REFERENCE 11

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Reference 11

PRELIMINARY NATURAL RESOURCE SURVEY

Lower Willamette River
Portland, Oregon
September 8, 1999 Site ID: 3R

FINDINGS OF FACT

SITE OVERVIEW

The lower Willamette River is a highly industrialized waterway that supports an active shipping industry and diverse urban development. The area of concern is a six-mile section of the lower river where discharges and spills have contaminated sediments with polynuclear aromatic hydrocarbons (PAHs), trace elements, and pesticides. Seventeen sites have been identified as potential sources of contamination to the river, but sediment investigations indicate the contamination beyond the areas adjacent to these sites. The area is being evaluated as a candidate for inclusion on the U.S. EPA National Priorities List.

The Willamette River is an important fish stream with spawning populations of chinook and coho salmon, steelhead, American shad, Pacific lamprey, and white sturgeon. The lower Willamette River upstream to the Willamette Falls provides a migratory corridor for both juvenile and adult anadromous fish and juvenile rearing habitat for several anadromous fish species. Three runs of chinook, two runs of steelhead, and individual runs of coho and sockeye salmon occur in the area. Several of these runs are either listed or proposed for listing under the Endangered Species Act. Pacific lamprey is classified as a species of special concern because of declining populations.

The contaminants of concern in the lower Willamette River are PAHs, polychlorinated biphenyls (PCBs), trace elements, organotins, and chlorinated pesticides. PAHs are ubiquitous at highly elevated concentrations in the sediments of three of five reaches in the lower river. Trace elements are ubiquitous at lower concentrations, but are elevated near specific sites. Pesticides have also been detected near an agricultural chemical plant. All of the substances of concern have been detected in the river sediments at concentrations shown to cause adverse effects in aquatic organisms in other studies. Invertebrate toxicity due to sediment exposure has been demonstrated in limited laboratory bioassays, but toxicity to fish has not been determined.

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SITE HISTORY

The Willamette River originates in the Cascade Mountain Range and flows approximately 187 miles north before discharging to the Columbia River. The six-mile study area has been divided into five reaches to facilitate environmental investigations. The lower Willamette River study area extends from river mile (Rm) 3.5 to Rm 9.5 (Weston 1998; Figure 1).

Much of the upland areas adjacent to the Willamette River within the study area are heavily industrialized, and marine traffic within the river is considered intensive. The river shore has been altered to accommodate urban development and a growing shipping industry. Steeply sloped banks covered with riprap or constructed bulkheads, piers, or wharves characterize the shoreline. Industrial operations in the study area include hazardous waste storage, marine construction, bulk petroleum product storage and handling, wood treating, agricultural chemical production, battery processing, chlorine production, and ship maintenance and repair (Weston 1998).

Seventeen industrial sites have been identified as potential sources of contamination to the sediments in the Willamette River study area (Table 1). Past investigations have found numerous industrial contaminants in site soils and river sediment including PAHs, pesticides, PCBs, dioxins, trace elements, organotins, pentachlorophenol, and solvents. Contaminants have likely entered the river via accidental spills, direct discharge, contaminated groundwater discharge, surface water and stormwater runoff, or contaminated soil erosion (Weston 1998).

The Willamette River study area is being evaluated for potential inclusion onto the EPA National Priorities List of hazardous waste sites. A Site Inspection (SI) for the study area was conducted in 1997 and the SI Report was completed in 1998 (Weston 1998).

PATHWAY CHARACTERIZATION

Source and pathway investigations were not conducted as part of Site Inspection activities. However, most industrial activity in the area takes place within 300 m of the river shore and discharges to the river occur via outfalls, direct discharge, and spills (Weston 1998).

Surface Runoff Pathway

Surface runoff pathways have not been investigated area-wide, but information indicates that direct surface discharges are a significant contributor of site-related contaminants to the lower Willamette River. Fuel and other hydrocarbon spills have been documented at the Time Oil Northwest and Linnton Terminals, Terminal 4 - Port of Portland, Mobil Oil Bulk Plant, and Elf Atochem. Direct

discharge of fuel or sandblast wastes have been reported at the following facilities: U.S. Moorings, GASCO, McCormick and Baxter, Rhone-Poulenc, Gould, Inc., Elf Atochem, Port of Portland Ship Repair, and Gunderson, Inc. Leaking underground storage tanks have been reported at Reidel Environmental Services, and Gunderson, Inc. (Weston 1997).

Groundwater Pathway

The groundwater pathway to the Willamette River has not been investigated across the entire study area, but as reported, most of the sites are adjacent to or within 300 m of the river shore. Nearshore sediments may capture areas of significant groundwater contamination (Weston 1998). Leaking underground storage tanks have been reported at Reidel Environmental Services at Gunderson, Inc. (Weston 1997).

POTENTIALLY EXPOSED RESOURCES

Habitats potentially at risk include the surface waters and associated bottom substrates of the lower Willamette River. Resources at risk include anadromous species, benthic invertebrates, and other resident species that provide a prey base and supporting habitat. The Willamette River is the second largest tributary of the Columbia River and it supports large salmonid, shad, and sturgeon populations. Spawning of anadromous species occurs throughout the upper river basin, upstream of the study area. Substantial recreational fisheries are present on the river and annual stocking programs are currently used to sustain salmonid populations within the basin (Foster personal communication 1998).

Juvenile salmonids use the lower Willamette River as a critical rearing habitat during their outmigration. Trust resources may be at risk by remaining for long periods in the study area during sensitive early life stages.

Habitat Characterization

The Willamette River originates in the Cascade Range and flows north for approximately 300 km before discharging into the Columbia River, 160 km upstream from the Pacific Ocean. Surface waters in the study area are tidal freshwater (Foster personal communication 1998). Channel depths range from 3 to 42 m with an average depth of 13.6 m (Weston, 1998). Mean river flow is 31,370 cubic feet per second (cfs) with monthly flow ranging from 7,626 cfs in August to 44,190 cfs in December (USGS 1998).

Lower Willamette River habitat in the study area has been altered to accommodate urban development and a growing shipping industry. Development in the harbor has replaced the natural shoreline with riprap, bulkheads, other artificial structures, and sand-beached lagoons. Because of dredging, the river has a steeply sloped, silt and sand bottom (PTI 1992).

Resource Utilization

Several species of anadromous fishes, including chinook salmon, steelhead, coho salmon, sockeye salmon, American shad, and white sturgeon occur in the area. Both juveniles and adults use the study area as a migratory corridor and as rearing habitat by juveniles. Cutthroat trout are also present, but their abundance is low, particularly in the lower Willamette River (Bennett and Foster 1991; Foster personal communication 1998).

Chinook salmon

Two genetically distinct stocks of chinook salmon—spring chinook and fall chinook—use the Willamette River. The stocks are named for the period in which they enter fresh water.

During their annual migration, Willamette River spring chinook begin entering the Columbia River during January. Peak densities occur in late March, with entries tapering off by mid-May. Spring chinook migrate past the site, bound for upstream tributaries. Spawning takes place in the early fall.

