the majority of total TEQ exposure, but the total dioxin/furan TEQ fraction also exceeds its TRV in some locations of the study area.

10.0 RI CONCEPTUAL SITE MODEL SUMMARY

The CSM for the Portland Harbor study area is sumarized in this section. A CSM is a representation of an environmental system and the biological, physical, and chemical processes that affect the transport of contaminants from sources through environmental media to human and ecological receptors in the system. This section presents a CSM for the Portland Harbor Site that draws on and synthesizes supporting information presented previously in this RI. Specifically, this includes the physical setting information detailed in Section 3, the source information presented in Section 4, the contaminant distributions across all media described in Section 5, the contaminant loading, fate and transport evaluations presented in Section 6, and finally, the human health and ecological risk assessments summarized in Sections 8 and 9, respectively.[1]

Section 10.1 presents a study area-wide overview of the physical setting; contaminant distribution in sediments; contamination sources identified to date; external loading and internal fate and transport mechanisms; and human health and ecological receptors, and exposure pathways and scenarios.

Section 10.2 is a CSM presentation for the specific indicator contaminants described in Section 5, consistent with USEPA (2005d) guidance. It includes a series of contaminant-specific maps of the study area's abiotic and biotic data sets that illustrate relationships between the observed contaminant distributions and known and likely historical and current sources and pathways. These displays are intended to provide a picture of the distribution, transport, and fate of contaminants in the study area across a range of physical, chemical, and biological processes, as well as potential sources.

The objective of this CSM is to illustrate our understanding of the sources and fate and transport mechanisms that determine the observed distribution of individual contaminants in affected abiotic and biotic media across the study area, based on the information and data collected, compiled, and evaluated in this RI.

10.1 SITE CONCEPTUALIZATION

A pictorial representation illustrating the major elements of the CSM (sources, pathways, fate and transport mechanisms, and human and ecological receptors) for the Portland Harbor study area is shown in Figure 10.1-1, while Figure 10.1-2 presents a graphical conceptualization of the sources, release mechanisms, transport media, and exposure media of the CSM. The detailed human health and ecological CSMs for the Portland Harbor Site are summarized in Appendix F, Figure 3-1 and Appendix G, Attachment 2, Figure 1 (also RI Section 9, Figure 9.6-1), respectively, and focus on exposure routes and receptor groups.

[1] Section 7 of this RI details the approach used to generate background concentrations for the site contaminants for use in the FS. This information is not summarized here in Section 10.

10.1.1 Physical Setting and Sediment Dynamics

The Portland Harbor study area (RM 1.9 to 11.8 of the Willamette River) is located at the downstream end of the lower Willamette River, which extends from the Willamette Falls at RM 26 to its convergence with Columbia River at RM 0. In its natural, undisturbed state, the study area reach was relatively shallow and meandering, surrounded by uplands, forested wetlands, and floodplains. Over the last century, much of the original riverbed has been dredged and the adjacent riverbanks have been filled, stabilized, and/or engineered for commercial, industrial, and marine operations with riprap, bulkheads, and overwater piers and docks. The extensive physical alteration and the associated anthropogenic activities as well as upstream river-stage control through the construction and management of dams, have resulted in a river reach that little resembles its pre-industrialized character in terms of hydrodynamics, sediment processes, and ecological habitat.

The effect of the multipurpose dams has been to dampen the flows during seasonal and storm events. The Columbia River also plays a role in the flow dynamics of the Willamette River. In spring, high flows in the Columbia River can increase the hydraulic head at the confluence causing the Willamette River to be detained and reduce flows until water levels drop in both river systems. Tidal action also compounds the hydrology and interplay of the two rivers, and affects the Willamette River upstream as far as Portland Harbor and beyond. These tidal fluctuations can result in short-term flow reversals (i.e., upstream flow) in Portland Harbor during times of extremely low river stage combined with a large variation in tide levels, which can occur in late summer to early fall.

Within the study area, there are distinct reaches that share similar hydrodynamic and sediment bed characteristics (see Section 3.1.5.2). Because of the affinity of both organic and inorganic contaminants to be associated with particulates, the transport and fate of sediments in the study area strongly affects the distribution of most contaminants. The primary factors controlling river flow dynamics, sediment deposition and erosion, and riverbed character appear to be the river cross-sectional area and navigation channel width. The upstream boundary of the study area to Willamette Falls is markedly narrower, more confined by bedrock outcrops, and faster flowing than the Portland Harbor reach. The river widens as it enters the study area and becomes increasing depositional, especially in the western portion of the river, until RM 7. From about RM 7 to 5, the river and navigation channel narrow, and this reach is dominated by higher energy environments with little deposition. From RM 5 to about RM 2, the river widens again and becomes depositional, especially in the eastern portion of the river. Immediately downstream of the study area, the river narrows as it turns and converges with the Columbia River. Multnomah Channel exits at RM 3, considerably reducing discharge to the Columbia River.

Sediment accumulation data from the sediment traps provides information on the mobile sediment loads at the site. Table 5.3-1 presents data showing that sediment accumulation rates in sediment traps placed throughout the site in 2006 and 2009 range

from less than 1 cm to approximately 69 cm per quarter. Of the 16 traps deployed in the fall of 2006, all 13 retreived in the winter of 2007 and 11 of the 16 retrieved in the fall of 2007 had accumulations exceeding 5 cm in the quarter the trap was deployed.

While much of this suspended load passes through the study area (see Section 6.2.1.3), long-term net sedimentation rates in the study area were estimated based on time-series bathymetric surveys and other lines of evidence (e.g., sediment accumulation in borrow pits). The measured riverbed elevation changes over the 7-year period from 2002 to 2009 illustrates a pattern of general shoaling in the relatively wide reaches from RM 7 to 10 and RM 2 to 5, and no change or scour in the higher energy, narrow reaches upstream of RM 10 and between RM 5 and 7 (Map 3.1-6) The maximum net sedimentation accumulation rates (exceeding 30 cm/yr in some places) occur in the navigation channel between RM 8 and 10 and in the upstream borrow pits at RM 10.5 and 10.9.

The western half of the navigation channel from RM 8 to 10 has historically required regular maintenance dredging. Bathymetric change data from 2002 to 2009 in the downstream channel shoaling area, which begins at RM 2.8 and extends downstream towards RM 1.5 showed a net maximum sediment accumulation rate of about 18 cm/yr at RM 2 over this 7-year time frame (Map 3.1-6). The decrease in net sedimentation rates between upstream and downstream channel shoaling areas is consistent with a single major source of sediments that enter the study area from upstream and settle out or are trapped in depressions and shoaling areas as they move downstream.

Bathymetric change data, SPI observations (SEA 2002b), and the radioisotope sampling (Anchor 2005b) data indicate that sediments do not generally accumulate in nearshore areas at the levels they do in the shoaling areas in the main channel. Nonetheless, many nearshore areas exhibit fine-grained sediment accumulation based on both bathymetric change data and SPI interpretation. The bathymetric change data (Map 3.1-6) shows that some nearshore areas (RM 2–3E, RM 4–5, RM 7–8, RM 8–9W) show net sedimentation rates of at least 4 cm/yr (total sediment accumulations exceeding 30 cm from 2002 to 2009). In other areas, such as RM 9-11E, areas within Swan Island Lagoon and Willamette Cove, RM 6-7W, and RM 5-7E, little net elevation change and/or small-scale scour was observed.

10.1.2 Contaminant Distribution

This section provides a brief overview of the overall distribution of contaminants in study area sediments. Based on examination of the contaminant distribution trends, some general patterns emerge among subsets of different contaminants that reflect study area fate and transport processes, as well as the relative importance of regional versus study area sources. These patterns are discussed below.

Sediment contaminant concentrations are greatest in nearshore areas. Concentrations of contaminants are generally higher in localized nearshore and off-

channel areas as compared to sediments in the navigation channel, Multnomah Channel, and downstream areas.

Organic contaminant concentrations are greater in subsurface sediments. Concentrations of organic contaminants tend to be higher in subsurface sediments than in surface sediments. Concentrations of total PCBs, DDx, total PAHs, hexachlorobenzene, total chlordanes, aldrin and dieldrin, gamma-HCH, lead, and TBT are higher in subsurface than in surface sediments, indicating that historical inputs were likely greater than current inputs. In contrast, arsenic, copper, chromium, mercury, and zinc do not have large concentration ranges and generally show similar levels in surface and subsurface sediments.

Regional inputs exhibit uniform concentrations across the area. Contaminants that may be derived predominantly from regional or upstream inputs show widespread surface sediment distributions without distinct, isolated areas of higher concentrations. Examples of this are arsenic, chromium, and mercury, which occur at relatively low concentrations throughout the study area, and no strong concentration gradients are apparent.

Areas of high concentrations are present throughout the study area and generally are associated with known upland sources. A number of contaminants exhibit relatively high sediment concentrations in distinct areas offshore of known or likely sources. These areas are separated by large areas with relatively lower concentrations lacking obvious concentration gradients. Contaminants that exhibit this trend include total PCBs, TCDD, BEHP, butylbenzyl phthalate, PCP, hexachlorobenzene, total chlordanes, gamma-HCH, copper, zinc, and TBT.

Some contaminants have areas of high concentrations that are more common in the lower (downstream) half of the study area. DDx and total PAHs exhibit elevated concentrations at locations adjacent to known upland sources. Concentrations of these contaminants are elevated relative to upstream concentrations.

Concentrations of certain metals are correlated to sediment grain size: A comparison of metals concentrations to the distributions of percent fines in the study area shows that where sediments are composed of less than 40 percent fines, chromium and copper concentrations are relatively low (above RM 10, between RM 5 and 7, and in the Multnomah Channel. A similar, but less pronounced, correspondence exists between sandy sediments and zinc concentrations.

Multiple contaminants co-occur: Several locations within the study area have relatively high surface sediment concentrations of more than one contaminant. Some of these areas and the co-occurring contaminants are as follows:

- **RM 11E:** total PCBs, total PCDD/Fs, DDx, chromium, copper
- **RM 9.7W:** total PCBs, total PCDD/Fs, BEHP, zinc
- **RM 8.7–9.3W:** total PCBs, total PCDD/Fs, total PAHs, total chlordanes, copper, mercury, nickel, zinc
- **RM 8.3W:** total PCBs, total PAHs, BEHP, total chlordanes, dieldrin, lead, copper
- **Swan Island Lagoon:** total PCBs, total PCDD/Fs, total PAHs, BEHP, total chlordanes, chromium, copper, zinc, TBT
- **RM 6.8–7.5W:** total PCDD/Fs, DDx
- **RM 6.7–6.8E:** total PCBs, total PCDD/Fs, copper
- **RM 5.6–5.7E:** total PCDD/Fs, total PAHs, total chlordanes, gamma-HCH, chromium, copper, lead, mercury, zinc,
- **RM 4.3–4.5E:** total PCBs, total PCDD/Fs, total PAHs, total chlordanes, zinc
- **International Slip:** total PCBs, total PCDD/Fs, total PAHs, BEHP, total chlordanes, chromium, copper, lead, zinc, TBT.

This degree of contaminant co-occurrence in specific study area locations reflects the history of upland site development, including wastewater and stormwater conveyance systems and industrial and commercial activities, as described in Section 4 and summarized in Section 10.1.3 below.

10.1.3 Site Sources

The following is a summary of information and the sources of that information presented in Section 4 on the nature of historical and current sources and associated pathways to the study area known thus far.[2]

10.1.3.1 Historical

Historical sources dating back to the early 1900s contributed to the majority of the observed contaminant distributions in sediments within the study area. This is reflected in the extent and degree of subsurface sediment contamination as discussed in the previous section. Nearly all the identified chemical pathways have a historical component.

[2] The source information presented in this Portland Harbor RI report is a compilation of public information available from site owners and operators and from DEQ, and is based upon information provided through September 2010, and DEQ's September 2010 Source Control Milestone Report. Detail regarding the origins and scope of the source control information is presented in Section 4. Source information will be updated in future DEQ Source Control documents.

In the early 1900s, rivers in the United States were generally used as open sewers, which was also true for the Willamette (Carter 2006). Untreated sewage, contaminated stormwater runoff from various land uses, as well as process water from a variety of industries, including slaughterhouses, lumber mills, paper mills, and food processors, was discharged directly into the river, as were pollutants from less conspicuous (non-point) sources, including agricultural fields, oil spills, rubber and oils, and garbage dumps. With the exception of manufactured gas operations and bulk fuel storage, which began in the late 1800s, most chemical manufacturing and use began in the 1930s.

Commercial and industrial development in Portland Harbor accelerated prior to World War I and again during World War II. These industrial operations and their associated COIs are discussed in more detail in Section 4 and summarized here:

- **Ship Building, Dismantling, and Repair.** VOCs, SVOCs, PAHs, PCBs, TPH, copper, zinc, chromium, lead, mercury, phthalates, and butyltins are common sediment contaminants associated with shipyards. Approximate areas of former shipyards include RM 4E, 5.6E, 7E, 7.4E, Swan Island, RM 9W, 10W, and 11E. Ship building continues at a much smaller scale in Portland Harbor today, with most work focused on ship maintenance and repair.
- **Wood Products and Wood Treating.** COIs typically associated with sawmills include metals, TPH, and PAHs. In addition to these COIs, plywood manufacturing could include VOCs and SVOCs, as well as possibly pesticides and fungicides (Eaton et al. 1949; USFS 1964; Moore and Loper 1980; Stellman 1998). Lumber mills and wood treatment facilities operated at various locations within the study area historically. McCormick and Baxter, a large wood-treating facility, was located at RM 6.9–7.2E. COIs associated with wood treatment include creosote/diesel oil mixtures, PCP, and a variety of water- and ammonia-based solutions containing arsenic, chromium, copper, and zinc (USEPA 2006d). PCP wood treatment products routinely contain dioxin/furans as contaminants, and these are an additional COI of wood treatment facilities (USEPA 2004a). Many other lumber mills and plywood manufacturers were found throughout the study area, including Linnton Plywood, St. Johns Lumber (which operated on the present-day Crawford Street and BES Water Pollution Control Laboratory sites), Kingston Lumber, and former mills in Willamette Cove.
- **Chemical Manufacturing and Distribution.** Chemical plants within the study area (RM 6.8–7.5W) that manufactured pesticides and herbicides were in place as early as 1941. Rhone Poulenc and Arkema were the two primary pesticide and herbicide manufacturers in this area. Several distributors of chemicals have existed at the Site, including Univar and Mt. Hood Chemical. COIs typically associated with these operations include pesticides, herbicides, VOCs, dioxins/furans, and metals (especially arsenic).

- **Metal Recycling, Production, and Fabrication.** Metal salvage and recycling facilities operated at RM 4E, 5.8W, 7.3W (Schnitzer-Doane Lake), 8.5W (Calbag/Acme), 8.9W (Gunderson – Former Schnitzer Steel auto dismantling), and 10W (Calbag) in the study area, and several scattered locations upriver. COIs commonly found in waste streams from metal recycling facilities include VOCs, TPH, PCBs, phthalates, cyanide, and a variety of metals. Metal production and fabrication currently takes place in the Burgard Industrial Park and several sites in the RM 8 to 10.3W reach. COIs associated with metal production and fabrication include metals, PAHs, and TPH. Hydraulic oil with PCBs was often used for high-temperature applications such as die-casting machines. Metal plating also has occurred at a few locations in the study area, including Columbia American Plating at RM 9.5W. COIs associated with metal plating activities include VOCs, PAHs, TPH, cyanide, and several metals.
- **Manufactured Gas Production.** Manufactured gas production operations took place between 1913 and 1956 at Portland Gas & Coke (RM 6.2W). The Pintsch Compressing Company Gas Works operated between 1890 and the mid-1930s at RM 7.3W and manufactured compressed gas from crude oil for railroad train lighting. Prior to 1913, gas production also occurred just upstream of the study area at the Portland MGP site at RM 12.2E. COIs associated with manufactured gas operations include VOCs, SVOCs, TPH, PAHs, metals, and cyanide.
- **Electrical Production and Distribution.** Electrical transformers and capacitors are associated with all of the major industries in the harbor. Some of these transformers and capacitors may contain PCBs. Seven current and one historical substation are found in the study area. Transformer repair, servicing, and salvaging operations were found on the east bank from RM 11.3 to 11.5 (Tucker Building, Westinghouse, and PacifiCorp Albina Properties), at RM 3.7W (ACF Industries), RM 9.5E (Portable Equipment Salvage), RM 9.5W (GE Decommissioning), and the GE facility at NW 28th Ave (TSCA site). COIs linked with these types of operations include PAHs, TPH, and PCBs.
- **Bulk Fuel Distribution and Storage and Asphalt Manufacturing.** Bulk fuel facilities have a long history in Portland Harbor. By 1936, most of the facilities currently in place had been established between RM 4 and 8 on the west side of the river. COIs typically associated with bulk fuel storage operations include VOCs, SVOCs, PAHs, TPH, and metals.
- **Steel Mills, Smelters, and Foundries.** Several foundries were located within the study area, at RM 11.4W (Gender Machine Works), RM 9.7W (Schmitt Forge), and RM 2.7E (Consolidated Metco). Smelters were located at RM 7.2W (Gould), RM 9W (National Lead/Magnus Smelter), and RM 11.6W (RiverTec Property). Steel mills are or were located at RM 2.4E (Evraz, aka Oregon Steel Mill) and at RM 8.3W (former Oregon Steel Mill operation at Front Ave LP). COIs associated with these types of operations include metals, TPH, PCBs, and PAHs. PCBs were a component of hydraulic fluid for high temperature applications (machining and die casting) where fire resistance was important,

and were also a component of heat transfer fluid used in applications like heat exchangers and recirculating cooling systems.