Wild juvenile spring chinook reside in fresh water from 3 to 18 months following egg deposition. Emigration from natal streams occurs during one of three periods: (1) a movement of yearlings in late winter and spring soon after emergence (subyearlings); (2) a movement of yearlings in late fall and early winter; and (3) an emigration of smolts the following spring (Howell et al. 1985). Based on the small size of juveniles caught at collection facilities at Leaburg on the McKenzie River, it is probable that many of the naturally produced spring chinook in Willamette sub-basins emigrate to the lower reaches of tributaries and the mainstem Willamette River to complete rearing before smolting (ODFW 1990). Chinook reside in the ocean for 1 to 5 years before returning to spawn (Bennett and Foster, 1991).

Five large hatcheries produce approximately 5 to 6 million smolt-size spring chinook for release into the Willamette River each year, plus additional fingerling salmon to seed under-used reservoir and tributary streams. Current hatchery practices include the release of one-third of the annual production as subyearlings in November and two-thirds as moderate-sized yearlings (smolts) in March. Subyearlings are released into streams or reservoirs for further rearing. Most of the smolts are released near the adult collection sites, but some are also trucked to areas within the lower Willamette River to increase survival (Foster personal communication 1998).

A stock of fall chinook was introduced to the Willamette River in 1964. This stock spawns and rears in the mainstem of the upper Willamette River and lower reaches of east-side tributaries upstream of the site. Fall chinook begin entering the Columbia and Willamette rivers in late August and runs taper off by mid-October. Spawning typically occurs from mid-September to late October (Bennett

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and Foster 1991). Wild fry begin emigrating in late December. The migration of wild juveniles peaks the first week of June at Willamette Falls. Fall chinook juveniles migrate to the Columbia River estuary as subyearlings (Howell, et al. 1985). Fall chinook generally spend two to five years in the ocean before returning to spawn. The fall chinook run had primarily been maintained by a hatchery program, but was discontinued in 1996, because of budgetary constraints and lack of importance in the Willamette basin. Natural spawning is expected to continue in the upper river, but at diminished numbers (Foster personal communication 1998).

Knutsen and Ward's (1991) study of the behavior of juvenile salmonids migrating through the Portland Harbor area found that subyearling chinook salmon appeared to be actively migrating through the area. Even during periods of low river flow, they did not spend more than a few days in the harbor area. Information on the migratory behavior of subyearling chinook is limited. Subyearling chinook were found in the harbor area over a longer period than other species or races of salmonids, probably because they actively fed during migration. There was little certainty to what extent they were actively migrating. Electrofishing catches from 1987 indicated that some juveniles might over-winter in the lower Willamette River.

Steelhead

There are two stocks of steelhead on the Willamette River, winter and summer run, named for the time period in which spawning runs begin. The Willamette River winter steelhead run occurs during the late winter to spring, with adults migrating upstream from February through May. Spawning occurs from March through May. Naturally spawned juveniles generally spend two years in fresh water before smolting; out-migration begins in early April and extends through June (Bennett and Foster 1991). Juvenile steelhead appear to actively migrate through the Portland Harbor area, spending less time in the area than other juvenile salmonids (Knutsen and Ward 1991). Hatchery stocks have supplemented runs since the 1960s, but this practice is in the process of modification due to the recent listing of the wild steelhead on the endangered species list (Foster personal communication 1998).

Summer steelhead begin entering the Willamette River starting in early March migrating to spawning grounds above Willamette Falls. Peak migrations occur from mid-May through June. Adult fish remain in the river through the fall and spawn during the winter months. The majority of returning adults spend two years in saltwater. Summer steelhead were introduced above Willamette Falls in the late 1960s for sport fishing. Natural production is low. The Oregon Department of Fish and Wildlife closely monitors production to ensure that populations are sustained by hatchery releases and angling regulations (Foster personal communication 1998).

Coho salmon

Coho migrate up the Willamette from late August through early November with peak numbers beginning in mid- to late September. Spawning occurs from September through December and juveniles outmigrate the following spring. Coho return to freshwater as age-3 adults and age-2 jacks (precocious male adults). Due to concerns regarding competition between coho salmon and other game fish and a lack of contribution to Willamette River fisheries, the management of coho runs has been de-emphasized (Foster personal communication 1998).

Sockeye salmon

Small numbers of sockeye salmon return to the Willamette River. Juvenile sockeye salmon were introduced into several reservoirs in the upper reaches of the Willamette and Santiam rivers in the 1950s. Presumably, the downstream migration of some individuals derived from these transplants led to returns of anadromous sockeye salmon (Foy et al. 1995).

American shad

American shad are not indigenous to the Willamette River, but were introduced to the Columbia basin in the late 1800s. Shad enter the lower Willamette River and migrate upstream to Willamette Falls from mid-May to mid-July, peaking in June. Shad rarely use the Willamette Falls fishway due to structural limitations that inhibit the species from proceeding upstream. Data for sport catch indicate that shad are abundant in the Willamette River, but spawning location and general resource use by the species is unclear. Shad are broadcast spawners, releasing eggs into open water. The eggs are only slightly heavier than water and non-adhesive; they settle and are carried along by the current. Larvae hatch in eight to twelve days and spend their first summer in fresh water. They drift downstream and enter the ocean in autumn (Scott and Crossman 1973). Management of the underused shad fishery is considered unnecessary (Foster personal communication 1998).

White sturgeon

White sturgeon are plentiful throughout the lower Willamette River, and transplants have established a small resident population above Willamette Falls. Most white sturgeon spawn immediately below Willamette Falls, upstream of the site, during the late fall and winter. Juveniles are present in the river year round and congregate in the Portland area near the site. Sturgeon have been stocked in limited numbers (approximately 1,000 to 2,000 per year) above the falls for the last three years (Bennett and Foster 1991; Foster personal communication 1998).

Juvenile salmonid diet in soft-bottom freshwater environments

Juvenile salmonids are habitat opportunists, feeding on benthic and drift organisms in freshwater environments as they migrate downstream (Becker 1973). Feeding habits have been shown to differ from watershed to watershed (McCabe et al. 1983). In tidal freshwater areas of the Columbia River, the amphipods *Corophium salmonis* and *C. spinicorne* are the principal prey of subyearling chinook, coho, and steelhead juveniles. These amphipods are critical to juvenile salmonids below the Bonneville Dam. Biological assessments to determine their potential impact is necessary before areas can be used to dispose of dredged materials (McCabe and Hinton 1996). Amphipods are very common in tidal freshwater areas of the Columbia estuary, and are an important prey of juvenile salmonids up to the Bonneville Dam (upstream of the mouth of the Willamette River). However, there has been no broad characterization of the complete benthic community in the tidal Willamette River. Limited benthic sampling shows that *C. salmonis* was one of the five dominant taxa at Rm 1 and at 9, but not at Rm 6 (Tetra Tech 1993)

Chironomid larvae, *Daphnia* spp., and adult dipteran insects also composed significant portions of juvenile salmon diets in freshwater areas of the Columbia River estuary (McCabe et al. 1983). In the central Columbia River, juvenile chinook salmon consumed almost entirely adult and larval stages of aquatic insects dominated by chironomids (75-81 percent; Becker 1973).

Threatened or Endangered Species

Several of the anadromous fish runs (considered evolutionarily significant units; ESUs) in the area are either listed or proposed for listing under the Endangered Species Act (50 CFR 17.11 and 17.12). Steelhead from Willamette River tributaries downstream of Willamette Falls are included in the Lower Columbia River ESU, listed as a threatened species in March 1998. Steelhead from Willamette River tributaries upstream of Willamette Falls are included in the Upper Willamette ESU, listed as a threatened species in March 1999. Spring chinook salmon from Willamette River tributaries downstream of Willamette Falls are included in the Lower Columbia River ESU, listed as a threatened species in March 1999. Spring chinook salmon from Willamette River tributaries upstream of Willamette Falls are included in the Upper Willamette River ESU, listed as a threatened species in March 1999. Coho salmon from Willamette River tributaries downstream of Willamette Falls are included in the Lower Columbia River ESU, a candidate species for listing. Sea-run cutthroat in Willamette River tributaries downstream of Willamette Falls are included in the Southwestern Washington/Columbia River ESU, proposed for listing as a threatened species in March 1999. Listing assessments for candidate species are expected by mid-1999. Final listing determinations for proposed species are expected in April 2000. A threatened species is defined as a species that is likely to become endangered in the foreseeable future (Federal Register 1998).

The U.S. Fish and Wildlife Service (USFWS) classifies Pacific lamprey as a species of special concern. The USFWS defines species of special concern as those organisms whose conservation status is of concern to the USFWS, but for which further information is needed. The Oregon Fish and Wildlife Commission also classifies Pacific lamprey as a sensitive species. The state of Oregon defines a sensitive species as a naturally reproducing native vertebrate that is likely to become threatened or endangered throughout all or a significant portion of its range in Oregon. The Sensitive Species List explicitly encourages actions that will prevent further decline in species populations and/or habitats and thus avoid the need for listing (Weston 1998).

Commercial and Recreational Fisheries

There are no commercial fisheries for the anadromous salmonids on the Willamette River (Foster personal communication 1998). The Columbia River supports a valuable commercial fishery. Because of precipitous declines in stocks, stock-preservation activities, competing fishing gears, and conflicting uses of the Columbia River (e.g., hydropower and shipping), commercial fisheries are highly regulated in that river (Bennett and Foster 1991).

Recreational fishing is extremely popular throughout the lower Willamette basin. Species most desired are spring chinook, steelhead, coho, shad, and white sturgeon (Foster personal communication 1998). Spring chinook contribute substantially to the mainstem Columbia River sport fishery and consistently support the largest recreational fishery in the lower Willamette River. The chinook fishery in the Willamette River occurs between Oregon City and the confluence of the Willamette and Columbia rivers, and throughout the Multnomah Channel. The study area is located within this 75-km reach, and recreational angling may occur within areas of concern. Angling is conducted primarily from anchored or slow-moving boats (Bennett and Foster 1991; Foster personal communication 1998).

Peak effort for white sturgeon occurs during the spring and summer months of this year-round fishery. Although estimates were not available, harvest of legal-sized sturgeon is considered to be less than 1,000 individuals per year. Most sturgeon angling is upstream near Willamette Falls (Bennett and Foster 1991; Foster personal communication 1998).

Fishing Advisories

The Willamette River has two fishing advisories. One advisory is for arsenic, creosote, and pentachlorophenol in crustaceans and crayfish near the McCormick and Baxter site. The other advisory is for mercury in large- and smallmouth bass and squawfish in the mainstem of the Willamette River.

Indian Tribal Fisheries

Indian treaty rights on Willamette River salmonids may be asserted off the coast of Washington and also in the Lower Columbia and Willamette rivers. The general rule, established in the ongoing litigation known as U.S. v. Washington and U.S. v. Oregon, is that treaty Indian tribes have a right to half the fish that, absent prior interception, would pass through their usual and accustomed fishing grounds and stations (commonly known as u&a grounds). Under CERCLA, Indian tribes are natural resource trustees for these fisheries resources (42 U.S.C. 9607(f)(1) and 40 C.F.R. 300.610.)

Washington Coast: Willamette spring chinook travel north after they exit the Columbia River, pass through the Washington coastal tribes ocean u&a grounds, and return along the same route when they are ready to spawn. The Washington coastal tribes are the Makah, Quileute, Hoh, and Quinault. The Makah Tribe's ocean u&a grounds have been adjudicated, and all four tribes' ocean u&a grounds have been recognized administratively by the U.S. Department of Commerce, as extending approximately forty miles offshore north of Point Chehalis (Grays Harbor), Washington. However, it is likely that Willamette fish have very minor impacts (a fraction of one percent) in the tribes' ocean fisheries, because they typically return through the area early, before the tribal fisheries begin.

Lower Columbia and Willamette: Willamette River salmonids spend portions of their life cycles in the Lower Columbia and Willamette Rivers, where the four mid-Columbia treaty tribes (Yakima, Warm Springs, Nez Perce, and Umatilla) claim u&a grounds. These rights have not been adjudicated in U.S. v. Oregon, due to a settlement that effectively resolved the tribes' claims above Bonneville Dam. The Yakima Tribe has conducted a treaty fishery in the Willamette for the last several years.

CHEMICAL CONTAMINANTS OF CONCERN

The primary contaminants of concern in the lower Willamette River study area are PAHs, several trace elements, and tributyltin (TBT). Elevated concentrations of these substances were detected in the sediments of all five reaches of the study area. Chlorinated pesticides and PCBs were also detected at elevated concentrations, but these substances appear to be less widespread.

To identify contaminants of concern in sediment, measured concentrations were compared with freshwater sediment guidelines. There are fewer regulatory criteria for contaminated sediments than for water, and no criteria similar to the U.S. EPA Ambient Water Quality Criteria (AWQC) are available. However, several regulatory agencies have calculated sediment effects concentrations for freshwater sediments using local or regional sediment effects data. Many of these effects concentrations were derived from synoptic sediment chemistry and sediment toxicity test results.

Environment Canada has developed freshwater sediment quality values using a weight of evidence approach using laboratory toxicity tests, benthic studies, and modeling studies from watersheds throughout North America (Smith et al. 1996). The U.S. EPA Great Lakes National Program Office (GLNPO) has developed freshwater sediment effects concentrations based on sediment bioassays using the amphipod *Hyalella azteca* and the midge *Chironomus riparius*. Data used by GLNPO are from the Great Lakes and several other watersheds in the Midwest and South (Ingersoll et al. 1996). U.S. EPA has produced sediment criteria based on equilibrium partitioning theory, but has developed actual criteria for only a few organic compounds (U.S. EPA 1989). The Washington State Department of Ecology has developed freshwater sediment quality values based on *H. azteca* and Microtox tests from sites in the Pacific Northwest (Cubbage et al. 1997).

For this report, NOAA has chosen to use freshwater sediment quality guidelines developed by Environment Canada to screen contaminated sediments for their aquatic toxicity potential. Two assessment values, a Threshold Effect Level (TEL) and Probable Effect Level (PEL) were used. The two values define three ranges of chemical concentrations. Concentrations below the TEL are rarely associated with adverse biological effects; those between the TEL and PEL are occasionally associated with adverse biological effects; and those above the PEL are frequently associated with adverse biological effects (Smith et al. 1996).