- **Commodities Maritime Shipping and Associated Marine Operations.** In addition to the Port of Portland's large presence in Portland Harbor with three deep-water terminals committed to import/export, currently there are or have been several other commodity shipping facilities in the harbor (Map 3.2-20). These include the grain handling operations at CLD Pacific Grain (RM 11.4E) and Centennial Mills (RM 11.3W), edible oils at the former Premier Edible Oils facility (RM 3.6E), scrap metal export at International Terminals (RM 3.7E), cement import and distribution at Glacier NW (RM 11.3E), anhydrous ammonia and solid and granular urea at JR Simplot in the South Rivergate Industrial Park (RM 3E), and alumina, electrode binder pitch, and grain at the former Goldendale Aluminum property (RM 10E). Supporting maritime activities include overwater tug and barge moorage, maintenance and repair facilities, overwater bunkering and lightering, tug-assisted and independent maneuvering of vessels in and around marine facilities, and stevedoring (loading and discharging) product at vessels. Incidental spills into the river from commodities maritime shipping include organic materials, VOCs, PAHs, and TPH.
- **Rail Yards.** Rail yard and freight car repair facilities operated at several locations within the study area. Active facilities are located at approximately RM 9.8 to 11.1E (UPRR Albina Yard), RM 8.6 to 9.5W (PTRR Guilds Lake Yard), and RM 4.8E (UPRR – St. Johns Tank Farm). Historical rail yard operations were located at and around RM 11.6W (BNSF Hoyt Street Railyard, and UPRR Union Station operations). Historical rail car maintenance operations were located at RM 3.6 (ACF Industries). Dependent on the activities conducted, COIs could include VOCs, SVOCs, TPH, PCBs, and metals.

Contaminant migration to in-water media occurs through several migration pathways, including stormwater, industrial wastewater, overland flow, groundwater, bank erosion, and overwater releases. Contaminated surface soils in upland areas and along riverbanks can be carried directly to the river as riverbank erosion and in stormwater runoff, particularly during high flows and floods. In some locations, contaminated dredged material may have been placed in low-lying areas subject to erosion. While the quality of this fill material is generally undocumented, because of the history of sediment contamination from industrial and maritime sources, contaminated sediment could have been included in fill material.

Migration of contaminants from upland areas to the river via groundwater is a historical source of contamination to the river at a limited number of upland sites within the study area. At a subset of these sites, the historical groundwater pathway has contributed significant loading of upland contaminants to sediment and TZW. While some complete historical groundwater transport pathways have been mitigated or eliminated

through source control actions, others remain complete, as identified in Section 10.1.3.2 below.

Overwater releases were likely common occurrences at industries that relied on maritime shipping and located on the banks of the Willamette River, and are likely important historical contributors to in-water contamination. However, prior to the relatively recent enactment of reporting requirements, overwater spills were generally undocumented.

Upstream sources also contributed to the historical contamination of the lower Willamette River. These sources included sewerage, stormwater runoff, and direct discharge of industrial wastes from upstream cities, towns, and industrial areas; agricultural runoff; and aerial deposition on the water surface and drainage areas within the Willamette Valley.

10.1.3.2 Current

Operations that continue to exist today include bulk fuel storage, barge building, ship repair, automobile scrapping, recycling, steel manufacturing, cement manufacturing, transformer reconditioning, operation and repair of electrical transformers (including electrical substations), and many smaller industrial operations. Locations of both current and historical major industrial operations in Portland Harbor are presented on Map 3.2-10 and Maps 3.2-13 through 3.2-21.

Stormwater and wastewater discharges are regulated and permitted for many of the sites adjacent to the study area. However, sampling for RI-related chemicals in stormwater and catch basins only began in recent years and, for the most part, has only been done for those facilities that have voluntarily conducted a stormwater source control evaluation. With the construction of stormwater treatment systems and wastewater treatment systems over the years, overland transport has been largely abated at most sites. A current likely complete overland transport pathway has been identified at very few sites.

Current known complete or likely complete groundwater pathways have been identified at 11 sites, 51 sites have insufficient data to make a determination, and 58 sites have been identified as not having a complete pathway. The groundwater pathway assessment conducted during the RI consisted of detailed groundwater discharge and TZW sampling at nine high priority sites. Based on these efforts, a current complete groundwater pathway with influence on TZW and sediment chemistry was confirmed at four sites, groundwater migration was found to have no significant influence at four other sites, and groundwater effects could not be determined at one site (see Appendix C2).

Riverbank erosion from contaminated and unstabilized bank areas may represent an ongoing release mechanism in the study area. Currently, about 75 percent of the riverbanks within the study area are stabilized and armored with various materials,

including seawalls, riprap, and engineered and non-engineered soil. Known or likely complete riverbank pathways have been identified at a few sites with unstabilized banks.

The activities most commonly associated with current overwater spills in the study area are product handling, overwater activities such as refueling, and spills from vessels. Overwater releases are likely important contributors to in-water contamination at sites that have long histories of overwater operations and product transfers. Spill records collected over the past approximately 30 years do not generally record large releases, but there have been some exceptions.

DEQ's JSCS program focuses on the abatement of current and threatened future releases of contaminants to the study area. The current status of that program is summarized in Section 4.4.7.

As with historical sources, current upriver sources also play a role in the contaminant distribution in the lower Willamette River. Current upstream loading is discussed in the following section.

10.1.4 Loading, Fate and Transport

This section summarizes the information detailed in Section 6 of the RI on contaminant mass inputs and internal mass transfer mechanisms within the study area on a site-wide basis. A comparison of the relative magnitude of these terms is presented for each indicator contaminant in Section 10.2. External loads include upstream loading via surface water and sediment bedload, stormwater, permitted industrial discharges, upland groundwater transport, atmospheric deposition, upland soil and riverbank erosion, groundwater advection through subsurface sediments, and overwater releases.

Upstream loading represents the largest current contaminant loading term for the studyarea. While upstream surface water and suspended sediment concentrations are typically lower than those measured in the study area, the very large flow volume of the river compared to the flow volumes for the other loading terms results in a relatively large mass load of contaminants compared to other current sources. With the exception of total PAHs and TBT, upstream loading is greater than other loading terms by 1 to 3 orders of magnitude for all of the indicator contaminants. Estimated flow volumes used for the various loading terms are presented on Figure 10.1-3.

Stormwater runoff is the second largest quantified annual external loading term to the study area for all indicator chemicals except total PAHs and arsenic (dioxins/furans and TBT were not sampled in stormwater). Loading from CSO discharges is also a factor. Contaminants present in stormwater runoff are transported mostly via conveyance systems and discharged through numerous outfalls along the river shoreline within the study area. Overland flow of stormwater to the river also occurs in some relatively limited areas.

The other external loading mechanisms (permitted discharges, groundwater transport, atmospheric deposition, direct upland soil and riverbank erosion, groundwater advection through subsurface sediments, and overwater releases) are generally lower in magnitude than the upstream and stormwater loading. Where notable, the other mechanisms are discussed on a contaminant-specific basis in Section 10.2

Internal transfer mechanisms involve the transport of contaminant mass from one media to another within the study area, but do not add new contaminant mass to the study area. Internal fate and transport mechanisms include sediment resuspension, transport, and deposition, solid/aqueous-phase partitioning, abiotic/biotic transformation and degradation, biological uptake and depuration, and partitioning from surface sediment to surface water. Due to the hydrophobic nature of most of the organic contaminants found in the study area, they tend to preferentially partition to the dissolved and particulate organic matter.

Lateral and vertical movement of chemicals in surface water occurs primarily as a result of turbulent (eddy) dispersion (mechanical mixing). Higher flow velocities typically cause greater mixing and increased transport of suspended and bedload sediments. Relevant processes that influence sediment transport include deposition, erosion/resuspension, mixed-layer turbation, long-term burial, and ingestion/uptake by biota. The relative significance of these transport and fate mechanisms varies by contaminant, depending on physical/chemical properties specific to each contaminant. A potentially important mass transfer mechanism is surface sediment resuspension and movement of contaminants from bedded sediment to the water column with a resultant increase in mobility and bioavailability. Degradation processes relevant for transformation and degradation of contaminants in the study area include oxidation/reduction, hydrolysis, dehalogenation, volatilization (primarily from dissolved phase in surface water), and photolysis (primarily in upper levels of surface water). Biodegradation involves the metabolic oxidation or reduction of organic compounds and is carried out predominantly by bacteria in aqueous environments.

Finally, a number of processes govern how organisms living in the study area are exposed to contaminants and how contaminants are transformed, excreted, or stored in tissue. Organisms living in the study area may bioaccumulate contaminants through physical, chemical, and biological processes, including transfer of water-borne contaminants across gill structures or other tissues, ingestion of sediment, or consumption of prey, which may increase relative tissue concentrations at progressively higher trophic levels in the food chain. Contaminant burden in body tissues is mediated through growth, reproduction, excretion, metabolic transformation, or sequestration.

10.1.5 Human and Ecological Receptors, Exposure Pathways, and Summary of Site Risks

People interact with the river in a number of ways. Portland Harbor is a major industrial water corridor and working harbor, and the majority of the study area waterfront is currently zoned for industrial land use (City of Portland 2006b). The

study area also contains some natural areas and provides recreational opportunities, both on the water and along the riverbanks, including boat ramps, beaches, and waterfront parks. Recreational and subsistence fishing is conducted in the lower Willamette River basin, including the study area, both by boaters and from shore. The extent to which commercial fishing occurs within the study area is not known, but it is presumed to be negligible. For Native American anglers, the Willamette River provides a ceremonial and subsistence fishery for Pacific lamprey and spring Chinook salmon. There is also documented evidence of transients camping along the river for extended periods of time.

Currently or potentially exposed populations were identified based on consideration of both current and potential future uses of the study area, and include populations who may be exposed to contamination though a variety of activities. The specific populations and exposure pathways evaluated were:

- Dockside workers—Direct exposure via incidental ingestion and dermal contact with beach sediments.
- In-water workers—Direct exposure to in-water sediment.
- Transients—Direct exposure to beach sediment, surface water for bathing and drinking water scenarios, and groundwater seeps.
- Recreational beach users—Direct exposure to beach sediment and surface water while swimming.
- Tribal fishers—Direct exposure to beach or in-water sediments, and consumption of migratory and resident fish.
- Recreational and subsistence fishers—Direct exposure to beach or in-water sediments, consumption of resident fish, and consumption of shellfish.
- Divers—Direct exposure to in-water sediment and surface water.
- Domestic water user—Direct exposure to untreated surface water potentially used as a drinking water source in the future.
- Infants—Consumption of human breast milk.

The presence of uncertainty is inherent in the risk assessment process, and USEPA policy calls for numerical risk estimates to always be accompanied by descriptive information regarding the uncertainties of each step in the risk assessment to ensure an objective and balanced characterization of the true risks and hazards. Additionally, it is important to note that the risks presented here are based on numerous conservative assumptions in order to be protective of human health and to ensure that the risks presented are more likely to be overestimated rather than underestimated. A detailed analysis of the uncertainties associated with the BHHRA is found in Section 6 of Appendix F.

The major findings of the BHHRA are:

- Estimated cancer risks resulting from the consumption of fish or shellfish are generally orders of magnitude higher than risk resulting from direct contact with sediment and surface water. Risks and noncancer hazards from fish and shellfish consumption exceed the USEPA point of departure for cancer risk of 1×10^{-4} and target HI of 1 when evaluated on a harbor-wide basis, and when evaluated on the smaller spatial scale by river mile. Consumption of resident fish species consistently results in the greatest risk estimates. Evaluated harbor-wide, the estimated RME cancer risks are 4×10^{-3} and 1×10^{-2} for recreational and subsistence fishers, respectively.
- Noncancer hazard estimates for consumption of resident fish species are greater than 1 at all river miles. Based on a harbor-wide evaluation of noncancer risk, the estimated RME HI is 300 and 1,000 for recreational and subsistence fisher, respectively. The highest hazard estimates for recreational fishers are at RM 4, RM 7, RM 11, and in Swan Island Lagoon.

  The highest noncancer hazards are associated with nursing infants whose mothers consume resident fish from Portland Harbor. When resident fish consumption is evaluated on a harbor-wide basis, the estimated RME HI is 4,000 and 10,000 for breastfed infants of recreational and subsistence fishers, respectively. Evaluated on a harbor-wide scale, the estimated RME HI for tribal consumers of migratory and resident fish is 600 assuming fillet-only consumption, and 800 assuming whole-body consumption. The corresponding HI estimates for nursing infants of mothers, who consume fish, are 8,000 and 9,000 respectively, assuming maternal consumption of fillet or whole-body fish.
- PCBs are the primary contributor to risk from fish consumption harbor-wide. When evaluated on a river mile scale, dioxins/furans are a secondary contributor to the overall risk and hazard estimates, particularly at RM 6 and 7. PCBs are the primary contributors to the noncancer hazard to nursing infants, primarily because of the bioaccumulative properties of PCBs and the susceptibility of infants to the developmental effects associated with exposure to PCBs.

Ecological habitat is affected by the fact that the majority of the study area is industrialized, with modified shoreline and nearshore areas (e.g., wharfs, piers extending out toward the channel, bulkheads, and riprap-armored banks). The federal navigation channel has less habitat diversity than the shallow, nearshore areas, but this is consistent with river systems generally. Some segments of the study area are more complex, with small embayments, shallow water areas, gently sloped beaches, localized small wood accumulations, and less shoreline development, providing some habitat for a suite of local fauna. Riparian, shallow-water, and vegetated habitats are limited to the nearshore area or shoreline, and are much less extensive.

Organisms that use the lower Willamette River include invertebrates, fishes, birds, mammals, amphibians, reptiles, and aquatic plants. Each group contributes to the

ecological function of the river based on trophic level, abundance, biomass, and interaction with the physical-chemical environment and other species. The lower Willamette River is an important migration corridor for anadromous fish, such as salmon and lamprey, and provides habitat for numerous resident fish species (more than 40 species have been collected in many historical and recent studies) that represent four feeding guilds: herbivores/omnivores, invertivores (either from the water column or bottom habitats), piscivores, and detritivores.

Habitat in the study area is limited for aquatic-dependent mammals because of past human modification of riparian habitats. The upland environment near the lower Willamette River is primarily urban, with fragmented areas of riparian forest, wetlands, and associated upland forests. Numerous aquatic and shorebird species, such as cormorants and spotted sandpipers, use the habitats, where available, in the study area.

The following complete and significant exposure pathways were quantitatively evaluated in the BERA using multiple lines of evidence:

- **Benthic invertebrates**—Direct contact with sediment and surface water, ingestion of biota and sediment, and direct contact with shallow TZW
- **Fish**—Direct contact with surface water, direct contact with sediment (for benthic fish receptors), ingestion of biota, incidental ingestion of sediment, and direct contact with shallow TZW (for benthic fish receptors)
- **Birds and mammals**—Ingestion of biota and incidental ingestion of sediment
- **Amphibians and aquatic plants**—Direct contact with surface water and shallow TZW.

The following presents the primary conclusions of the BERA:

- In total, 93 contaminants (as individual contaminants, sums, or totals) pose potentially unacceptable ecological risk. The list can be condensed if individual PCB, DDx, and PAH compounds or groups are condensed into three comprehensive groups: total PCBs, DDx, and total PAHs. Doing so reduces the number of contaminants posing potentially unacceptable risks to 66.
- Risks to benthic invertebrates are clustered in 17 benthic areas of concern.
- Sediment and TZW samples with the highest HQs for many contaminants also tend to be clustered in areas with the greatest benthic invertebrate toxicity.
- COPCs in sediment that are most commonly spatially associated with locations of potentially unacceptable risk to the benthic community or populations are PAHs and DDx compounds.
- The most ecologically significant contaminants are PCBs, PAHs, dioxins and furans (as TEQ), and DDT and its metabolites. PAHs and DDx risks are largely

limited to benthic invertebrates and other sediment-associated receptors. PCBs tend to pose their largest ecological risks to mammals and birds.

- The combined toxicity of dioxins/furans and dioxin-like PCBs, expressed as total TEQ, poses the potential risk of reduced reproductive success in mink, river otter, spotted sandpiper, bald eagle, and osprey. The PCB TEQ fraction of the total TEQ is responsible for the majority of total TEQ exposure, but the total dioxin/furan TEQ fraction also exceeds its TRV in some locations of the study area.

10.2 CHEMICAL-SPECIFIC CONCEPTUAL SITE MODELS

The CSMs for the 13 indicator contaminants are presented in the following sections. Each discussion includes a brief presentation of contaminant distribution; potential sources and pathways; and loading, fate, and transport. For each CSM, a three-section panel series is provided that presents cross-media contaminant distributions and available source information and presents a subset of the contaminant distribution data. An electronic version of the three-section CSM panels is included in Appendix I.

Panel A presents summary information on the observed concentrations in surface sediment (using Thiessen polygons to spatially represent concentrations between data points), sediment traps, riparian soil/sediment, surface water, and TZW from RM 1.9 to 11.8, excluding dredge and cap sample locations. A histogram of the surface sediment data is included in the top left-hand corner of each panel to show the distribution of the data. Unfiltered push probe, filtered push probe, and peeper results are displayed for TZW. Surface water XAD data are presented for total PCBs, dioxins/furans, DDx, total PAHs, total chlordanes, aldrin, and dieldrin. Surface water peristaltic pump data are presented for arsenic, chromium, copper, zinc, and TBT. The BEHP data presented are a combination of the XAD and peristaltic pump data.

Panel B presents a summary of subsurface sediment concentrations and large-scale (>30 cm) erosional/depositional areas predicted for a major flood based on the FS HST model for the study area (Chen 2011, pers. comm.). Thiessen polygons on these panels represent concentrations in the sediment interval just below the surface sediment (typically the B interval). A histogram of the subsurface sediment data is included in the top left-hand corner of each panel. Also included are icons depicting the locations of 10 major types of historical industries that are or were active in the study area.

In addition to the erosional/depositional information shown on Panel B, Map 10.2-1 shows areas in the study area at risk for surface sediment disturbance from incidental anthropogenic activities based on water depth and in-water operations. This includes all areas above the –5 ft NAVD88 contour that are potentially subject to boat wakes, areas in the immediate vicinity of docks and berths, and any additional areas where sediment scour that did not appear to be due to natural forces was evident in the 2002–2009

bathymetric time-series data set.[3] This map does not include an analysis of those activities that are specifically intended to move sediments (shoreline/structure construction, maintenance dredging, or remedial capping/dredging).

Panel C presents whole-body concentrations in field-collected smallmouth bass, clams, crayfish, and sculpin. A detailed view of the composite groupings can be found on Map 2.1-7a–d.

For each upland site that has undergone sufficient investigation to identify known or likely complete pathways, a box is shown on the panels listing the applicable pathways and noting whether they are complete or likely complete. Where there are insufficient data to make a determination or when a complete pathway was determined to be not present (see Tables 10.2-1through 10.2-13), no information is presented.

Along with the panels, three figures are provided for each CSM chemical to portray loading, fate, and transport processes under current conditions in the study area.[4] The first figure consists of a set of box and whisker plots—an initial plot comparing the range of the estimated external and internal annual loads to the study area for each of the loading terms quantified for a given CSM contaminant, followed by a pair of plots comparing the concentrations of the chemical in surface sediment, sediment traps, and suspended solids in surface water for the entire study area. The second figure is a box-and-arrow diagram[5] depicting relevant loading, fate, and transport processes for each CSM chemical at the study area scale. The third figure provides a graphical comparison, by river mile, of the quantified external and internal loading terms, including central, upper, and lower estimates, and affords additional resolution of spatial patterns in loading to the study area.

As documented in Section 6.1 and Appendix E, external loading of each CSM contaminant to the study area was estimated quantitatively for upstream surface water,[6] stormwater, atmospheric deposition to the water surface, and groundwater advection through subsurface sediments. Quantitative estimates were also generated for upland groundwater plumes and permitted point-source discharges for a subset of the CSM contaminants for which these terms may be significant. Unquantified loading terms,

[3] Map 10.2-1 is a qualitative presentation of areas where there is a reason to believe that anthropogenic disturbance risk may be relatively higher than other areas.

[4] Includes surface water and bedded sediments in the surface mixed layer (0–40 cm bml).

[5] This diagram does not attempt a mass balance because sufficient data are not available and because of the varying levels of quantification (qualitative to quantitative) of each term.

[6] As discussed in Section 6.1, estimated upstream surface water loads were developed using data from both RM 11 and RM 16. Because of the complex hydrodynamics on the lower Willamette River between its confluence with the Columbia River (RM 0) and the entrance to Multnomah Channel at RM 3 (frequent flow reversals, see Section 3.1.4.3), surface water chemical loads leaving the Study Area at RM 1.9 could not be estimated using the simplified approach described in Section 6.1. The furthest downstream surface water loads for the lower Willamette River were estimated at RM 4. Surface water loads exiting the Study Area via Multnomah Channel were also estimated.

including bedload, volatilization, and riverbank erosion, are represented qualitatively on the box-and-arrow diagrams. The only contaminant fate and transport mechanism internal to the study area for which quantitative estimates were developed in the RI is pore water advection from surface sediment to the overlying surface water column. Other internal fate and transport mechanisms, including sediment erosion, sediment deposition, sediment burial, and biological and geochemical transformation (degradation) are represented qualitatively on the box-and-arrow diagrams.

10.2.1 Total PCBs

The study area graphical CSM for PCBs is presented on Panels 10.2-1A–C. PCBs are a class of nonpolar, synthetic, halogenated hydrocarbons that were manufactured in the United States between 1929 and 1977 and widely used for a variety of purposes. Current allowed uses include transformers, heat transfer systems, natural gas pipelines, existing carbonless copy paper, and electrical switches. Historical PCB uses included dielectric fluids in transformers and capacitors, electrical cables, cutting oils, hydraulic oils, lubricants, heat transfer fluids, plasticizers, flame retardants, additives to pesticides, paints, carbonless copy paper, caulk, adhesives, sealants, in heat transfer systems, electromagnets, and for dust suppression. PCB sources in waste materials include scrap metal recycling, auto salvage, used oil, recycled paper, asphalt roofing materials, building demolition, and in the repair and salvaging of ships, locomotives, heavy equipment, and manufacturing equipment. Although PCBs are ubiquitous in the environment, commercial PCB production in the United States ended in 1977. Consequently, most of the mass of PCBs found in the study area sediments is primarily derived from historical sources. In addition, secondary sources may introduce PCBs to the lower Willamette River through a variety of environmental pathways as described in Section 10.2.1.2

Although PCBs do degrade in the environment (e.g., by reductive dehalogenation), they are persistent. PCBs are hydrophobic/lipophilic organic substances that accumulate in organisms both by uptake from the environment over time (bioaccumulation) and along the food chain (Erickson 1997). PCBs biomagnify with each trophic level in the food web (biomagnification). In aquatic organisms, the rate and physiological mechanism of PCB metabolism depend on the species and the specific type of PCB.

10.2.1.1 Total PCBs Contaminant Distribution

On a harbor-wide basis, the highest PCB sediment concentrations occur in nearshore areas and in locations proximal to local upland sources (Maps 5.2-3a-hh and Panels 10.2-1A–B). Relatively high concentrations of PCBs are also often found in riparian sediments, sediment trap samples, surface waters, and biota samples in the areas with elevated sediment concentrations.

Similar spatial and concentration trends are observed in subsurface sediments (Panel 10.2-1B). Areas where surface and subsurface concentrations are not well correlated may be an indication of spatially and temporally variable inputs and sources, or to different influences from sediment transport mechanisms. Areas where the highest

concentrations of PCBs in sediment are observed include RM 11.3E, RM 8.8-10W, Swan Island Lagoon, International Slip (RM 3.7-3.8E), RM 2.1-2.5E, and RM 4.0–4.1E. Total PCBs concentrations are generally higher in subsurface sediments (Panels 10.2-1A–B, Maps 5.2-3a-hh, and Figure 5.2-3), pointing to predominantly historical total PCBs sources and higher past loads.

Exceptions to the pattern of higher concentrations at depth are found at RM 11.3E, in Willamette Cove, and in Swan Island Lagoon. PCB concentrations in the area of RM 11.3 are greater in surface than subsurface samples along the eastern nearshore area and adjacent channel edge. The nearshore sediment PCB distribution, as well as the collocated surface water and sediment trap data, indicate a local, recent input and/or redistribution of PCBs historically released into this area and present in the sediments. Anthropogenic sediment disturbance in this area also may have altered the distribution of PCBs with depth in the sediment column and re-exposed and re-mobilized subsurface contamination.

Collocated surface and subsurface samples from the inner portion of Willamette Cove also exhibit higher surface PCB concentrations than at depth, which may be indicative of higher recent inputs. Finally, in Swan Island Lagoon, mean surface and subsurface total PCBs concentrations are approximately the same. The lack of a vertical gradient may reflect a combination of time-varying inputs, low net sedimentation rates, and localized high surface sediment mixing rates that result in variable spatial trends in sediment quality with depth.

Relatively high concentrations of PCBs in surface water are generally found in areas with elevated sediment concentrations. The highest total PCB concentrations were associated with single-point samples in Willamette Cove and at RM 5.5. Total PCB concentrations at RM 11 were consistently higher than at RM 16, suggesting a source or sources between these locations. Aside from these exceptions, the range of total PCB concentrations within the study aea surface water was fairly consistent.

Total PCB congener concentrations in the study area sediment trap samples were 1- to 5-fold greater than upstream concentrations. These trends were also reflected in the Aroclor data. Downstream total PCB concentrations are similar to concentrations observed in Multnomah Channel and the upriver reach. The concentrations entering the site, at least in the western nearshore region, are similar in concentration to the upriver sediment traps for the time periods measured. However, the concentrations entering the eastern nearshore region sediments may be more influenced by sources immediately upriver in the downtown reach.

The highest concentrations of PCBs in the study area were typically found in biota samples from areas with high sediment concentrations, for example RM 2.2E to 2.4E, International Slip, RM 4.0E to 4.1E, Willamette Cove, Swan Island Lagoon, and near OF 44 and OF 43 near RM 11.2E.

Spatial variations in PCB composition (based on congener data) are evident throughout the study area, and areas of elevated PCB sediment concentrations often exhibit congener homolog patterns that are distinct from surrounding areas of lower PCB concentrations (Appendix D1, Maps D1.5-1 and D1.5-2; Figures D1.5-2a-c and D1.5-3a-c). PCB homolog patterns in surface and subsurface sediment, sediment traps, and in the particulate portion of the surface water samples, are often similar within each area. Subsurface sediment patterns are less consistent with surface sediment homolog patterns for the areas at RM 6.9 to 7.5W and RM 2.1 to 2.5E when compared other contaminated locations.

Relatively low concentrations of PCBs are widespread in portions of the harbor away from the localized areas of elevated concentrations (Panel 10.2-1A and Map 5.2-2). The homolog patterns in these widespread, low level PCB areas are generally similar in both depositional and erosional areas, have less distinct variations than areas of higher concentration, and may reflect inputs from upstream and transport within the study area.

10.2.1.2 Potential PCB Sources and Pathways

Numerous upland sites have been identified as being known or likely historical and/or current sources of PCBs. These sites discharge directly to the river or discharge through shared conveyance systems (Table 4.4-3). Historical and current known or likely complete pathways for PCBs in stormwater have been identified at several properties associated with former shipyards and sites where transformers were serviced and/or dismantled. Historical wastewater discharges associated with ship building and decommissioning, electrical component manufacturing, and leaks and spills from equipment that used fluids that may have contained PCBs are likely, but have not been specifically identified or quantified. Wastewater discharges are currently regulated primarily through NPDES permits.

Potential upland and overwater sources and identified known and likely complete migration pathways are identified on Table 10.2-1 and Panels 10.2-1A–C. These sources and pathways, identified on the basis of the process described in Section 4.2, focus on ECSI sites and are based on a review of information in the associated DEQ ECSI files and other readily available site information, including, in the case of LWG-member sites, information provided by the site owner.

The most significant migration pathways for PCBs in the study area are historical and included industrial wastewater, stormwater, overland transport, overwater releases, and riverbank erosion (Table 10.2-1). Atmospheric deposition and upstream inputs may have also contributed PCBs to the study area; the releases from these pathways are not quantifiable and are difficult to distinguish.

Stormwater PCB loads have decreased substantially from historical levels since implementation of stormwater controls and the statutory ban on PCB manufacture in the 1970s. Overland transport was likely more important prior to the development of extensive stormwater conveyance systems. Bank erosion is also likely more important

when PCBs were in wider use, or when contaminated material was used in construction fill activities. Historical PCB overwater releases have not been identified through the file review process, but are likely to have occurred in association with overwater operations, such as ship building and dismantling, ship repair and maintenance, and with the use of hydraulic fluids in dock operations. The locations of elevated PCB concentrations in sediments coincide in some cases with ship construction, dismantling, and repair operations, and it is likely that overwater releases occurred concurrently as a result of historical activities in these locations. PCBs are also detected in sediments near outfalls draining facilities historically engaged in electrical equipment manufacturing, such as at RM 11.3E and at OF-17. Stormwater discharges and riverbank erosion associated with fill soil from offsite and/or steel manufacturing activities at RM 2E have also resulted in PCB contamination in sediments.

Current PCB inputs to the study area are lower than historical inputs. However, measured elevated levels of PCB concentrations in surface sediments and other media, including biota in the International Slip and Swan Island Lagoon, indicate ongoing localized inputs and/or internal mass transfer of historical PCB inventory from subsurface to surface sediments and then to other media by processes such as sediment resuspension (due to both natural and anthropogenic disturbance factors) and biological uptake. While surface sediments generally exhibit lower PCB concentrations than subsurface sediments, the temporal persistence of elevated PCB levels in surface sediments in many nearshore and off-channel areas suggests that net sedimentation rates may be low in many nearshore areas. This is supported by the bathymetric change data and the limited radioisotope data from the study area (Anchor 2005b); sediment column mixing rates are high, and inputs of PCBs still occur. Potentially important current pathways include stormwater and riverbank erosion. The effects of current releases and these physical site features are expressed in surface sediment concentrations (Panel 10.2-1A).

Known or likely complete historical pathways for PCBs have been identified at 40 sites, and include stormwater (38 sites), overland transport and riverbank erosion (6 sites), and overwater releases (1 site). Current known or likely complete pathways for PCBs have been identified at 18 sites, and include stormwater (16 sites), overland transport (2 sites), riverbank erosion (3 sites), and groundwater transport (1 site). Historical and current sources are presented in Table 10.2-1 and Panels 10.2-1A–C.

10.2.1.3 Loading, Fate, and Transport of PCBs

PCB loading, fate, and transport in a typical year for the study area is summarized on Figures 10.2-1a-b, 10.2-2, and 10.2-3. Estimates are for current conditions and likely differed historically. Much of the PCB mass in the study area, especially in deeper sediments, is attributable to historical loading that occurred under different loading conditions and rates.