For the polar ionic compound TBT, concentrations measured in the sediment and pore water were compared to screening level guidelines developed for Puget Sound, Washington (Weston 1996). TBT sediment guidelines for freshwater are not available. As a member of the U.S. EPA Region 10 TBT workgroup, NOAA has supported the lower sediment screening value of 1,255 µg TBT/kg organic carbon and corresponding interstitial water concentration of 0.05 µg TBT/L. These screening values are not protective of all marine organisms (they were estimated to represent 18th percentiles), but were developed to be protective of most organisms and life stages for most chronic endpoints. The screening values were developed for Superfund sites in Puget Sound.

The SI for the lower Willamette River collected 150 surface sediment samples, 37 subsurface sediment cores, and 28 sediment porewater samples. The river was divided into five sections by river mile and the SI data are discussed by river section. All samples were analyzed for trace elements, semi-volatile organic compounds, total organic carbon (TOC), and grain size. Sixty-one surface sediment samples were analyzed for PCBs, pesticides, and organotins. Three sediment samples were analyzed for dioxins/furans and seven for chlorinated herbicides (Weston 1998). This report evaluates the surface sediment and porewater data expected to be within the biotic zone of aquatic organisms.

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Habitat Exposure Characterization

Reach A

Reach A is the segment of the study area farthest downstream extending from river 3.5 to mile 5.0 with four identified sites on the river shore (Figure 1 and Table 1). PAHs were the most widespread contaminant observed at elevated concentrations, with nearly all PAHs exceeding their respective TELs and PELs (fluoranthene, pyrene, chrysene, phenanthrene, benzo(a)anthracene, and benzo(a)pyrene). Eleven individual PAHs had maximums exceeding 25 mg/kg (Table 2). The highest PAH concentrations were observed in sediments at station SD032 in a Terminal 4-Port of Portland waterway. That station contained 16 of the maximum PAH concentrations detected in the reach. Two other stations in the waterway (SD033 and SD031) also contained highly elevated concentrations of PAHs (individual PAHs exceeded 1.0 mg/kg, which is an order of magnitude higher than both TELs and PELs). Concentrations of several PAHs in samples collected near the Time Oil-Northwest Terminal and the Linnton Oil Fire Training Grounds exceeded 1 mg/kg.

Trace elements were not as elevated relative to screening guidelines as the PAHs in Reach A. Maximum concentrations of seven trace elements exceeded their respective TELs and PELs for lead at three stations and zinc at two stations. In general, concentrations only slightly exceeded the TEL. The highest concentrations of lead and zinc (and the only exceedances of PELs) were in the Terminal 4-Port of Portland (SD032 and SD033) waterway, the same area with high PAH contamination. In addition, lead and zinc exceeded their respective PELs at Station SD023 in a waterway further downstream. Zinc exceeded its PEL slightly while lead exceeded its PEL by a factor of nearly 3.

TBT was observed in the sediments above screening guidelines in six of eight samples analyzed for the substance. The detections above guidelines appeared to be spread throughout the waterway without a clear association to any of the identified sites. Reach A had the highest TBT levels observed in the study area.

Reach B

Reach B extends from River mile 5.0 to 6.0, with three sites identified on the river shore (Figure 1 and Table 1). PAHs exceeded their respective TEL concentrations in sediment at all stations measured in Reach B, and many PAHs also exceeded their PEL (Table 2). Maximum concentrations of phenanthrene, fluoranthene, and pyrene exceeded 10 mg/kg and numerous others exceeded 1.0 mg/kg. Phenanthrene exceeded its PEL at six stations. Four stations were located across the channel from the two identified sites, with three of those located upstream of Mobil Terminal. The most PAH-contaminated sediment station in Reach B, station SD041, was located on the western shore of the river between the Arco and Mobil terminals. The second most PAH-contaminated station was station SD056 with all PAHs exceeding their respective PEL. This station is located at about

Rm 6 near the eastern shore of the river, not associated with either identified site. At the remaining stations, PAHs were moderately elevated above PELs.

The trace elements were not as elevated relative to screening guidelines as the trace elements in Reach A, but maximum concentrations of six elements exceeded their respective TEL concentrations. A PEL was exceeded in only one sediment sample—lead was observed at 122 mg/kg in the same area as the high PAH concentrations on the eastern shore of the river.

TBT was observed in the sediments above screening guidelines in five of six samples analyzed for the substance. Four of the five stations where TBT concentrations exceeded guidelines were collected on the eastern shore of the river. The highest concentration of TBT (4272.0 µg/kg OC) was co-located with the highest concentrations of PAHs. Similar to the PAHs, sample locations with the highest concentrations were not in the vicinity of the identified sites in Reach B.

Reach C

Reach C extends from Rm 6 to Rm 7 with three sites identified on the river shore (Figure 1 and Table 1). The highest concentrations of PAHs in the entire study area were found in Reach C with five individual compounds exceeding 100 mg/kg (Table 2). Most detected concentrations exceeded both their respective TELs and PELs. Highly elevated concentrations of PAHs were observed in almost all sediment samples collected on the western shore of the reach. Pyrene and phenanthrene exceeded their respective PELs at 12 stations in the reach. Of the 7 stations located on the eastern shore, only 2 contained PAHs at concentrations greater than the TEL. The eastern side of the river in Reach C has fewer industries.

Similar to Reach B, the maximum concentrations of six trace elements slightly exceeded their respective TELs. Detection limits for arsenic were above the TEL. Only one detection of nickel exceeded its PEL on the west side of the river.

Tributyltin was observed in the sediments above screening guidelines in 10 of 13 samples analyzed for the substance. Unlike the PAHs, which were highly elevated on the western shore, the highest concentrations of TBT were observed on the eastern shore not associated with any of the identified sites. TBT also exceeded screening guidelines in all samples collected near the railroad bridge on the eastern shore.

Elevated concentrations of pesticides (DDT and metabolites) were observed in sediment samples within Reach C. Concentrations of DDD in five of eight samples and DDE in three of eight samples exceeded their respective PEL (no PEL has been developed for DDT). Four of the stations with high DDD concentrations were located on the western shore of the Willamette near Rm 7. The fifth station with high DDD was located in Willamette Cove. The highest concentration of

concentration of DDT (320 µg/kg) was measured in Willamette Cove. Pesticides were detected throughout the reach.

Concentrations of total PCBs exceeded the TEL in two of eight sediment samples, and four non-detect samples exceeded the TEL. No detected samples exceeded the PEL for total PCBs, however, one non-detect value did exceed the PEL.

Reach D

Reach D extends from Rm 7 to Rm 8 with six identified sites on the river shore (Figure 1 and Table 1). Contamination in Reach D was not as extensive for the contaminants of concern compared to the other reaches, despite having the greatest number of identified sites. Between 50 and 85 percent of PAH concentrations detected exceeded their respective TELs, but only concentrations of phenanthrene exceeded the PEL. This exceedance, as well as the general distribution of PAHs, was on the northeastern shore of Reach D. PAHs exceeded TELs in eight sediment stations in this region, generally clustered off the shore of the Rhone-Poulenc, Gould, and Elf Atochem facilities. On the southwestern shore of Reach D, elevated concentrations of PAHs were only detected at three stations. The highest concentrations, with several individual PAHs exceeding their respective TELs, were adjacent to the Reidel facility.

Trace element concentrations in the sediment were comparable to those observed in the other reaches. Six trace elements commonly exceeded their respective TELs, but only lead and nickel exceeded their PEL, at one sediment station on the northeastern shore of the reach.