Upstream surface water represents the largest estimated current loading term for PCBs to the study area (Figures 10.2-1a and 10.2-2), and is associated with both the dissolved

and suspended fractions. On an annually averaged basis, the majority of this load occurs during low-flow conditions (Figure 6.1-2), which exist for approximately two-thirds of the year. Surface water samples collected during high-flow consistently exhibited lower concentrations of PCBs than in low-flow samples, indicating that inflow concentrations at high flow rates have greater influence than local effects. Total PCB concentrations in sediments accumulating in upstream borrow pits, which are likely a mixture of upstream bedload and suspended load, are comparable to the upriver bedded sediment background concentrations.

PCB loads in surface water increase between the upstream and downstream boundaries of the study area in both the particulate and dissolved fractions, and is in part attributable to quantified external loads (stormwater, atmospheric deposition, and advection through subsurface sediments). Other possible reasons for the increased loading are due to internal fate and transport processes such as sediment resuspension, which have not been quantified. The distribution of total PCBs in surface sediments, sediment trap samples, and the particulate fraction of surface water samples, on both a dry-weight and OC-normalized basis, is presented on Figure 10.2-1b.

Estimates of current PCB loading via stormwater are approximately half the estimated upstream load, atmospheric deposition directly to the study area river surface is nearly an order of magnitude lower than the upstream surface water load (Figure 10.2-2). PCBs were detected in stormwater in Round 3A and 3B sampling in each land use area sampled (see Section 6.1.2.3). Groundwater advection through subsurface sediments is estimated the least significant of the quantified terms, but is subject to a relatively high degree of uncertainty due to the variability in published organic-carbon partitioning values for PCBs. As discussed in Section 6.1.1.2, bedload into- and out of the study area is expected to be low relative to dissolved and particulate surface water loading. PCB volatilization from the water column is relevant for only a small fraction of the less chlorinated PCB congeners and is also expected to be low.

Fate and transport processes internal to the study area for total PCBs are shown on Figure 10.2-2. PCB transport to the water column due to pore water advection through surface sediments is the only process for which quantitative estimates were developed, and is estimated to be similar in magnitude to the subsurface advective loading. Other internal fate and transport processes are depicted on Figure 10.2-2 on a qualitative basis only. Sediment erosion, deposition, and burial are a function of locally and temporally variable hydrodynamic conditions and the surface sediment mixing rate. PCB partitioning between suspended sediment and surface water depends on the relative concentrations associated with suspended particulate organic carbon and the dissolved surface water fraction, as well as reaction kinetics. The fate of PCBs within the study area may also be influenced by relatively slow microbially facilitated degradation and photolysis.

PCB loads from upland groundwater plumes are not expected to be significant and estimates were not generated. Loading from permitted point source discharges were not

estimated because PCBs are not regulated and monitored under any active discharge permits within the study area. Estimates of PCB loading from upland soil and riverbank erosion also were not assessed due to a paucity of data for riparian soil PCB concentrations and erosion rates.

The load of total PCBs in surface water increases downstream through the study area to RM 4[7] (Figure 10.2-3); the largest PCB stormwater inputs enter the study area between RM 3 and 4. As described in Section 6.1.2, the estimated load (1 kg/yr) to this reach is largely from a non-representative (unique) site (Outfall WR-384) and exceeds the next highest stormwater load, between RM 8 and 9, by a factor of 10.

Atmospheric deposition is estimated to contribute a total PCB load approximately one-third that of stormwater at the study area scale. Deposition loading to the water surface varies only as a function of water surface area by river mile.

No current known or likely complete PCB overwater pathways have been identified. Current overwater releases may be locally important at sites with continuous waste handling or operational activities, but are considered a minor current pathway overall.

While areas of PCB contamination in the study area appear to be the result of releases from specific localized sources, PCBs also enter the study area from non-point and diffuse sources such as private and public stormwater and sewer outfalls, and sources upstream of the study area in the Willamette River. Harbor-wide loading estimates indicate that the highest current external inputs to the study area are from upstream surface water and, to a lesser degree, stormwater runoff and atmospheric deposition. These estimates indicate that the mass flux of PCBs in surface water exiting the study area at RM 2 and at the Multnomah Channel entrance exceed the estimated fluxes entering the study area from all quantified external loading terms. This indicates an internal mass transfer of PCBs from bedded sediment to the water column, likely through sediment resuspension.

10.2.1.4 Human and Ecological Risks Associated with PCBs

PCBs are a primary contributor to human health risks at Portland Harbor, primarily through consumption of resident fish, and to breast-fed infants whose mothers have been exposed to PCBs. Total PCBs were identified as one of the primary contaminants that pose ecologically significant risks to mink, river otter, and spotted sandpiper, and low risk to osprey, bald eagle, sculpin, and multiple fish species. Total PCBs pose risks to ecological receptors through more lines of evidence than did any other contaminants evaluated in the BERA. They were also identified as one of the primary contaminants in sediment contributing to potentially unacceptable risk to the benthic community.

[7] At approximately RM 3, the Columbia River and Multnomah Channel hydraulically influence the flow regime complicating interpretation of load conditions in this area (see Section 3.1.4.3).

10.2.2 Total PCDD/Fs

A graphical CSM for total PCDD/Fs in the study area is presented Panels 10.2-2A–C. As a group, PCDDs represent 75 different isomers, while PCDFs comprise over 135 compounds (Eisler 1986). These two chemical classes are generally referred to as dioxins and furans, respectively. PCDD/Fs are byproducts of combustion, incineration, certain industrial chemistry processes, and natural sources, including combustion, metal smelting, and production of bleached paper, polyvinyl chloride, inks/dyes, certain chlorine production technologies, chlorophenols, chlorinated herbicides, and commercial Aroclor (PCB) mixtures (ATSDR 1998). Examples of combustion and incineration that may lead to the formation of PCDD/Fs include hazardous or medical waste incinerators, cement kilns, boilers and industrial furnaces, vehicle emissions, fossil fuel power plants, burning PCB-containing electrical equipment (such as transformers), and backyard burning (e.g., refuse piles, burn barrels). PCDD/Fs are naturally produced from forest fires, volcanic eruptions, and sedimentary deposits. Currently the largest source is from backyard burning (USEPA 2006n). When released into the air, some PCDD/Fs may be transported long distances, even around the globe. In the atmosphere, it has been estimated that 20 to 60 percent of 2,3,7,8-TCDD is in the vapor phase. Sunlight and atmospheric chemicals can break down a very small portion of the PCDD/Fs, but most PCDD/Fs will be deposited on land or water (ATSDR 1998).

Behavior of PCDD/Fs in the environment is characterized by low vapor pressures, high octanol-water and organic carbon partitioning coefficients (K_{ow} and K_{oc}, respectively), and extremely low water solubilities. They are hydrophobic and have a strong affinity for sediments with high organic matter content; as a result, transport of PCDD/Fs in aquatic systems is closely tied to fine-grained sediment transport processes. Some PCDD/Fs, present near the water surface and not bound to solids, may be subject to photodegradation (USEPA 1994). In general, PCDD/Fs are stable in all environmental media, with persistence measured in decades. Chemical degradation of PCDD/Fs through reductive dechlorination can also occur, but it is typically a slow process. PCDD/Fs have been shown to biomagnify in aquatic food webs and associated avian and mammalian species (ATSDR 1998).

10.2.2.1 Total PCDD/F Contaminant Distribution

Panels 10.2-2A–C present the study area graphical CSM for total PCDD/F. Care should be taken in interpreting Panels 10.2-2A–B because relatively few sediment samples were analyzed for PCDD/Fs. Total PCDD/Fs were detected in sediments in several locations along the eastern and western nearshore zones and in Swan Island Lagoon. The highest detected concentrations were found in the eastern nearshore zone at RM 2E-8E, Swan Island Lagoon, RM 11E, RM 6W-10.3W, from RM 4W-6W, and at RM 3.4W. There are a number of distinct locations scattered throughout the study area that exhibit elevated PCDD/F concentrations in sediment and coincide with currently identified known or likely historical industrial dioxin and/or furan sources, including RM 11E, Swan Island Lagoon, Willamette Cove, and between RM 6.5W and 7.5W, adjacent to Arkema and Rhone-Poulenc. Total PCDD/F concentrations in the

subsurface are generally greater than that observed in surface sediments. The higher concentrations observed in subsurface sediment relative to concentrations in surface sediment are indicative of a primarily historical input of these contaminants to the study area. Areas of apparent PCDD/F contamination in sediment in other locations in the study area not associated with documented sources and pathways indicate that all point sources may not have been identified. However, these locations are coincident with areas exhibiting higher concentrations of other indicator contaminants, such as PCBs and/or PAHs. While the relatively low density of PCDD/F data makes surface to subsurface concentration gradients difficult to discern on a study area-wide basis, there does not appear to be strong trends with depth.

Surface water concentrations are elevated in Willamette Cove, at RM 6.8W, and in the RM 4 transect sample. Total PCDD/F surface water concentrations within the study area did not display any consistent trends from upstream to downstream.

There are no strong spatial or temporal gradients evident in total PCDD/F concentrations measured in suspended sediments collected in sediment traps within the study area (Figure 5.3-3a-b). In general, study area sediment trap samples had higher total PCDD/F concentrations than the upstream locations near RM 15.6.

PCDD/Fs were detected in all fish and invertebrate tissue samples collected from the study area, with the highest concentrations observed in samples collected between RM 6.5 and 7.5 (Panel 10.2-2C).

10.2.2.2 Potential PCDD/Fs Sources and Pathways

Historical known complete or likely complete pathways for PCDD/Fs have been identified at four sites (Table 10.2-2 and Panels 10.2-2A–C) and include stormwater (four sites), groundwater (one site), overwater releases (one site), overland transport (two sites), and riverbank erosion (two sites).

Current known complete or likely complete pathways for PCDD/Fs have been identified at two sites and include stormwater (both sites), overland transport (one site), and riverbank erosion (one site). Stormwater transport is expected to be the most significant current pathway for PCDD/Fs to enter the study area from adjacent upland sites. Gould Electronics, Rhone Poulenc, and McCormick and Baxter are identified as having known complete historical pathways.

No current known or likely PCDD/F overwater pathways have been identified. However, McCormick and Baxter is identified as having a known historical pathway.

No sites have been identified as having current known or likely complete groundwater pathways for PCDD/Fs, though McCormick and Baxter had a historical complete pathway, the potential for migration in the past is known to have existed at McCormick and Baxter.

10.2.2.3 Loading, Fate, and Transport of PCDD/Fs

The loading, fate, and transport assessment for total PCDD/Fs is summarized on Figures 10.2-4a-b, 10.2-5, and 10.2-6. The greater PCDD/Fs mass in the study area deeper sediments (Panel 10.2-2B) is likely attributable to historical loading that occurred under different past loading conditions and rates. Due to the limited data available, PCDD/F loading terms were quantified only for upstream surface water and advection through subsurface sediments. Upstream loading contributes much greater estimated loads of total PCDD/Fs to the study area than advection through subsurface sediments (Figures 10.2-4a and 10.2-5). Upstream surface water loads are associated primarily with the suspended particulate fraction, with similar total PCDD/F mass loads entering the study area during high-flow and low-flow conditions (see Figure 6.1-4). The total PCDD/F upstream loads in surface water are comparable with downstream loads. A cross-media comparison and statistical assessment of surface sediment, sediment trap samples, and the particulate fraction of surface water samples on a study area-wide basis is shown in Tables 10.2-14a-b and Figure 10.2-4b. An apparent increase in the estimated surface water flux of PCDD/Fs from upstream to downstream within the study area may reflect contributions from a combination of other external loading terms (stormwater, advective transport, and atmospheric deposition) or internal fate and transport processes, such as sediment resuspension.

10.2.2.4 Human and Ecological Risks Associated with PCDD/Fs

Dioxins and furans pose unacceptable risks to human health at Portland Harbor, primarily due to exposures through consumption of shellfish and resident fish, as well as a direct contact exposure to contaminated sediments for people engaged in fishing activities. They were identified as one of the primary contaminants that pose ecologically significant risks. Dioxins and furans pose an ecologically significant risk to mink, spotted sandpiper, osprey, and bald eagles. They are also contributors to the overall risk to river otters.

10.2.3 DDx

The graphical CSM for DDx compounds is presented in Panels 10.2-3A–C, and loading information is summarized in Figures 10.2-7a-b through 10.2-9.

DDT was widely used as an insecticide from about 1943 (Porter 1962) until 1972, when it was banned for most uses in the United States, because of its toxicity to wildlife. DDE and DDD are the primary metabolites of DDT, but technical-grade DDT may also contain DDE and DDD as impurities (ATSDR 2002a). DDT was released historically to air and soil through widespread spraying of crops and forests, and for mosquito control. Releases also occurred at more local scales at pesticide manufacturing and storage facilities. Ongoing releases occur in countries where its use is not banned, and some of these releases can be transported globally through the atmosphere. Because DDT is no longer produced or sold in the United States, significant new releases to the environment are uncommon. Consequently, most of the mass of DDx found in the study area is derived from historical sources. However, DDx compounds continue to be

introduced to the lower Willamette River through a variety of environmental pathways, as described in Section 10.2.3.2.

DDT degrades slowly via abiotic and microbially-mediated processes to the more persistent DDx compounds, DDE (under aerobic conditions) and DDD (in anoxic systems; USEPA 2000b). In the environment, DDx compounds are persistent and are readily bioaccumulated in aquatic organisms (USEPA 2000b). While there is no clear evidence that DDT, DDD, or DDE causes cancer in humans, there is sufficient evidence of carcinogenicity of these substances in rodents, which has led to their classification as probable human carcinogens (ATSDR 2002a).

10.2.3.1 DDx Contaminant Distribution

Within the study area, the highest DDx concentrations in sediments are limited to localized areas in nearshore zones. The highest reported concentrations in sediment are located in the western nearshore zone between RM 6W and 7.5W, and are proximal to known upland sources. Other areas of elevated DDx sediment concentrations are smaller in extent and are located at RM 8.8W, at the mouth of Swan Island Lagoon, and in subsurface sediments only at RM 4.8W and the head of the International Slip.

The concentrations of DDx in surface sediments are greater in the study area than in the upriver, downtown, Multnomah Channel, and downstream reaches. When DDx concentrations are averaged on a river-mile basis, the greatest difference between surface and subsurface sediment concentrations is observed in the western nearshore zone between RM 7 and 8, where the highest concentrations are found at depths greater than 10 ft (Figures 5.2-10 and 5.2-11; Panels 10.2-3A–B), indicating greater past loads. DDx concentrations found downstream of RM 8 are typically in the 5 to 100 µg/kg range. Upstream of this location concentrations are typically less than 5 µg/kg.

DDx compounds are widely detected in Portland Harbor surface and subsurface sediments; other abiotic media, such as surface water, sediment traps, and TZW; and fish and shellfish tissues. The highest DDx concentrations are found in several nearshore areas associated with known historical DDx sources (Arkema, Rhone Poulenc, and Willbridge Terminal) along the western shore of the river from about RM 6.8 to RM 7.5. Throughout the study area, DDx concentrations are generally lower in surface than subsurface sediment, indicating greater historical inputs or past releases.

The highest DDx concentrations observed in surface water, sediment traps, TZW, and biota samples are from the area of RM 6.8 to 7.5. Sediment concentration gradients along this western nearshore area and in the edge of the navigation channel downstream from this source area indicate the downstream transport of DDx in sediments and possible inputs from other point sources. This pattern is consistent with the hydrodynamic and sediment transport characteristics in this portion of the study area, particularly from RM 5 to 7. Less extensive areas with elevated DDx occur at Gunderson, at the head of International Slip, RM 4.8W (subsurface only), and at the Cascade General Shipyard at depth in the sediment column.

DDx concentrations in surface water transect samples collected at the upstream end of the study area and upriver (Panel 10.2-3A) in high-flow conditions (Figure 5.4-20) are indicative of inputs from upriver areas. The results of single-point samples collected downstream of RM 7.5 and the transect at RM 6.3 exhibit elevated DDx concentrations in both low-flow and high-flow conditions (Figure 5.4-20; Panel 10.2-3A). Results of surface water samples collected at RM 2 do not exhibit elevated concentrations, although results from the surface water transect at the mouth of Multnomah Channel exhibited elevated DDx concentration during low-flow conditions (Panel 10.2-3A; Figure 5.4-20). The DDx concentrations were higher in unfiltered samples than in filtered samples. Combined with the low aqueous solubility of DDx compounds, this indicates that DDx is more associated with solids.

DDx concentrations in the sediment trap samples were generally low throughout most of the study area, although higher concentrations were measured in traps at RM 6 and 7.5W and in Swan Island Lagoon in the summer and fall periods. The elevated DDx concentrations reported at RM 11E in the fall period are likely an artifact resulting from analytical interferences associated with PCBs also detected in that sample.

Elevated DDx concentrations were observed in TZW samples collected near RM 7.2W. TZW samples from other areas were not analyzed for DDx, precluding comparisons with other areas. As stated above with respect to surface water, the TZW DDx concentrations were higher in unfiltered samples than in filtered samples.

The highest concentrations of DDx in biota are found where sediment concentrations are highest, and most extensive near RM 7 (Figure 5.6-4a-e; Panel 10.2-3C).

10.2.3.2 Potential DDx Sources and Pathways

Within Portland Harbor, DDx was historically associated with pesticide manufacturing and storage facilities. It also was released to air and soil through widespread spraying of crops and forests, and for mosquito control throughout the Willamette River Basin. Some riverbank facilities and other upland properties likely applied DDT for mosquito control before it was banned. Known historical chemical manufacturing and/or storage sites are presented on Map 3.2-14, and include Arkema, Rhone Poulenc, and the Shell Terminal at Willbridge. As shown on Table 10.2-3 and Panels 10.2-3A–C, historical known complete or likely complete pathways for DDx have been identified at four sites. Of these, the groundwater pathway is included at two sites, stormwater at four sites, and riverbank erosion at two sites. Historical known complete or likely complete pathways for DDx were not identified for overwater releases or overland runoff. Currently known complete or likely complete pathways for DDx have been identified at three sites and include groundwater migration, stormwater, and riverbank erosion at one site. No current known complete or likely complete pathways were identified for overwater releases or overland runoff.

Areas of DDx contamination are found downstream of RM 7, and may be related, in part, to downstream transport of sediment in the relatively higher energy areas that

extend from about RM 7 to 5 (see Section 3.1.5.2.6). DDx concentrations observed in other upstream and downstream areas are not associated with known sources (Panels 10.2-3A–B).

Historical DDx sources to the study area included upstream surface water, stormwater, and riverbank erosion (Table 10.2-3). The historical releases from these pathways are not quantifiable. Overall, current DDx inputs to the study area are much lower than historical inputs because DDT is no longer manufactured or used in widespread spraying applications and because waste management practices have greatly improved. However, elevated DDx concentrations in surface sediments and in other media, including biota, at RM 6.8 to 7.5W, and at RM 8.8W indicate localized, external inputs or ongoing internal mass transfer of historical DDx from subsurface/surface sediments to other media by processes such as sediment resuspension and biological uptake.

The most significant current influx of DDx to the study area is upstream surface water, while stormwater transport is the most significant current pathway to the study area from adjacent upland sites. DDx was detected in stormwater from each land use area sampled. Outfalls associated with the heavy industrial land use category and selected individual non-representative outfalls contributed the majority of the estimated DDx stormwater load (see Section 6.1.2.3). Current and/or historical known or likely complete pathways for DDx in stormwater have been identified at sites including Arkema, Rhone Poulenc, Metro Central Transfer Station, the Shell facility at the Willbridge Terminal, and City of Portland Outfall OF-22B. Most of the facilities either drain stormwater or infiltrate contaminated groundwater to shared conveyances (e.g., Saltzman Creek and OF-22B). Source control measures taken at the Arkema site have largely eliminated the stormwater pathway from this site. No potentially complete current or historical overland transport pathways or historical overwater releases of DDx have been identified for any sites.

Known or likely historical DDx groundwater pathways have been identified at Arkema and Rhone Poulenc. Cleanup efforts conducted by Rhone Poulenc are expected to eliminate the preferential groundwater pathway to stormwater. DDx is present in upland groundwater plumes at the Arkema site, and it has been detected in nearshore wells. Groundwater controls at the Arkema site have greatly reduced the groundwater pathway.

Contaminated riverbanks that are known or likely complete historical DDx erosion pathways have been identified at Arkema and Willbridge Cove. At Arkema, the riverbank area received fill that included miscellaneous materials from spent chlorine cells for several years (ERM 2005). The fill material included clean soil. In addition, dredge spoils were deposited on the riverbank. Riverbank erosion at the site has also been identified as a known complete current pathway for DDx. The riverbank in Willbridge Cove may have been contaminated by the deposition of sediment containing DDx, and is subject to erosion.

10.2.3.3 Loading, Fate, and Transport of DDx

DDx loading, fate, and transport assessment for the study area in a typical year is summarized on Figures 10.2-7a-b through 10.2-9. Estimates are for current conditions, and likely differed historically. Much of the DDx mass in the study area, especially in deeper sediments, is attributable to historical loading that occurred under different loading conditions and rates.

Historical DDx sources to the study area included upstream surface water, stormwater, and riverbank erosion (Table 10.2-3). The most significant current influx of DDx to the study area is upstream surface water, and is associated with both the dissolved and suspended particulate fraction. The majority of the mass load enters the study area during high-flow conditions (Figure 6.1-6), indicating that erosion of upstream agricultural areas is an important upstream source. While additional DDx mass also enters and remains in the study area with upstream bedload sediments, it has not been quantified. DDx loads in upstream surface water (RM 11) and the downstream boundary of the study area (combined loads at RM 2 and the Multnomah Channel entrance) are comparable. Additional DDx loading sources, in order of importance, are stormwater[8], atmospheric deposition to the river surface (atmospheric deposition to the watershed is included in the stormwater term), groundwater advection through subsurface sediments, and upland groundwater plume discharge.

Internal DDx fate and transport for the study area is shown on Figure 10.2-8. DDx transport to the water column due to pore water advection through surface sediments is the only process for which quantitative estimates were developed. Other internal fate and transport processes are depicted on Figure 10.2-8 on a qualitative basis only. DDx partitioning between suspended sediment and surface water depends on the relative chemical concentrations associated with suspended particulate organic carbon and the dissolved surface water fraction, as well as reaction kinetics.

DDx loads from permitted non-stormwater point source discharges are not expected to be significant and estimates were not generated.[9] Estimates of DDx loading from upland soil and riverbank erosion also were not assessed in the RI due to a paucity of data for riparian soil DDx concentrations and erosion rates.

DDx load in surface water increases moving downstream through the study area (Figure 10.2-9), with the largest DDx stormwater inputs entering between RM 6.8 and 7.4. Upland groundwater plume loads are highest between RM 7 and 8. Estimated

[8] The DDx stormwater loading term developed in the RI is dominated by the estimated load from a single "non-representative" site. As discussed in Section 6, the estimated loads from this non-representative site are subject to a high degree of uncertainty related to extrapolation of stormwater concentrations measured in the non-representative outfalls (<10 percent of the drainage sub-basin) to areas that are larger than the catchments that drain to the non-representative outfalls.

[9] NPDES permitted wastewater discharge is not expected to contain significant amounts of DDx relative to other loading terms.

current DDx annual loads from advection through subsurface and surface sediments follow the patterns of DDx sediment concentrations (Figure 6.1-59), with the highest loads between RM 7 and 8.

Estimates of quantifiable external loading terms indicate that the highest current external inputs to the study area are from upstream surface water. Estimates of DDx fluxes in surface water at RM 2, the downstream end of the study area, and in Multnomah Channel suggest that slightly more DDx mass may be leaving the study area downstream in surface water than entering the study area from all quantified sources. This possible increase may reflect an internal mass transfer of DDx from bedded sediment to the water column, likely through sediment resuspension. The relationships between tissue body burdens and abiotic concentrations across the study area are a primary focus of the fate and transport modeling to be conducted at the Site for the FS.

10.2.3.4 Human and Ecological Risks Associated with DDx

DDD, DDE, and DDT pose unacceptable human health risks associated with consumption of resident fish, though this was largely limited to the area at RM 7W. DDx was identified as one of the primary contaminants that pose ecologically significant risks. It poses potentially unacceptable risk primarily to benthic invertebrates and sediment-associated receptors. DDx compounds in sediment pose potentially unacceptable risk to the benthic community only on the western side of the river between approximately RM 6.8 and 7.4.

10.2.4 Total PAHs

The graphical CSM for PAHs is shown on Panels 10.2-4A–C. PAHs are a large chemical group composed of more than 100 chemicals that are constituents of crude and refined oil, shale oil, coal tar, and creosote. PAHs are also formed during the incomplete combustion of organic materials including coal, oil, gas, wood (wood stoves, fireplaces), garbage (municipal waste incineration), or other organic substances, such as tobacco. Natural sources of PAHs include volcanoes and forest fires. The largest historical sources of the high concentrations of PAHs in study area sediments were localized releases, such as historical industrial direct discharges, from facilities along the study area that formerly or currently use, manufacture, and/or store products and waste materials containing PAHs (petroleum oils and coal-based products, petroleum product use and storage, used oil, and asphalt roofing materials).

PAHs may accumulate in benthic organisms, fish, and other organisms that ingest sediments while feeding. However, biomagnification through the food chain is expected to be minimal as fish, mammals, and birds all possess the ability to metabolize PAH compounds.

10.2.4.1 Total PAH Contaminant Distribution

PAHs are present at a wide range of concentrations throughout the study area in all media. On a harbor-wide basis, the highest PAH concentrations in sediments generally

occur downstream of RM 7 in nearshore areas proximal to local upland sources (Maps 5.2-16 and 5.2-17a-hh; Panels 10.2-4A–B) offshore of Siltronic, Gasco, Marine Finance, and Foss Brix. Elevated PAH concentrations are also observed in surface and subsurface sediments in the navigation channel between RM 4 and 6.5. Other areas of elevated total PAH concentrations in surface sediments include Mar Com South (RM 5.5–5.6E), Terminal 4 Slip 3 and Wheeler Bay (RM 4.3–4.6E), Slip 1 (RM 4.3E), and the International Slip (RM 3.7–3.8E). The portion of the study area upstream of RM 7 (not including Swan Island Lagoon) is characterized by widespread total PAH concentrations less than 500 µg/kg. In contrast, downstream of RM 7 and away from the high concentration areas associated with known sources, and also in Swan Island Lagoon, total PAHs concentrations are generally 1,000–5,000 µg/kg.

Total PAH concentrations are generally higher in subsurface sediments within the study area as a whole (Panel 10.2-4A–B; Maps 5.2-17a-hh; Figure 5.2-15), pointing to higher historical inputs to the study area. The most notable exception to this pattern is the navigation channel at RM 5 to 6.5 where the total PAH concentrations in surface sediment are greater (Maps 5.2-17k-m), indicating downstream transport of PAHs in surface sediments once they reach the channel from adjacent or upstream nearshore zones. This is consistent with the relative dynamic channel environment found from RM 5 to 7 (see Section 3.1.5.2.6). Other exceptions to the general pattern of higher subsurface total PAHs include Swan Island Lagoon and Multnomah Channel, where higher PAH concentrations are observed in the upper portion of the sediment column and not just the surface layer.

PAH compositions in sediment trap and high-flow surface water particulate samples were generally similar to that of the sediments, indicative of increased bedded sediment resuspension during higher flow periods. PAH composition in sediment trap and surface water samples during low-flow and stormwater-influenced sampling events generally did not correlate well, indicating that current, lateral and upstream sources differ in composition from the PAHs in the bedded sediments. Total PAH concentrations in surface water are elevated predominately during low-flow conditions (Figure 5.4-24), further illustrating the localized nature of the PAH sources in the study area. Total PAH concentrations in sediment trap samples are notably elevated at RM 6W in all seasons sampled (Figure 5.3-6a-b). Less distinct spikes were measured from May to August in Swan Island Lagoon, and from August to November in Multnomah Channel.

Total PAH concentrations in TZW were reported in areas that correspond with elevated areas of sediment concentrations. The highest concentrations reported in biota samples also correspond with areas where total PAH concentrations in sediment are elevated.

10.2.4.2 Potential PAH Sources and Pathways

PAHs are associated with bulk fuel storage, MGP, ship and automobile scrapping, asphalt roof manufacturing, use of lubricants, hydraulic, and fuel oils in a large number of industrial and commercial operations, and leaks from vehicles and machinery.

Known complete or likely complete historical pathways for PAHs have been identified at 56 sites, and include stormwater (48 sites), groundwater (11 sites), overwater releases (21 sites), overland transport (10 sites), and riverbank erosion (14 sites). Current known complete or likely complete pathways for PAHs have been identified at 30 sites and include stormwater (16 sites), groundwater (9 sites), overwater releases (14 sites), overland transport (3 sites), and riverbank erosion (4 sites). This information is summarized in Table 10.2-4 and on Panels 10.2-4A–C. Known or likely current and historical upland sources that correlate with areas of high concentrations in sediment include the former MGP site at Gasco, dry dock operations at Cascade General in Swan Island Lagoon, the International Slip, Mar Com, bulk fuel terminals at ARCO, ExxonMobil, and Kinder Morgan, and historical releases from McCormick and Baxter in Willamette Cove. Based on reported PAH concentrations in sediment near outfalls draining facilities, it is also likely that stormwater/wastewater/overland transport releases occurred concurrently at Burgard Industrial Park (WR-123), Siltronic and Gasco (OF-22C), and Greenway Recycling, PGE-Forest Park, Willbridge Terminal, Front Avenue LP, and Chevron Asphalt (OF-19). Because wastewater discharges in CSO areas are regulated through municipal pretreatment permits, PAHs are not identified as a COI at any sites with a pretreatment permit (see Table 4.4-7).

Current known and likely complete pathways for migration of PAHs in groundwater have been identified at nine facilities, most of which are associated with bulk fuel storage (Table 10.2-4). Overwater releases are likely to have occurred in association with overwater operations, such as fuel transfers and spills, drydock and berth operations, overwater maintenance operations, vessel servicing and emissions, ship repair and maintenance activities, direct discharges of PAH contaminants (tar, oil) to the river, releases during product loading/unloading at docks, and tug and barge operations.

Known complete groundwater pathways were identified at the Siltronic and Gasco sites. Potentially complete groundwater migration pathways were identified at Willbridge Terminal, Kinder Morgan Linnton, ARCO, and ExxonMobil. However, results from TZW samples collected offshore of these four sites indicate that the role, if any, of groundwater transport of PAHs is minor and is not significantly influencing TZW and sediment chemistry.

Bank erosion likely played a bigger role historically as well, particularly during construction in places where contaminated sediments or manufacturing material and debris from upland activities were used as fill. Based on limited riverbank sampling, riverbank erosion is a historical known or likely complete pathway for PAHs at 13 sites: Crawford, Gasco, Gunderson, Mar Com South Parcel, Marine Finance, Port of Portland Terminal 4, Slip 1 and Slip 3, Premier Edible Oils, Siltronic, Sulzer Bingham, Triangle Park property, Willamette Cove, and the Willbridge Terminal facility.

10.2.4.3 Loading, Fate, and Transport of PAHs

Total PAH loading, fate, and transport in the study area in a typical year are summarized on Figures 10.2-10a-b, 10.2-11a, and 10.2-12, relative loads for LPAHs

and HPAHs are presented on Figures 10.2-11b and 10.2-11c, respectively. While these loading estimates are for current conditions, much of the total PAH mass in the study area is attributable to historical loading.

Advection through subsurface sediments, upstream surface water, and upland groundwater plumes is estimated to contribute comparable (within an order of magnitude) total PAH loads to the study area (Figures 10.2-10a and 10.2-11a). Estimated external PAH loads associated with stormwater, atmospheric deposition to the river, and direct discharges from permitted non-stormwater point sources are 1 to 2 orders of magnitude lower than the other external terms. LPAHs contribute the bulk of the total PAH load for all loading terms evaluated quantitatively (Figures 10.2-11b and 10.2-11c). The majority of the total PAH mass load from upstream surface water enters the study area during high-flow conditions (Figure 6.1-8). Upstream surface water total PAH and LPAH loads are associated primarily with the dissolved fraction, whereas HPAH loads are slightly higher in the particulate than in the dissolved fraction. Total PAH load in surface water increases moving downstream through the study area, particularly downstream of RM 7, in both the particulate and dissolved fractions (Figure 10.2-12) under all flow conditions. PAH loading terms that were assessed qualitatively are also shown on Figures 10.2-11a–c. PAH volatilization from the water column may be significant for LPAHs, although this was not evaluated.