Reach D had the highest concentrations of pesticides in the entire study area. Nearly all concentrations detected of DDD and DDE exceeded their respective PELs. DDT was also detected at concentrations substantially higher than its metabolites DDD and DDE, suggesting a more recent source for the discharge. The highest concentrations were observed near and downstream of the Rhone-Poulenc facility on the northeastern shore of the reach. This facility was known to produce and discharge agricultural chemicals. Concentrations of DDD exceeded the PEL by more than an order of magnitude, and concentrations of DDT were observed between 800 and 3,100 µg/kg near the facility.

TBT was measured in the sediments above screening guidelines in 14 of 16 samples analyzed for the substance along the eastern shore of Reach D. Unlike the PAHs, trace elements, and pesticides, all exceedances of TBT were on the eastern shore, but it should be noted that few analyses for TBT were conducted on the northeastern side of the river.

PCBs were observed in only two sediment samples, with only one concentration exceeding the TEL.

Reach E

Reach E is the upstream end of the study area extending from Rm 8 to Rm 9.5, with two identified sites on the river shore (Figure 1 and Table 1). PAHs were widespread in this reach but concentrations were not as high as those observed in Reaches A, B, and C. The highest PAH concentrations were near Swan Island and the Port of Portland Ship Repair facility. At many of the stations near the facility, concentrations of individual PAHs exceeded their respective PELs by more than an order of magnitude.

Elevated concentrations of eight trace elements were observed in Reach E, four of which exceeded their respective PELs. As with PAHs, the highest concentrations of trace elements were detected near the Port of Portland Ship Repair facility. Maximum concentrations of copper (two stations), zinc (four stations), lead (one station), and mercury (one station) exceeded their respective PELs in this area.

TBT was detected in the sediments above screening guidelines in nine of 18 samples analyzed for the substance. All but one exceedance of guidelines were observed in the vicinity of the Port of Portland Ship Repair facility. TBT in porewater was detected at concentrations above screening guidelines in two samples collected near the Port of Portland facility.

PCBs were detected in 38 percent of the samples in which they were measured. However, detection limits exceeded screening guidelines. The concentration of PCBs exceeded the TEL in 80 percent of the samples in which it was detected, and the maximum concentration exceeded the PEL by a factor of two.

Harbor Wide Trends

This section of the Preliminary Natural Resource Survey evaluates the degree and distribution of sediment contamination over the entire Portland Harbor study area. Several studies conducted in the lower Willamette River have collected nearly 300 surface sediment samples. Together, the sample coverage in these investigations provides a reasonable characterization of sediment contamination in the harbor. This evaluation uses the results of surface sediment samples from the following studies:

- Columbia River/Willamette River Sediment Quality. U.S. Army Corps of Engineers, 1994/95
- Willamette River Site Investigation. U.S. Environmental Protection Agency, 1998
- McCormick and Baxter Creosoting, Remedial Investigation, Phases I & II, 1992
- Portland Shipyard Study, 1998.

Over 290 sediment samples, collected harbor-wide, were analyzed for PAH and trace element content; 130 sediment samples were analyzed for PCBs; and 60 to 90 samples were analyzed for their concentrations of many pesticides and TBT.

Similar to the evaluation of river segments, harbor-wide surface sediment data indicate that PAHs are the contaminants of most concern to NOAA. PAHs were measured in surface sediments of the harbor at concentrations exceeding ecological screening guidelines. Some trace elements, TBT, PCBs, and pesticides are also of concern, but were detected less frequently and at lower concentrations relative to screening guidelines.

PAHs

PAHs were the most widely measured contaminants in surface sediment of the harbor. Maximum concentrations of 18 individual PAHs measured ranged from 17 mg/kg (acenaphthylene) to 2,500 mg/kg (naphthalene). Phenanthrene and five high-weight compounds (benz(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, and pyrene) are the only PAHs for which freshwater TEL and PEL screening guidelines have been developed. These PAHs are generally representative of the total PAH distribution in the study area though. These six individual PAHs were frequently detected over the entire harbor; concentrations exceeded at least one respective TEL in 87 percent of all samples. All individual TELs were exceeded in 200 samples representing a stretch of the river from downstream of Multnomah Channel to approximately river mile 6.5, and in the Swan Island Basin. PAH Toxic Units (Σ concentration$_x$/guideline$_x$) for high-weight PAHs (Figure 2) indicate widespread contamination of harbor sediments.

The incidence of concentrations of individual PAHs that exceeded their higher, PEL benchmarks was less widespread, as expected, but still occurred in up to approximately one-third of surface sediment samples, even for just the five high weight PAHs (Figure 3). Stations with PAHs above PEL guidelines identified several "hot-spot" clusters (areas where all guidelines were exceeded) in the following areas:

- An area along the northeastern shore from Willamette Cove to the McCormick and Baxter facility, and extending out into channel;
- An entire segment of river from downstream of the St. Johns Bridge to the SP&S bridge (approximately Rm 6 to Rm 7), especially along the southwestern shore of the harbor between the GASCO and Elf Atochem;
- The three waterways on the east shore near the Port of Portland Terminal 4 Facility and the eastern portion of the river in that vicinity;
- The south shore of the harbor near the ARCO and Mobil facilities; and
- The central portion oft the river near the Time Oil Linnton Terminal.

The largest cluster of PAH-contamination was observed in river and wetland sediment adjacent to the McCormick and Baxter creosote site. PEL guidelines were exceeded at 27 sediment stations near the site with concentrations of the six

individual PAHs ranging from 24 to 390 mg/kg. Screening guidelines were exceeded at stations up to 150 m offshore and 800 m downstream of the site.

Another cluster of PAH contamination with concentrations above PEL screening guidelines was on the south shore between the GASCO and Elf Atochem facilities. In this area, a line of eleven sediment stations extending for about 1 km contained the six individual PAHs at concentrations ranging from 0.89 to 140 mg/kg. The highest concentrations were measured near the GASCO facility. Concentrations of PAHs exceeding PELs were also detected at a mid-channel sediment station off of the GASCO facility. Measured concentrations ranged from 99 to 260 mg/kg at this mid-channel station.

PAH concentrations exceeded their respective PELs near two Port of Portland facilities—near Terminal 4 and the adjacent waterways on either side of this facility, and at the mouth of the Swan Island basin near Port of Portland Ship Repair. At Terminal 4, up to seven stations within the waterways contained PAHs at concentrations exceeding PELs, ranging from 0.4 to 12 mg/kg. Near the Port of Portland ship repair facility, one to five stations contained individual PAHs at levels exceeding their PELs, with maximum concentrations of 4.3 mg/kg. Up to 30 stations in the Swan Island basin contained PAHs exceeding the lower TELs.

PAHs exceeded their respective PELs at three sediment stations near the Linnton Oil Fire Training Grounds at concentrations ranging from 0.48 to 2.3 mg/kg. Similar concentrations were also observed at a mid-channel station near this area.