Fate and transport processes internal to the study area for total PAHs, LPAHs, and HPAHs are also shown on Figures 10.2-11a, 10.2-11b, and 10.2-11c, respectively. Quantitative estimates were developed only for transport to the water column due to pore water advection through surface sediments, and this term is lower in magnitude than the subsurface advective loading term for total PAHs and LPAHs, and similar in magnitude for HPAHs. Estimates of PAH loading from upland soil and riverbank erosion were not assessed due to a paucity of data for riparian soil PAH concentrations and erosion rates.

The total PAH load in surface water increases moving downstream through the study area,[10] particularly downstream of RM 7 (Figure 10.2-12). Most of the load from the two largest external lateral loading terms, subsurface sediment advection and upland groundwater plumes, enters the study area between RM 6 and 7.

PAH contamination in sediments is associated with known or likely historical and current sources. Two areas of elevated total PAH concentrations, offshore of the Gasco former MGP site at RM 6.5W and the Port's Terminal 4, Slip 3, are the focus of early cleanup actions independent of the harborwide RI/FS. Releases associated with Gasco and other known and potential sources along the west side of the river between RM 6 and 7 have resulted in higher nearshore total PAH concentrations in both surface and subsurface sediments. Downstream concentration gradients, both nearshore and in the

[10] At approximately RM 3, the Columbia River and Multnomah Channel hydraulically influence the flow regime complicating interpretation of load conditions in this area (see Section 3.1.4.3).

navigation channel, in this relatively high-energy portion of the river indicate downstream transport of PAHs extending approximately to the Multnomah Channel entrance. In the navigation channel from RM 5 to 6, high surface sediment concentrations relative to subsurface levels are indicative of the transport of material through this reach rather than long-term accumulation. Other, less extensive areas of PAH sediment contamination in the study area, are associated with known or likely sources, including offshore of Cascade General, in Willamette Cove (subsurface sediments), offshore of Mar Com, at the head of the International Slip, and at several nearshore locations along the west bank from RM 3 to 5.

In general, total PAH concentrations in subsurface sediment are greater than in surface sediment, indicating greater inputs or releases historically that have been reduced or eliminated over time. Elevated total PAH levels in other media—TZW, surface water, sediment traps, and biota (particularly clams)—are largely restricted to the most extensive area of elevated sediment concentrations, along the western shore around RM 6.

Overall, current PAH inputs to the study area are much lower than historical inputs because material handling and waste management practices have greatly improved. Measured elevated concentrations of PAHs in surface sediments and other media including surface water (e.g., Swan Island Lagoon, RM 7.4W, RM 6.8W) and biota in specific areas (e.g., International Slip; Terminal 4, Slips 1 and 3; offshore of Gasco; and Swan Island Lagoon) indicate that localized inputs and/or internal mass transfer of sediment PAHs by processes such as sediment resuspension likely affect other media. Potentially important current pathways from upland sources include groundwater plumes, overwater releases, overland transport, and riverbank erosion.

Empirical estimates of current external PAH loads (mass/yr) to the study area indicate that advection through subsurface sediments, upstream surface water, and upland groundwater plumes contribute comparable total PAH loads to the study area, whereas loads associated with stormwater, direct atmospheric deposition to the river, and direct discharges from permitted non-stormwater point sources are considerably less important. These data indicate that surface water PAH mass loads increase from upstream to downstream, likely reflecting inputs from the other external loading terms, which peak at RM 6 to 6.9. Internal mass transfer from bedded surface sediments to surface water/biota from sediment resuspension erosion was not quantified but likely also contributes to this pattern.

10.2.4.4 Human and Ecological Risks Associated with PAHs

PAHs were estimated to pose unacceptable risks to human health based on fish and shellfish consumption and direct contact with sediment exposures, generally limited to the area of RM 4W to 6W. PAHs were identified as one of the primary contaminants that pose ecologically significant benthic risks. As a group, PAHs are associated with the benthic risk areas from RM 5.1 to 6.9 on the west side of the river. Within this area, some PAH concentrations observed in TZW and surface water samples pose localized

potentially unacceptable risks to fish, invertebrates, amphibians, and aquatic plants. Risks to aquatic-dependent birds and mammals are negligible.

10.2.5 Bis(2-ethylhexyl)phthalate

A graphical CSM for BEHP in the study area is presented on Panels 10.2-5A–C. Phthalates are manufactured, colorless liquids with little to no odor. The primary sources of phthalate emissions are the industries that manufacture it or use it in production, such as the chemical industry, the plastics industry, the cosmetic industry, machinery manufacturers, and manufacturers of plywood and millwork. Phthalates are commonly added to plastics and paint to make the finished product more flexible (ATSDR 2002b) and are widely used as plasticizers in polyvinyl chloride resin. In addition, phthalates are common components of detergents and carriers in pesticide formulations (Xie et al. 2005). Releases to the environment can occur as direct spills from industrial facilities that manufacture or use these chemicals. More commonly, releases occur by leaching of low volumes of phthalates from the wide variety of products that contain them (ATSDR 2002b). Despite its low vapor pressure, BEHP is ubiquitous in the atmosphere due to its widespread use in plastics. BEHP, which is present in the atmosphere in both the vapor phase and associated with particulates, is subject to both wet (rain and snow) and dry (wind and settling) deposition on the earth's surface (ATSDR 2002b).

The behavior of BEHP in the study area environment is largely defined by its high hydrophobicity (the central estimate of log K_{oc} is 7.4). Due to this hydrophobicity, BEHP has a strong tendency to sorb to solids and organic matter in surface water and in sediment-pore water environments. As such, it is not expected to migrate significantly in groundwater. Because of its low vapor pressure, volatilization is a minor loss mechanism for BEHP, particularly when sorbed to solids. BEHP is subject to fairly rapid degradation in the atmosphere, but much slower abiotic and microbially-mediated degradation processes under aerobic conditions in sediment and surface water (HSDB 2006; ATSDR 2002b). Its physical properties indicate that BEHP would be expected to bioconcentrate in aquatic organisms; however, study area biota results suggest that BEHP is readily metabolized.

10.2.5.1 BEHP Contaminant Distribution

Elevated BEHP concentrations in sediments were reported, with minor exceptions, in nearshore areas outside the navigation channel and proximal to local upland sources (Maps 5.2-20a-o and Panels 10.2-5A–B). Elevated concentrations are observed in Swan Island Lagoon and in the International Slip (RM 3.7–3.8E), along the riverside of Schnitzer-Calbag site RM 3.8–4.1E, 7.6E, 7.6W, 8.3W, 8.8W, 9.7W, and offshore of RM 7.1 and 10 in the navigation channel. Elevated subsurface concentrations were less widespread, and typically observed in areas with elevated surface concentrations. Exceptions were noted at RM 10.5W and 5.7W.

Elevated concentrations of BEHP were detected in only one surface water sample collected during high-flow conditions, at RM 8.6W. BEHP concentrations in sediment

trap samples did not vary widely spatially or temporally throughout and upstream of the study area, with the exception of notably elevated concentrations measured in the two samples (summer, fall) collected in Swan Island Lagoon (see Figure 5.3-7a-b).

Because of BEHP's hydrophobic nature, groundwater is unlikely to be a significant historical or current pathway for BEHP migration into the study area and was not included in the TZW sampling program. Thus, no data exist to corroborate this hypothesis.

BEHP was detected in laboratory-exposed clams and worms, mussels, and fish. However, it was not detected in crayfish, juvenile Chinook, or carp. The highest reported concentrations in biota were generally detected on both sides of the river near RM 4 and above RM 9.5, and one location just off the downstream end of Swan Island. With the exception of the surface sediment on the east bank near RM 4 and subsurface sediment at the downstream end of Swan Island, elevated BEHP concentrations in biota do not correlate well with elevated concentrations in sediment.

10.2.5.2 Potential BEHP Sources and Pathways

Historical known complete or likely complete pathways include stormwater (28 sites), overwater releases (3 sites), overland runoff (1 site), riverbank erosion (2 sites), and groundwater (1 site) (Table 10.2-5). Current known complete or likely complete pathways for BEHP have been identified at 16 sites and include groundwater (3 sites), stormwater (12 sites), and overwater releases (2 sites).

BEHP concentrations are elevated in surface sediment in current and former shipyards such as Swan Island and the International Slip. BEHP is likely to have been released to Swan Island Lagoon and the Portland Shipyard for many years, and continued inputs may occur from known sources and contributions from the numerous outfalls in this area. The lack of elevated concentrations at depth in the sediment column in Swan Island Lagoon may indicate low burial rates, surface sediment mixing, and/or higher recent inputs. Higher concentrations in subsurface sediment near the shipyard docks indicate historically high levels and burial over time.

There are no known sources of BEHP associated with sites that discharge stormwater to the International Slip. However, this area has an auto shredding facility, and BEHP has been identified with metal scrapping (see Section 3.2.3.1.4). It was also the former location of a large shipyard owned by the Oregon Shipbuilding Corporation. Several metals facilities (either fabrication or scrapping) and a historical paint spill area have been identified as BEHP sources that discharge to OF-19 at RM 8.3W. Identified sources of BEHP at RM 8.8W include Gunderson (outfalls from the Marine Barge Paint and Blast Area) and multiple facilities discharging to OF-18.

BEHP migration by overland transport has been identified at the Mar Com South Parcel as a historical likely complete pathway. Current overwater releases may be locally important at sites with continuous waste handling or operational activities, but are

considered a minor current pathway overall. Cascade General and Mar Com South represent the only currently known or likely complete BEHP overwater pathways. Groundwater discharge has been identified as a current or historical complete pathway at Premier Edible Oils, Triangle Park property, and the Willbridge Terminal facility. There are no known atmospheric sources of BEHP within the study area.

No upriver watershed sources of BEHP have been identified.

10.2.5.3 Loading, Fate, and Transport of BEHP

BEHP loading, fate, and transport assessment for the study area in a typical year is presented on Figures 10.2-13a through 10.2-15. The highest relative current external inputs are from upriver surface water,[11] with relatively minor additional contributions from study area stormwater and advection through subsurface sediments. The total BEHP loads in surface water upstream and at the downstream boundary of the study area are generally comparable. Although the current upstream surface water load estimate exceeds the other loading terms, there is no indication that the surface water load is responsible for spatial distribution of the BEHP observed in study area sediments, and much of the surface water load appears to pass through the Site. As noted, the off-channel and nearshore elevated BEHP concentrations appear to be associated with localized upland sources and pathways.

A cross-media comparison of surface sediment, sediment trap samples, and particulate suspended solids on a study area-wide basis (Tables 10.2-14a-b and Figure 10.2-13b) show that the mean BEHP concentrations differ across all media. The highest average concentrations were observed in surface sediment, followed by surface water particulates, and then sediment trap samples.

10.2.5.4 Human and Ecological Risks Associated with BEHP

BEHP poses a risk to human health for tribal fishers consuming both resident and migratory fish caught within Portland Harbor. It was identified as posing potentially unacceptable risk to invertebrates, fish, amphibians, and aquatic plants. However, based on the frequency of exceedances and generally low magnitude of ecological risks for all species except smallmouth bass and sculpin, negligible risks are expected.

10.2.6 Total Chlordanes

A graphical CSM for total chlordanes in the study area is presented on Panels 10.2-6A–C. Chlordane is a manufactured chemical that was used as a pesticide on crops, including corn and citrus, and on home lawns and gardens in the U.S. from 1948 to 1988. It was also used from the 1950s to the 1980s to prevent or eliminate termites. EPA banned all uses of chlordane with the exception of termite control in 1983; all uses were banned in 1988 (ATSDR 1995). Chlordanes are hydrophobic, and sorb to solids

[11] The surface water data set only has total concentrations for BEHP; therefore, Figure 10.2-13a presents only the total estimated surface water loading rates for this chemical.

and organic matter in surface water and sediment. They are persistent in sediments, and subject to very slow abiotic degradation processes. The dissolved fraction in surface water is subject to volatilization. Chlordanes can bioaccumulate in the tissues of fish, birds, and mammals (ATSDR 1995).

10.2.6.1 Total Chlordanes Contaminant Distribution

Total chlordanes are the sum of oxychlordane, *trans*-chlordane, *cis*-chlordane, *trans*-nonachlor, and *cis*-nonachlor. Each of these chemicals is analyzed individually and the concentrations are summed to obtain the total chlordanes value.

Several sediment, surface water, and biota samples were reported with high detection limits for total chlordanes (Panels 10.2-6A–C). These high detection limits are the result of chromatographic interferences, laboratory blank contamination, mass spectrometer details related to identification of the components of total chlordanes, or limited sample sizes. High detection limits may obscure the presence of total chlordanes at a concentration below the elevated detection limit, but a high detection limit does not imply the presence of the chemical.

On a harbor-wide basis, the highest detected concentrations of chlordane in sediments are restricted to small, widely scattered nearshore or off-channel areas, proximal to local upland sources (Maps 5.2-22 and 5.2-23a-o and Panels 10.2-6A–B). Areas where surface and subsurface sediment concentrations are greater than 10 µg/kg include RM 5.8W-9W, and approximately RM 3E, 4E, 5.5E, and 11E. Elevated surface and subsurface concentrations are also found in Swan Island Lagoon, RM 5.6, and International Slip along the eastern nearshore. Reported concentrations in sediment trap samples were typically low (<4 µg/kg), with no strong temporal or spatial patterns in the measured concentrations (Figure 5.3-8a-b). Total chlordanes were detected in a majority of surface water samples. Total chlordanes were detected at low concentrations with varying frequency in all fish and invertebrate samples.

10.2.6.2 Potential Sources and Pathways of Total Chlordanes

The known sources of total chlordanes to the study area are summarized in Table 10.2-6 and on Panels 10.2-6A–C. The former Rhone Poulenc pesticide manufacturing facility is the only source of chlordanes currently identified that historically discharged manufacturing waste and stormwater to the river at approximately RM 6.9, and site groundwater infiltrates to City of Portland outfall OF-22B. However, the distribution of total chlordanes in nearshore sediments is indicative that other sources may also be present.

Historical known pathways for stormwater exist at the Rhone Poulenc facility, including infiltration of contaminated groundwater into the storm system and the City of Portland outfalls, specifically OF-22B (RM 6.9W). Total chlordanes have been detected in upland soils at the former Rhone Poulenc property, and stormwater is a likely complete historical pathway. Historically, manufacturing wastes from Rhone Poulenc were discharged to Doane Lake, which occasionally discharged to the river via a historical

drainage ditch from 1972 to 1980. This ditch entered the river near RM 6.9, an area with elevated surface and subsurface sediment total chlordanes concentrations. Currently, site stormwater is collected, treated, and discharged through WR-6, also located at RM 6.9W. No current known or likely complete overland transport pathways for total chlordanes have been identified.

Total chlordanes were detected in sediment samples collected during the PGE Willamette River Sediment Investigation, and chlordanes were likely used as a pesticide in the agricultural areas of the Willamette River watershed up until the late 1980s, so upriver sources continue to exist.

10.2.6.3 Loading, Fate, and Transport of Total Chlordanes

The loading, fate, and transport of total chlordanes in the study area in a typical year is summarized on Figures 10.2-16a through 10.2-18. Current external inputs are dominated by upriver surface water, with relatively minor additional contributions from study area stormwater, advection through subsurface sediments, and atmospheric deposition to the river surface. Upstream surface water loads for total chlordanes are comparable with the combined loads at RM 2 and the Multnomah Channel entrance in both the dissolved and particulate fractions. Although the current upstream surface water load estimate exceeds the other current loading terms, there is no indication that this load is responsible for the distribution of total chlordanes in study area sediments.

Cross-media comparisons of surface sediment, sediment traps, and suspended solids in surface water (Tables 10.2-14a-b and Figure 10.2-16b) show that the overall surface sediment concentrations are greater than those in surface water particulate and sediment trap samples. Surface water particulate and sediment trap concentrations are similar.

10.2.6.4 Human and Ecological Risks Associated with Chlordanes

Total chlordanes are estimated to pose a cancer risk greater than the lower end of USEPA's risk management range based on a harbor-wide consumption of resident fish at a subsistence level. Chlordanes in sediment were identified as posing potentially unacceptable risks to benthic invertebrates. They were not identified as posing potentially unacceptable risks to other ecological receptors.

10.2.7 Aldrin and Dieldrin

Graphical study area CSMs for aldrin and dieldrin are presented on Panels 10.2-7A–C and 10.2-8A–C, respectively. Aldrin and dieldrin are organochlorine insecticides with similar chemical structures, manufactured for agricultural use from the 1950s to 1987. From the 1950s until 1970, aldrin and dieldrin were widely used insecticides for crops and livestock. Peak production occurred in the mid-1960s. Aldrin/dieldrin ranked second—after DDT—among agricultural insecticides used in the U.S. in the 1960s (Jorgenson 2001). USEPA banned the use of aldrin and dieldrin in 1974, except to control termites. By 1987, USEPA banned all uses (ATSDR 2002c).

Aldrin and dieldrin are hydrophobic and have a strong tendency to sorb to solids and organic matter in surface water and sediment. Aldrin is subject to abiotic and microbially-mediated degradation processes as well as photolysis in surface water. Dieldrin degrades very slowly in the environment. Dieldrin can bioaccumulate, whereas aldrin does not as it is quickly metabolized to dieldrin in plants and animals (ATSDR 2002c).

10.2.7.1 Aldrin and Dieldrin Contaminant Distribution

A number of sediment, surface water, and biota samples were reported with high detection limits for aldrin or dieldrin (see data reports in Appendix A5 for more information). High detection limits may obscure the presence of aldrin or dieldrin at a concentration below the detection limit, but a high detection limit does not imply the presence of the chemical.

Aldrin and dieldrin contamination in sediment is generally restricted to small, widely scattered nearshore areas. Elevated concentrations were generally not detected in off-channel or navigation channel areas, with the exceptions of detections of dieldrin at RM 11.4E (which includes several samples nearshore and offshore with elevated concentrations) and the head of the International Slip (RM 3.7E). Surface and subsurface sediments results show elevated concentrations of aldrin and dieldrin at RM 6.8 to7.5W and RM 8.8W. Overall, aldrin concentrations are slightly higher in subsurface sediment, while dieldrin concentrations are generally higher in the surface sediments. Areas with high concentrations of aldrin and dieldrin are generally collocated.

Aldrin and dieldrin were detected both in particulate and dissolved surface water samples, with the dissolved fraction slightly to largely predominating, with a major exception at RM 6.9. Aldrin and dieldrin were infrequently detected in sediment trap samples, most frequently downstream of RM 8. Tissue concentrations of aldrin and dieldrin were generally less than 10 µg/kg, although higher dieldrin concentrations were observed in sculpin collected from RM 2E to 4E.

10.2.7.2 Potential Aldrin/Dieldrin Sources and Pathways

The known sources of aldrin and dieldrin are summarized in Tables 10.2-7 and 10.2-8, respectively. The only currently identified source of aldrin and dieldrin within the study area is the former Rhone Poulenc pesticide manufacturing facility that historically discharged manufacturing waste and stormwater to the river at approximately RM 6.9. Aldrin and dieldrin have been detected in upland soils at this site, and stormwater is a known complete current and historical pathway. However, based on the distribution of aldrin and dieldrin in nearshore sediments, other sources may be present.

Historically, manufacturing wastes from Rhone Poulenc were routed to Doane Lake, which occasionally discharged to the river via a drainage ditch near RM 6.9 from 1972 to 1980. Currently site stormwater is collected, treated, and discharged through WR-6, also located at RM 6.9W. No current known or likely complete overwater or riverbank

erosion pathways for aldrin or dieldrin have been identified. Atmospheric deposition is a potential historical and current pathway, but has not been quantified.

Jorgenson (2001) lists Van Waters & Rogers (Univar), as a producer and/or distributor of aldrin and dieldrin. However, there is no information about releases to the environment from this facility.

10.2.7.3 Loading, Fate, and Transport of Aldrin and Dieldrin

The loading, fate, and transport assessment of aldrin in the study area for a typical year is summarized on Figures 10.2-19a through 10.2-21, and on Figures 10.2-22a through 10.2-24 for dieldrin. Upriver surface water is the largest estimated external loading term; surface water loading of dieldrin is approximately 50 times that of aldrin. Stormwater is the second highest estimated loading term, followed by atmospheric deposition to the river surface and advection through subsurface sediments. There is an apparent increase in aldrin loads in surface water between the upstream and downstream boundaries of the study area. Conversely, there is little apparent change in surface water dieldrin loads between upstream and downstream boundaries. Although the current upstream surface water load estimate exceeds the other loading terms, there is no indication that the surface water load is responsible for the spatial distribution of aldrin and dieldrin in study area sediments, and nearshore aldrin and dieldrin concentrations appear to be associated with localized upland sources and pathways.

Cross-media comparisons of surface sediments, sediment trap samples, and suspended solids in surface water for aldrin and dieldrin are provided in Tables 10.2-14a-b (summary statistics and statistical comparisons) and Figures 10.2-19b and 10.2-22b (box-whisker distribution plots). Aldrin surface sediment and sediment trap concentrations are not significantly different; concentrations in both of these media are greater than the concentration in surface water particles on a study area-wide basis. For dieldrin, study area-wide surface sediment concentrations are significantly greater than the concentrations in surface water particulates, but there appear to be no significant differences between sediment trap concentrations and sediments or surface water particulates.

10.2.7.4 Human and Ecological Risks Associated with Aldrin and Dieldrin

Dieldrin poses unacceptable human health risks based on consumption of resident fish on both a harbor-wide and localized scale. Dieldrin was identified as posing potentially unacceptable risk to benthic invertebrates. Aldrin, which is rapidly transformed into dieldrin by most fish and wildlife species, was identified as posing potentially unacceptable ecological risk to spotted sandpiper at a limited spatial extent.

10.2.8 Arsenic, Copper, and Zinc

Graphical study area-wide CSMs are presented for arsenic, copper, and zinc on Panels 10.2-9A–C, 10.2-10A–C, and 10.2-11A–C, respectively. All three metals are abundant elements in the earth's crust, and natural releases to environmental media can be significant.

Arsenic is a naturally occurring metal that is found widely in natural minerals, including realgar ($As_4S_{4(s)}$), orpiment ($As_2S_{3(s)}$), and arsenolite (As_2O_3; ATSDR 2005a). It occurs naturally in soil, water, and air as a result of mineral weathering, leaching, volcanic eruptions, and wind-blown dirt (ATSDR 2005a). Anthropogenic activities, including smelting, use in pesticides, combustion of wood and coal, waste incineration, and the production and use of treated wood products that utilize soluble chromated copper arsenate (CCA), can also release arsenic into the air, soil, water, and sediments.

Arsenic is a redox-sensitive species, existing at the +3 and +5 oxidation states in aqueous environmental conditions. Under oxidizing conditions the As(V) species (H_3AsO_4, $H_2AsO_4^-$, $H_2AsO_4^-$, $HAsO_4^{2-}$, AsO_4^{3-}) predominate, while under reducing conditions the As(III) species (H_3AsO_3, $H_2AsO_3^-$, $HAsO_3^{2-}$, AsO_3^{3-}) predominate (EPRI 1984). Arsenic is generally highly soluble, with few mineral phases exerting controls on aqueous arsenic concentrations under typical environmental conditions. Arsenic sulfide minerals, such as orpiment and realgar, can be formed under reducing and acidic conditions. Although arsenic minerals are generally highly soluble, adsorption reactions to sediment/aquifer mineral grain surfaces frequently limit dissolved arsenic concentrations (Kabata-Pendias and Pendias 1992). Arsenic is particularly strongly adsorbed to iron oxide minerals, with the As(V) species having a greater affinity for the oxide surface than the As(III) species. Because arsenic is frequently present as an anion under typical environmental conditions, its sorption to oxide surfaces is favored at pH <9 (Stumm 1992).

In aquatic environments, bioaccumulation of arsenic occurs primarily in algae and lower invertebrates (ATSDR 2005a). Fish and shellfish can also accumulate arsenic, mainly in the exoskeleton of invertebrates and in the livers of fish. While biomagnification in aquatic food chains is not generally considered significant, predatory fish may biomagnify arsenic through the consumption of prey species (especially bottom dwellers) (ATSDR 2005a).

Copper is an abundant metal element in the earth's crust. Natural releases to environmental media can be significant. Mining operations, agriculture, wastewater sludge, municipal and industrial solid waste, and other industrial processes can also result in environmental releases of copper (ATSDR 2004).

Copper exists in four oxidation states: Cu^0, Cu^{+1}, Cu^{+2}, and Cu^{+3} (Eisler 1998). Of these oxidation states, the cupric ion (Cu^{+2}) is most likely to be present in water, though rarely as a free ion. As free ions, cupric ions are the most readily available and toxic inorganic species of copper. However, the cupric ions have a strong tendency to complex with or sorb to numerous compounds normally found in natural waters, including suspended solids surfaces and dissolved or particulate organic carbon. Such complexation reduces bioavailability to aquatic organisms (Eisler 1998; USEPA 2000c). The amount of the various copper compounds and complexes present in solution in freshwater depend on water pH, temperature, hardness, and alkalinity; concentrations of bicarbonate, sulfide, and organic ligands; size and density of suspended materials; and rates of coagulation

and sedimentation of particulates. Up to 29 different species of copper can be present in aqueous solution in the pH range from 6 to 9. The majority of copper in freshwater from pH 6.0 to 9.3 is in the form of carbonate species ($CuHCO_3^+$, $CuCO_3$, $Cu[CO3]_2^{-2}$), which have low toxicity (Eisler 1998). Cupric ions account for less than 1 percent of the total dissolved copper in freshwater. Copper carbonate, cupric hydroxide, cupric oxide, and cupric sulfide will precipitate from solution or form colloidal suspensions when excess cupric ions are present (Eisler 1998). The majority of copper released to surface waters settles out or sorbs to sediments (Eisler 1998). While copper can transform in response to environmental chemistry, it does not degrade.

Copper is taken up by aquatic organisms primarily through dietary exposure and is an essential micronutrient for animals as a component of a number of essential enzymes. Most organisms retain only a small proportion of the copper ingested with their diet. Copper bioconcentrates in aquatic organisms but does not bioaccumulate in mammals or biomagnify in aquatic food chains (USEPA 2000c).

Zinc is a common element in the earth's crust and is released to the environment from both natural and anthropogenic sources. Mining and metallurgical processing are the primary anthropogenic sources, along with use of commercial products such as fertilizers and wood preservatives that contain zinc (ATSDR 1997a). Zinc is also used in galvanizing steel and in soldering formulas.

In the environment, zinc occurs as a sulfide, oxide, or carbonate. In freshwater, zinc is most soluble at low pH and low alkalinity: 10 mg Zn/L of solution at pH 6 that declines to 6.5 mg Zn/L at pH 7, 0.65 mg Zn/L at pH 8, and 0.01 mg Zn/L at pH 9 (Eisler 1993). Zinc in the water column can partition to dissolved and particulate organic carbon. Water hardness (i.e., calcium concentration), pH, and metal speciation are important factors in controlling the water column concentrations of zinc because the divalent zinc ion is believed to be responsible for observed biological effects (USEPA 2000c). Because zinc ligands are soluble in neutral and acidic solutions, zinc is readily transported in most natural waters (Eisler 1993). However, most of the zinc introduced into aquatic environments eventually is partitioned into the sediments (Eisler 1993). Zinc release from sediments is enhanced under conditions of high dissolved oxygen, low salinity, and low pH (Eisler 1993). Zinc may change forms in the environment, but it does not degrade.

Zinc is an essential trace element for all living organisms. As a constituent of more than 200 metalloenzymes and other metabolic compounds, zinc ensures stability of biological molecules such as DNA and of biological structures such as membranes and ribosomes (Eisler 1993). Most studies reviewed contain data that suggest that zinc is not a highly mobile element in aquatic food webs, and there appears to be little evidence to support the general occurrence of biomagnification of zinc within marine or freshwater food webs (USEPA 2000c). Bioavailability of zinc in sediment is controlled by the acid-volatile sediment concentration.

10.2.8.1 Arsenic, Copper, and Zinc Contaminant Distribution

With the exception of a broad area of relatively elevated copper and zinc concentrations in the vicinity of Swan Island Lagoon and zinc at Terminal 4, Slip 3, elevated arsenic, copper, and zinc concentrations in surface and subsurface sediment are generally restricted to small, widely scattered nearshore areas. The similarity of surface and subsurface concentrations in these areas suggests both recent and historical inputs of all three metals.

Total arsenic, copper, and zinc concentrations in surface water were generally consistent across the entire study area. Concentrations were generally higher in low-flow sampling events, and there is generally no relationship evident between elevated surface water and elevated surface sediment concentrations. Sediments collected in and upstream of the study area over the course of a year in sediment traps show little spatial or temporal trends in measured concentrations. The highest reported arsenic concentrations in TZW are located at the west side of the channel at RM 6.2–6.6, and the west bank at RM 7.7. However, there are no corresponding high arsenic concentrations in sediment. The highest copper and zinc concentrations in TZW were measured offshore of the Gasco and Siltronic sites in areas where no elevated surface sediment concentrations were reported. Arsenic, copper, and zinc were detected in nearly all fish and invertebrate species and tissues analyzed from within the study area.

10.2.8.2 Potential Sources of Arsenic, Copper, and Zinc

The areas of elevated sediment concentrations correspond to the locations of former shipyards, wood treatment facilities, metal recycling operations, pipe manufacturing facilities, metal plating operations, and marine repair facilities. Metals are also associated with some facilities where metal slag and sandblast grit were used as fill. The primary industries in Portland Harbor known to have handled, manufactured, or disposed of arsenic, copper, or zinc include pesticide manufacturing, shipbuilding/demolition and marine repair facilities, metals recycling, battery scrapping, wood treating, and MGP. However, a number of sites with known or likely complete pathways do not appear associated with proximal surface sediment contamination.

Known complete or likely complete historical pathways for arsenic, copper, and zinc have been identified at up to 46 sites.

Although one or more of these metals has been identified as a stormwater COI at sites that drain to a number of municipal and non-municipal shared conveyance systems, associated sediment concentrations are not present near all these outfalls (Tables 10.2-9 through 10.2-11).

Zinc is elevated in sediment in Balch Creek Cove, which is the discharge location for OF-16, OF-17, WR-258, and WR-235. Metals have not been identified as stormwater COIs at WR-258 (drains Fire Station 6) and WR-235 (Port of Portland Terminal 2). GE Decommissioning has a known historical and likely current complete stormwater pathway for zinc. Calbag-Nicolai and Galvanizers have likely historical and known

current complete stormwater pathways for zinc. All three of these sites are located within the basins of these outfalls.

Arsenic, copper, and zinc concentrations are elevated in sediments offshore of the areas adjacent to Gunderson and the small cove adjacent to the Shaver Transportation and Front Avenue LP properties. Gunderson has known complete pathways, both historical and current, for stormwater and overland transport, and Front Avenue LP has a historical known complete stormwater pathway for these metals. Two shared conveyance systems also drain to this area, OF-18 and OF-19. However, none of these metals are elevated in the cove that OF-18 discharges to, and only copper is elevated in the vicinity of the OF-19 discharge. Front Avenue LP has a historical likely complete pathway for copper in stormwater, and Chevron has a historical known complete pathway for copper in stormwater. Both of these sites drain, at least in part, to OF-19 (Table 10.2-10).

Elevated sediment concentrations of copper and zinc are present on the nearshore areas on the west side of Swan Island Lagoon and the north end of Swan Island. Cascade General, Swan Island Upland Facility, and Fred Devine are identified as having a likely historically complete stormwater pathway for copper and zinc. Single samples with elevated concentrations of zinc and copper are also present near OFM-1 and of zinc near OFM-2. Freightliner TMP and TMP2 drain to these basins and are identified as having a likely historically complete stormwater pathway for copper and zinc.

Stormwater and groundwater infiltration from sites draining to OF-22B and OF-22C (RM 6.8W) are the likely sources of elevated arsenic concentrations in surface sediment at this location. Stormwater has been identified as a historical and/or current known complete pathway at Rhone Poulenc, Metro Transfer Station, Schnitzer-Doane Lake, Gasco, Siltronic, and Gould, which drained to or have had groundwater infiltration to these outfalls.