Average PAH concentrations in the Portland Harbor Study Area are up to two orders of magnitude higher than in areas immediately upstream and downstream of the harbor. For example, the average phenanthrene concentration in 210 sediment samples (excluding the McCormick and Baxter site data) in the harbor was 4,328 parts per billion (ppb) compared to an average of 73 ppb from 12 stations just outside the study area. Average PAH concentrations in Portland Harbor (excluding the McCormick and Baxter data) range from 1.6 (fluoranthene) to eight times (phenanthrene) their respective PEL concentrations. Individual PAHs in areas just upstream and downstream of the harbor area are typically only twice their lower TEL guideline values.

Trace Elements

Trace-element contamination was less widespread in sediments than PAH contamination. Trace elements, such as zinc (Figure 4) did not exceed screening guidelines in distinct clusters in the harbor, except for areas near Swan Island. Arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc exceeded their respective TEL in 5 to 91 percent of sediment samples collected. Copper and nickel exceeded their respective TEL the most frequently (75 and 91 percent of samples), followed by chromium (35 percent) and zinc (43 percent). Other trace elements exceeded their respective TELs in less than 25 percent of samples.

Concentrations of six trace elements exceeded their respective PELs in less than eight percent of samples collected. Zinc exceeded its PEL at 17 stations, with 13 located in the Swan Island basin, two located in the waterways near Terminal 4, and 2 located near the McCormick and Baxter site. Copper exceeded its PEL at 9 stations and nickel at 2 stations near Swan Island. Trace element concentrations rarely exceeded their corresponding PEL outside of the Swan Island basin.

Tributyltin

TBT was analyzed only in 61 surface sediment samples harbor-wide, but was detected in 90 percent of those samples. The screening guideline of 1255 µg/kg OC was exceeded in 56 percent of samples. A cluster of 8 sediment stations where TBT concentrations exceeded screening guidelines was observed in the Swan Island basin near the Port of Portland Ship Repair facility. Screening guidelines were exceeded at stations spread through most of the northern shore of the harbor; with fewer exceedances on the southern shore.

PCBs

Detectable concentrations of total PCBs in surface sediment of the harbor were clustered near the mouth of the Swan Island basin (Figure 5). Concentrations of PCBs exceeded the TEL at 17 stations and the PEL at 4 stations near Swan Island (300-394 µg/kg). In addition, PCB concentrations exceeded the PEL at three stations in source areas on Swan Island (284-2,600 µg/kg). The TEL was exceeded at only seven other stations spread throughout the rest of the harbor. PCB detection limits were higher than the TEL at most stations where non-detects were reported and thus provided censored information for most of the harbor. Combined data sets do indicate that concentrations in the navigation channel are below the TEL. PCBs appeared to be elevated upriver from the study are too.

Pesticides

DDT and its metabolites DDE and DDD were the pesticides most frequently detected in the harbor (Figure 6). All three were measured at elevated concentrations clustered near Doane Lake; DDE and DDD exceeded their respective PELs (guidelines are not available for DDT). The PEL for DDD was exceeded at 17 stations with concentrations ranging from 22 to 460 µg/kg. The PEL for DDE was exceeded only at five stations; however, the detection limits for DDE exceeded the PEL at 11 other area stations where non-detects were reported. Elevated concentrations of DDT were also measured in the area, and DDT was a large proportion of total DDT, suggesting a more recent release (Figure 6). DDT was measured at 14 stations at concentrations ranging from 76 to 3,100 µg/kg, which is one to two orders of magnitude above the TEL for total DDTs (six isomers; 7 µg/kg). As discussed in the evaluation of river segments, the Rhone Poulenc facility, the site of pesticide manufacturing, is located on Doane Lake adjacent to harbor contamination. Beyond the Doane Lake area, concentrations of DDE and DDD infrequently exceeded their respective TELs in the harbor.

EFFECTS ON HABITATS AND SPECIES

Sediment contamination by PAHs, trace elements, and TBT in the lower Willamette River can cause adverse effects to biota occupying several trophic levels. All of these substances are persistent in aquatic systems and are toxic to aquatic organisms at low to moderate concentrations. PAHs are known to cause adverse reproductive effects, mutagenesis, teratogenesis, and cancer in fish (Eisler 1987). TBT has been described as the most toxic substance ever deliberately introduced into natural waters (Weston 1996).

Measured Impacts

Bioassessment studies within the study area have been conducted in association with the McCormick and Baxter NPL site located at Rm 7 within Reach D. Bioassays using the freshwater amphipod *H. azteca* and the Microtox test showed significant adverse effects with sediments collected from the nearshore environment adjacent to the McCormick and Baxter study site (PTI 1992).

Bioaccumulation studies using the edible muscle tissue of crayfish and largescale sucker showed concentrations of naphthalene, acenaphthene, and fluorene between 18 and 60 µg/kg. PAHs are rapidly metabolized in aquatic organisms, and detectable quantities are rarely found in tissue sample analyses. Hence, these data provide evidence for ongoing uptake of PAHs potentially associated with the McCormick and Baxter site (PTI 1992).

Liver tissues of 249 largescale suckers collected near the McCormick and Baxter site were examined for histopathological abnormalities. The most commonly observed abnormality (found in 66 percent of fish) was the presence of mononuclear cell infiltrates, an indication of mild liver inflammation. However, there were no statistical differences between the prevalence of this condition in pooled stations near the site and reference. There was no evidence of more serious injury (e.g., neoplasia or megalocytic hepatosis) in any of the fish livers examined (PTI 1992)

Predicted Impacts

NOAA estimates potential contamination to its trust resources and supporting habitat in the lower Willamette River by comparing the concentrations of those contaminants in sediment with the concentrations of those substances shown in other studies to be toxic to aquatic organisms. These estimates are preliminary for several reasons.

First, there is little comprehensive information regarding the areal and temporal distribution of contaminants. Because of this limited information, the maximum concentrations observed in the relevant media in the habitats of interest to NOAA are used for comparisons in this document.

concentrations observed in the relevant media in the habitats of interest to NOAA are used for comparisons in this document.

Second, there is little information about the toxicity of site-related substances to the aquatic species of interest to NOAA. For this document, toxicity estimates are based primarily on aggregate toxicity analyses that provide a basis for estimating the potential for overall impacts to the ecosystem. Specifically, chemical concentrations in the sediments are compared to available screening guidelines. It is recognized that the sediment screening guidelines used may not be the most appropriate for the specific habitats of the lower Willamette River because of site- and habitat-specific factors. However, these metrics do provide effects-based concentrations that should be reasonably protective of NOAA's trust resources from direct toxic effects, as well as from indirect injury resulting from a reduction in prey base or habitat quality.

Finally, little is known about the effects of exposure to the combination of substances that may be in the study area. In addition, it is not unlikely that other, unmeasured substances are present and contributing to the overall toxicity of the releases. The few studies that have been performed indicate that effects of multiple contaminants are more likely additive than either synergistic or antagonistic. As a result, the simple comparisons presented above may underestimate the actual threat posed by the releases. Below is a summary of the environmental behavior and toxic effects of some of the more prevalent contaminants of concern observed in the Lower Willamette River.

PAHs

PAHs are a group of hydrocarbon compounds composed of two or more fused benzene rings, which may have substituted groups attached to one or more rings. In general, toxicity increases as molecular weight increases and with increasing alkyl substitution on the ring. The higher molecular weight PAHs (four- to seven-ring aromatics) are known carcinogens or co-carcinogens. Other toxic effects associated with PAHs include cytotoxic, mutagenic, and reproductive effects. PAHs are relatively immobile in aquatic media with a strong tendency to accumulate in organically enriched sediments. The bioavailability of PAHs entrained in sediments is less than PAHs in solution, so they are generally less toxic. However, effects of PAHs in the sediments have been documented in aquatic organisms (Eisler 1987).

Data on the toxicity of PAHs entrained in freshwater sediments are limited, but some exposure data are available to compare with site conditions. In studies of heavily polluted areas, high mortality in sediment bioassays using the amphipod *H. azteca* and the midge *C. riparius* have been observed. For example, Yake (1986) found 95 percent mortality in *H. azteca* exposed to contaminated Lake Union, Washington sediment containing individual PAHs ranging from 40 mg/kg (fluorene and naphthalene) to 510 mg/kg (fluoranthene). Pope (1993) found 100 percent mortality with the mayfly *Hexagenia limbata* , *C. riparius* , and *H. azteca* at

total PAH concentrations ranging from 685 to 1,154 mg/kg. These concentrations are substantially above the threshold for adverse effects, but are near the level of contamination observed in the most contaminated samples in the lower Willamette River.

In a study of sediment toxicity in Waukegan Harbor, Illinois, Ingersoll and Nelson (1990) found statistically significant toxicity to *H. azteca* and *C. riparius* exposed to sediments contaminated with PAHs at the following concentrations: 120 µg/kg naphthalene; 1,100 µg/kg phenanthrene; 220 µg/kg anthracene; 1,000 µg/kg fluoranthene; 950 µg/kg pyrene; 490 µg/kg benzo(a)anthracene; 620 µg/kg chrysene; 460 µg/kg benzo(a)pyrene; and 300 µg/kg indeno (1,2,3-c,d)perylene. Concentrations of PAHs observed in the sediments of Reaches A, B, and C of the Willamette River study area consistently exceeded these levels.

Although PAHs are rapidly metabolized by many fish species, biological effects associated with high tissue burdens of PAHs have been documented in contaminated areas. The frequencies of external and grossly visible liver tumors were high in brown bullhead (*Ictalurus nebulosus*) collected from the Black River, Ohio. Tumor frequency occurred between 28 and 44 percent of age 4 fish compared to none found at a clean reference lake. Tissue concentrations associated with these effects ranged from 46 to 130 µg/kg naphthalene; 1,200-3,100 µg/kg phenanthrene, 780-1,200 µg/kg fluoranthene; 420-850 µg/kg pyrene; <10-16µg/kg benzo(a)anthracene; and 6.4-19 µg/kg benzo(a)pyrene (wet weight). The concentrations of individual PAHs in the sediments were reportedly between 10 and 100 mg/kg (Baumann et al. 1987). Concentrations of PAHs observed in the sediments of Reaches A, B, and C are within these ranges.

Juvenile chinook salmon from a contaminated urban estuary in Puget Sound, exposed to PCBs and PAHs, showed evidence of immunosuppression (Arkoosh et al. 1991). Immunosuppressed fish may be more susceptible to disease and ultimately experience increased mortality. Juvenile salmon from the contaminated estuary in Puget Sound, challenged with the marine pathogen *Vibrio anguillarum*, exhibited higher cumulative mortality after exposure to the pathogen than salmon from hatcheries or a non-urbanized estuary (Arkoosh et al. 1998). Factors that affect health in the early life stages may affect recruitment to adults. Therefore, mortality during estuarine and early life stages of juvenile salmon from increased disease susceptibility induced by immunotoxic compounds may be a factor in year-class strength for populations with polluted estuaries (Arkoosh et al. 1998).

No severe effects were noted in largescale sucker studies conducted near the McCormick and Baxter site in Reach D (reported above). However, PAH contamination in this reach was not as high as that found in Reaches A, B, or C. Adverse effects to fish from PAHs in the study area are possible.

Trace Elements

Trace elements are persistent contaminants that tend to sorb to particulates and sediments, are toxic at relatively low concentrations, and can bioaccumulate in aquatic organisms (Clement Associates 1985). Many trace elements are important in plant and animal nutrition, where, as micronutrients, they play an essential role in tissue metabolism and growth. Of those detected in site-related media, chromium, copper, and zinc are considered essential micronutrients. However, exposure to elevated concentrations of these substances can result in poor health, retarded growth, and death. The trace elements cadmium, lead, and mercury have no micronutrient value and are highly toxic to aquatic organisms. The embryonic and larval stages of aquatic animals are generally the most sensitive life stages to the toxic effects of trace elements.

Data on the toxicity of trace elements entrained in freshwater sediments are limited, but some exposure data are available to compare with site conditions. In sediment toxicity tests conducted on the Saginaw River, Michigan, mortality and sublethal effects to growth and reproduction were observed with *H. azteca* and *C. riparius* exposed to the following concentrations of trace elements: 3.6 mg/kg arsenic; 10 mg/kg cadmium; 319 mg/kg chromium; 187 mg/kg copper; 86 mg/kg lead; 0.3 mg/kg mercury; 157 mg/kg nickel; and 381 mg/kg zinc. Total PCBs were also observed in this sample at a concentration of 8.3 mg/kg. In addition, several PAHs were observed at concentrations between 100 and 500 µg/kg (Ingersoll et al. 1992). This suite of inorganic and organic substances and the concentrations observed are similar to those observed in the lower Willamette River.

In sediment tests conducted on the Clark Fork River, Montana within the influence of mining operations and no organic contamination, adverse biological effects were observed at higher concentrations of trace elements. Significant acute, growth, and reproductive effects were observed in *H. azteca, C. riparius*, and rainbow trout (*Oncorhynchus mykiss*) when exposed to sediments containing the following concentrations of trace elements: 404 mg/kg arsenic, 41.1 mg/kg cadmium; 7,820 mg/kg copper; 679 mg/kg lead; 4.54 mg/kg mercury; 15.7 mg/kg nickel; and 10,100 mg/kg zinc (Kemble et al. 1994). These concentrations are generally higher than those observed in the lower Willamette River.

Also in the Clark Fork River, a range of trace element concentrations were associated with sublethal effects to *H. azteca* growth but not to mortality. Sublethal effects to growth were observed within the following ranges: 25.6-56.5 mg/kg arsenic; 2.4-13.3 mg/kg cadmium; 31.6-39.3 mg/kg chromium; 255-878 mg/kg copper; 63.2-99 mg/kg lead; 0.043-0.81 mg/kg mercury; 14-23.8 mg/kg nickel; and 625-4,200 mg/kg zinc. Organic compounds were generally undetected in these samples. These trace element concentrations produced no significant impacts to exposed rainbow trout (*O. mykiss*; Kemble et al. 1994).

Many of the trace elements detected in the sediments of the lower Willamette River fall within the ranges where sublethal effects on invertebrates have been observed.

TBT

Organotin compounds such as TBT are most commonly used as pesticides in commercial and agricultural applications. The toxicity of an organotin compound increases with progressive introduction of organic groups at the tin atom (Fent 1996). TBT, with its three butyl groups, is highly toxic, which led to its use as a fungicide, bactericide, and algaecide, particularly in antifouling paints. TBT leaching from ship hulls, and releases of fugitive paint and paint chips from vessel repair and dry dock facilities, appear to be major pathways into the aquatic environment (Fent 1996; Uhler et al. 1993).