TZW sampling results indicate that groundwater is not a significant source to sediments. Low subsurface sediment arsenic concentrations may reflect the dynamic setting of the Site—arsenic may be transported downstream before there is an opportunity for long-term burial. Downstream surface sediment concentrations are low, suggesting that if this is the case, the mass of arsenic being discharged is relatively low and is readily dispersed.

Overland transport has been identified as a likely complete historical pathway for both Mar Com parcels, as well as a likely complete current pathway for the North parcel. Elevated surface sediment concentrations are located offshore of the Mar Com facilities and surface water concentration immediately upstream appears to support stormwater as a pathway. Calbag Metals, adjacent to the International Slip, has been identified as having a known current and historical complete stormwater pathways for zinc and copper; Terminal 4 has a likely historical complete overland pathway for zinc.

Arsenic, copper, and zinc are associated with Marine Barge Paint and Blast Area operations at Gunderson and a known historical and current complete pathway for groundwater has been identified for arsenic at Gunderson.

Groundwater is a known or likely current and historically complete pathway for these metals for the Siltronic and Gasco sites. However, none of these metals is present at elevated concentrations in surface or subsurface sediment.

Five sites have been identified as having historical known complete pathways for copper and zinc: Gunderson, Cascade General, Swan Island Upland Facility, McCormick and Baxter, and Schnitzer-Calbag. McCormick and Baxter also has a historical complete pathway for arsenic. All but McCormick and Baxter have known or likely current complete overwater pathways. McCormick and Baxter is the only identified site with a known historical complete pathway for arsenic.

Based on limited riverbank sampling, relatively large areas of elevated metals concentrations in surface sediment are associated with sites with known or likely historical complete riverbank erosion pathways for arsenic, copper, and zinc. These sites include Gunderson, Willamette Cove, Mar Com South, and McCormick and Baxter. A current known or likely complete pathway for riverbank erosion is limited to Gunderson.

10.2.8.3 Loading, Fate, and Transport of Arsenic, Copper and Zinc

The loading, fate, and transport of arsenic in the study area is summarized on Figures 10.2-25a through 10.2-27. Copper is summarized on Figures 10.2-28a through 10.2-30, and zinc is summarized on Figures 10.2-31a through 10.2-33. Estimated loads from upriver surface water dominate the current loads for all three metals, frequently exceeding the other quantified external loading terms by 2 or more orders of magnitude. Upstream and downstream surface water arsenic loads are comparable. Estimated copper and zinc loads entering the study area are slightly higher than the loads leaving. The distribution of arsenic, copper, and zinc (respectively) in surface sediments, sediment trap samples, and the surface water particulate fraction are presented on Figures 10-2-25b, 10.2-28b, and 10.2-31b, summary statistics in each media are presented in Table 10.2-14a, and the results of cross-media statistical testing are provided Table 10.2-14b. For each of these metals, all the distributions in each medium are significantly different from each other. Concentrations of each metal in surface water suspended particles are greater than in sediment trap or surface sediments on a study area-wide basis. Based on median values, sediment trap concentrations are slighter greater overall than surface sediment concentrations for all three metals.

Although the current upstream surface water load estimate greatly exceeds the other current loading terms, there is no indication that this load is responsible for the spatial distribution of the concentrations of these metals observed in study area sediments.

10.2.8.4 Human and Ecological Risks Associated with Arsenic, Copper, and Zinc

Arsenic concentrations in sediment pose unacceptable human health risks due to consumption of fish and shellfish, direct exposure to in-water sediment, direct exposure to beach sediment, and use of the Willamette as a drinking water source. Potentially unacceptable ecological risks from copper were identified for more lines of evidence than any other contaminant except for PCBs, and were identified for benthic invertebrates and multiple fish species, as well as for spotted sandpiper. Zinc was identified as posing potentially unacceptable risk to benthic invertebrates and localized risk to other benthic receptors. Arsenic was identified as posing low unacceptable risks to benthic invertebrates.

10.2.9 Chromium

The study area graphical CSM for chromium is presented on Panels 10.2-12A–C. Chromium is a naturally occurring element found in rocks, animals, plants, and soil. It can exist in several different forms in soil, sediment, water, and air. Chromium(III) occurs naturally in the environment but is also a product of industry. Chromium(0) is used for making steel. Chromium(III) and chromium(VI) forms are produced by the chemical industry and are used for chrome plating, the manufacture of dyes and pigments, leather tanning, and wood preserving. Smaller amounts are used in drilling muds, rust and corrosion inhibitors, textiles, and toner for copying machines (ATSDR 2008).

In the environment, chromium can be found in air, soil, and water. Chromium compounds will usually remain in the air for less than 10 days, depositing to the land and water, especially by wet deposition (ATSDR 2008). Most chromium in water binds to soil and other materials and is subsequently subject to sediment transport processes, though a small amount may dissolve in the water. It can easily change from one form to another in water and soil, depending on the conditions present (ATSDR 2008). The relation between Cr(III) and Cr(VI) in the environment is strongly dependent on pH and oxidative properties of the location, but in most cases the Cr(III) is the dominating species (Kotas and Stasicka 2000).

Although chromium(III) is required in trace amounts for sugar and lipid metabolism in humans and its deficiency may cause a disease called chromium deficiency, chromium(VI) is a toxin and a carcinogen (ATSDR 2008). Fish do not significantly accumulate chromium in their bodies from water (ATSDR 2008).

10.2.9.1 Chromium Contaminant Distribution

Areas of elevated chromium concentrations in surface and subsurface sediments in the study area all occur in a few, widely scattered nearshore areas and at the head of the International Slip. They are limited in spatial extent and include RM 2E, 4E, 6E, Swan Island Lagoon, 6W, 7W, and 9W. The distribution of concentrations in surface and subsurface sediments suggest both recent and historical sources.

Sediment trap samples show a uniform distribution of chromium levels seasonally and throughout and upstream of the study area (see Figure 5.3-12a-b). Most sediment trap samples fall between 30 and 40 mg/kg; the single highest value (60 mg/kg) was measured upstream of the study area at RM 15.7E during the May to August period.

Chromium was sampled offshore of sites between RM 6.2W and 7.6W. Elevated TZW concentrations (greater than 100 µg/L) were observed between RM 6.2W and 6.5W, offshore of the Gasco and Siltronic properties.

Chromium was detected in all fish and invertebrate species and tissues analyzed within the study area.

10.2.9.2 Potential Sources of Chromium and Pathways

In Portland Harbor, the primary industries known to have handled, manufactured, or disposed of chromium include the steel industry (EOSM), ship building/demolition and marine repair facilities (Gunderson, Cascade General, Mar Com), metal recycling (Schnitzer-Calbag, Calbag-Nicolai, Calbag Metals-Front Ave., and former operations at Schnitzer-Doane Lake), wood treating (McCormack and Baxter), and MGP sites (Gasco), and heavy oil facilities (bulk fuel and asphalt storage). Sodium bichromate was used in the sodium chlorate manufacturing process as a corrosion inhibitor at Arkema. Historical known complete or likely complete pathways for chromium have been identified at 43 sites (Table 10.2-12 and Panels 10.2-12A–C), and include stormwater (38 sites), groundwater (7 sites), overwater releases (5 sites), overland transport (9 sites), and riverbank erosion (10 sites). Current known complete or likely complete pathways for chromium have been identified at 20 sites and include stormwater (13 sites), groundwater (5 sites), overwater releases (4 sites), overland transport (3 sites), and riverbank erosion (3 sites).

Groundwater is a historical known or likely complete pathway for chromium at seven sites and a current pathway for five sites. Chromium concentrations near OF-22B and OF-22C may be related to sites with known or likely complete groundwater/stormwater infiltration draining to these outfalls.

Based on limited riverbank sampling, riverbank erosion is a historical known or likely complete pathway for chromium at 10 sites, and a current source at 4 sites. Chromium concentrations in sediment are indicative of potential releases at EOSM, Schnitzer-Calbag metals, Portland Shipyards, and Gunderson.

Chromium was identified as a COI at 17 upstream sites based on their hazardous substances/waste types. Of these 17 sites, chromium was detected in sampled media at the following 5 sites:

- Willamette Falls Locks—Chromium detected in upland soil, and direct releases/spills represent potential pathways to the river

- Zidell Marine Corporation—Chromium detected in upland soil, and direct releases/spills, groundwater, and stormwater represent potential pathways to the river
- OHSU-Moody Ave. Units A, B, C—Chromium detected in upland soils, and stormwater and groundwater represent potential pathways to the river
- Clackamette Cove Area—Chromium detected in upland soils, and groundwater represents a potential pathway to the river
- South Waterfront Redevelopment Area 3—Chromium detected in groundwater, which represents a potential pathway to the river.

10.2.9.3 Loading, Fate, and Transport of Chromium

Chromium loading, fate, and transport assessment for the study area is summarized on Figures 10.2-34a through 10.2-36. Estimated loads from upriver surface water dominate the current loads, exceeding the next highest external loading terms—stormwater and upland groundwater plumes—by more than 2 orders of magnitude. The chromium loads in upstream surface water and at the downstream boundary of the study area are generally comparable, reflecting the absence of significant loads within the study area. The nearshore and off-channel areas of elevated chromium concentrations generally appear to be associated with localized upland sources and pathways.

The cross-media comparison of surface sediments, sediment traps, and suspended solids in surface water (Table 10.2-14a-b and Figure 10.2-34b) show that the study area-wide concentrations of all media are statistically different, with surface sediment having the highest concentrations, followed by sediment traps and then by suspended solids in surface water.

Within the study area, numerous historical and current sources of chromium have been identified for all pathways, but primarily through stormwater discharge. The areas of elevated sediment concentrations generally correspond to the locations of current or former shipyards, wood treatment facilities, pesticide manufacturing, metal recycling operations, steel manufacturing, metal plating operations, and marine repair facilities. Chromium is also identified at some facilities where metal slag and sandblast grit were used as fill. Known and likely current and historical sources of chromium to the study area are summarized in Table 10.2-12 and Panels 10.2-12A–C.

The chromium loading estimates indicate that loads from upriver surface water dominate the current loads, exceeding the next highest external loading terms—stormwater and upland groundwater plumes—by more than 2 orders of magnitude. However, the estimated loads entering and leaving the study area are comparable, suggesting the absence of significant loads within the study area.

10.2.9.4 Human and Ecological Risks Associated with Chromium

Chromium is estimated to posing potentially unacceptable risk to benthic invertebrates, although the risk is of low magnitude and the areal extent is limited.

10.2.10 Tributyltin Ion

A graphical CSM for TBT is presented on Panels 10.2-13A–C. TBT is an organotin compound, and since the mid-1970s has been and is still used as an antifouling agent in paints on the immersed portions of boats and floating structures (Batt 2004). Antifouling paints represent the largest source of TBT in aquatic environments. Many countries restricted the use of antifouling paints based on the risks to shellfish. The U.S. partially banned the use of TBT-based antifouling paints in 1988 (Showalter and Savarese 2005). Use of TBT compounds as slimicides on masonry, disinfectants, and biocides for various industrial processes also may result in their release to the environment.

TBT is an ionic organic compound, and its partitioning behavior is affected by pH and the identity of anions in solution that pair with the TBT ion (Arnold et al. 1997). Specifically, for pH 10 to 7 the measured log K_{oc} values are on the order of 4; from pH 7 to pH 3 they drop to roughly 2. The mean surface water pH in Portland Harbor is 7.4 (10^{th} percentile is 7.0 and 90^{th} percentile is 7.8). Observed pore water pH values range from 5.6 to 8.1. TBT in its nonionic form (not likely observed at the site) is highly hydrophobic, with K_{ow} values on the order of 7 (K_{ow}WIN[12]).

Degradation of organotin compounds involves the breaking of the tin-carbon bond. TBT is subject to different degradation mechanisms depending on its location in the environment. In surface water, it is subject to fairly rapid[13] photodegradation and biodegradation (TBT can be degraded by microbial, microalgal, and fungal populations, as well as by some higher organisms, such as fish; Anderson et al. 2002). Degradation of organotin compounds in sediments is much slower than in water, and half-lives have been estimated to be several years (Alzieu 1998). Abiotic cleavage of the tin-carbon bond by hydrolysis is not an important fate process under environmental conditions (WHO 1990).

While accumulation of TBT from water into organisms may be a significant process that can result in elevated tissue concentrations, subsequent biomagnification through the food web is reportedly minor (ATSDR 2005b).

10.2.10.1 TBT Contaminant Distribution

TBT contamination is sediment is primarily located in the vicinity of the Cascade General Shipyard and adjacent to Swan Island Lagoon. Subsurface sediments exhibit

[12] K_{ow}WIN software available online as part of USEPA Estimation Program Interface (EPI) suite of programs: http://www.epa.gov/oppt/exposure/pubs/episuite.htm

[13] Half-life information for TBT in freshwater could not be found; however, the following information was found for seawater: the half-life of tributyltin in seawater varies, depending on pH, temperature, turbidity, and light; it is generally estimated to be in the range of 1 day to a few weeks (Alzieu 1998). Biodegradation is the major process in seawaters rich in suspended solids, but photolysis, in surface waters, exceeds biodegradation in clean seawater. Calculated half-lives range from 6 days in summertime waters rich in suspended particles to 127 days in clean winter waters (Watanabe et al. 1992).

slightly higher concentrations than surface sediments, suggesting that contributions from historical inputs were greater relative to current inputs. Upstream of RM 7.5, TBT was detected in sediment trap samples only in Swan Island Lagoon.

10.2.10.2 Potential Sources and Pathways of TBT

Within the study area, historical and current sources contributed TBT to the river primarily through the overwater and stormwater pathways. Areas of elevated TBT concentrations correspond with current and former shipyards, where ship hull washing, abrasive blasting, and painting occurred in dry docks and berths (see Map 3.2-10).

Identified known and likely current and historical sources of TBT to the study area are summarized in Table 10.2-13 and Panels 10.2-13A–C. Historical pathways for TBT migration are found at four current and historical shipyard facilities (Cascade General, Gunderson, Mar Com South, and Marine Finance) and include stormwater (four sites) and overwater, overland, and riverbank erosion (two sites). Current known complete or likely complete pathways for TBT have been identified at two sites (Cascade General and Gunderson).

A current and historical known complete stormwater pathway to the river exists at Gunderson, an active manufacturer and refurbisher of railroad cars and marine barges since 1913 (Integral 2007r). Historical likely complete stormwater pathways also exist at Cascade General, Mar Com South, and Marine Finance. Historical overland transport pathways are likely complete at Mar Com South and Marine Finance. Overwater discharge is considered to be the greatest contributor of TBT to the river; current and historical complete pathways for overwater discharge of TBT are found at Cascade General and a complete historical overwater pathway existed at Mar Com South. There are no current or historical groundwater pathways for TBT in the study area. Likely complete historical pathways for riverbank erosion have been identified at Mar Com South and Marine Finance. Information on atmospheric deposition of TBT is very limited, but long-range atmospheric transport of butyltins does occur.

TBT was identified as a COI at two upstream sites, Zidell Marine Corporation site (RM 14W) and Ross Island Sand & Gravel (RM 14.7E), based on detections in sampled media.

10.2.10.3 Loading, Fate, and Transport of TBT

The loading, fate, and transport assessment for TBT in the study area is summarized on Figures 10.2-37a through 10.2-39. Estimated TBT inputs from upriver surface water (11 kg/yr) are lower than those from advection through subsurface sediments (36 kg/yr). The relatively high overall subsurface advective load estimate is driven by localized TBT concentrations at RM 8 to 8.9. Quantitative estimates of internal fate and transport processes were developed only for advection through surface sediments (9.8 kg/yr), which is comparable in magnitude to upstream surface water loading. Advective loading for both pathways is greatest between RM 8 and 8.9 (Figure 10.2-39).

Cross-media comparison and statistical assessment of surface sediments, sediment traps, and suspended solids in surface water (Table 10.2-14a-b and Figure 10.2-37b) show that the concentrations in all media are statistically different.

10.2.10.4 Human and Ecological Risks Associated with TBT

TBT was identified as posing potentially unacceptable risk to fish and benthic invertebrates, though these risks are localized in historical shipyard areas.

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