After release into surface waters, TBT is likely to partition to suspended particles in the water column and sediments; up to 99 percent of the TBT may reside in the sediments (Huggett et al. 1986). Concentrations in sediment can be one to several thousand times higher than concentrations found in the overlying water (Bryan and Gibbs 1991). TBT has significant lipid solubility and thus a high potential for bioaccumulation in aquatic organisms. Fish, crustaceans, and bivalves can bioconcentrate TBT to concentrations that are orders of magnitude higher than the exposure concentration (Clark et al. 1988). Oysters are known to bioaccumulate TBT in their tissues at concentrations from 2,300 to 16,000 times higher than is found in the water (Wade et al. 1988; Bryan and Gibbs 1991).

Studies have demonstrated that TBT is deleterious at concentrations far lower than those indicated for other pollutants (Clark et al. 1988). In freshwater ecosystems, much less is known than in marine systems about which species are highly susceptible. In a freshwater snail, egg laying was reduced at TBT concentrations as low as 1 ng/L. Early life stages of European minnow were found to develop histologic alterations at 0.8 µg/L and rainbow trout yolk sac fry showed growth retardation after long-term exposure to TBT concentrations of 0.2 µg/L (Fent and Hunn 1995). TBT concentrations in pore water samples from the Willamette River study area are higher, in some areas, than those shown to cause chronic effects in other studies.

Few studies have evaluated the effects of sediment-entrained TBT to freshwater organisms. However, benthic studies have shown that freshwater bivalve populations can be completely eliminated when bulk sediment TBT concentrations exceed 800 µg/kg (Fent and Hunn 1995). Most of the TBT concentrations in the Willamette River study area were below this level, but some were within the same magnitude and a few exceeded this concentration.

DDT, DDE, DDD

DDT is a broad-spectrum organochlorine pesticide that was widely used until January 1973, when the U.S. EPA canceled all uses of the substances in the United States. Low vapor pressure, high lipid solubility and resistance to degradation and photo-oxidation make the substance both highly persistent in environmental media and a strong biomagnifier in aquatic and terrestrial food chains. Due to its extremely low solubility, DDT is strongly retained by soils and sediments. The breakdown products of DDT, primarily DDD and DDE, are similar in stability. DDT is highly toxic to aquatic organisms (generally at concentrations less than 50 µg/L) with invertebrates showing a greater sensitivity than fish. Reproductive impacts such as lower egg hatchability, fry survival, and abnormalities in fish have also been documented (Pesticide Information Profiles 1996).

Very few freshwater sediment studies have specifically evaluated the toxicity of DDT, DDE and DDD. In most studies, these substances have been co-contaminants with other pollutants such as PCBs or PAHs; therefore, it is not known to what extent the pesticides have contributed to the observed effects. Acute (survival) and chronic (growth) toxicity was observed when *H. azteca* was exposed to contaminated sediments from Waukegan Harbor. Concentrations of DDE in the Waukegan study ranged from 13 to 98 µg/kg in sediment. Concentrations of DDT ranged from 1 to 63 µg/kg while DDD ranged from 11 to 22 µg/kg. Concentrations of several PAHs exceeded 1.0 mg/kg and total PCBs ranged from 0.9 to 8.9 mg/kg in these sediments as well (Kemble 1998). In the Sheboygan River, *C. tentans* and *H. azteca* exposed to contaminated sediments experienced 100 percent mortality at concentrations of 710 µg/kg of DDE and 240 µg/kg of DDT. It should be noted that very high concentrations of PCBs (758 mg/kg) were also observed in the Sheboygan River sediments (NOAA 1998).

Concentrations of DDT, DDE and DDD in the sediments of Reach D near the Rhone-Poulenc agricultural pesticide facility far exceeded concentrations observed where toxic responses have been noted in other studies.

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Table 1. Identified sites at the Willamette River, Portland Harbor site.

Reach (River Mile)	Identified Sites	Period of Operation	Reported Source Contamination	River Sediment Contamination
A (3.5 — 5)	1) Time Oil-Northwest Terminal Active petroleum bulk storage and handling facility and tank farm. Pentachlorophenol (PCP) was stored from 1967 to 1982. Documented spills occurred in 1985, 1986, 1990, and 1994. A soil removal action occurred in 1985.	1967 to present	PCP and dioxins in soils around former treatment are; Total Petroleum Hydrocarbons (TPH) in groundwater in bulk storage area	PAHs and metals
	2) Linnton Oil Fire Training Grounds Operated as a fire fighting training area.)	1951-1988	TPH, PAHs, chlorinated solvents, arsenic in soils and groundwater	PAHs and metals
	3) GATX Active bulk oil storage facility.	Since 1903	TPH and BTEX in groundwater	TPH, PAHs and metals
	4) Terminal 4-Port of Portland Active ship loading and unloading facility. Coal tar pitch, fuel, oil spills have been reported. 35,000 cubic yards of sediment removed in 1995.	Unknown	TPH, PAHs, DDT, metals	TPH, PAHs, DDE, DDD, VOCs, metals
B (5 — 6)	5) ARCO Bulk Terminal Active bulk petroleum facility.	1963 to present	TPH and PAH product layers in groundwater	PAHs and metals
	6) Mobil Oil Bulk Plant Active bulk petroleum facility. In 1985 a petroleum spill of 46,000 gallons occurred.	1928 to present	TPH in soil and groundwater; metals in groudwater	BTEX, TPH, and metals
	7) Time Oil Linnton Terminal Active bulk petroleum facility. Spills have reportedly occurred in the past. A soil removal action was conducted in 1988.	Unknown	Not reported	PAHs and metals
C (6 — 7)	8) U.S. Moorings Maintenance port for ACOE vessels. Sandblasting, scaling, repair, painting, and refueling operations take place.	1904 to present	Metals. PCBs, PAHs, DDT, dioxins, TBT	Metals, PAHs, dioxins/ furans, pesticides, and PCBs detected
	9) GASCO A former oil gasification plant, now operates as a liquid natural gas plant. All gasification wastes were discharged to the river between 1913 and 1925. Wastes were later disposed of in settling ponds.	1913 to present	PAHs and volatile aromatics	TPH, volatile aromatics and PAHs

Table 1. Identified sites at the Willamette River, Portland Harbor site.

Reach (River Mile)	Identified Sites	Period of Operation	Reported Source Contamination	River Sediment Contamination
	10) Willamette Cove Various industrial uses occurred prior to current intended use as open space. These include a lumber mill, plywood mill, barrel manufacturing, and a ship building/repair facility.	1930s to 1960s	Metals, TBT, PCBs, PAHs, TCE, TPH	Metals, TBT, PCBs, PAHs, TCE, TPH
D (7 — 8)	11) McCormick and Baxter Creosoting Operated as a wood treating facility. Releases of wood-treated wastes and on-site disposal of wastes has occurred. Four outfalls are also present; one outfall discharged non-contact cooling water and three discharged stormwater runoff.	1944-1991	Metals (Cr Cu As), PCP, PAHs	Metals, PCP, PAHs
	12) Rhone-Poulenc Operated as a production facility for agricultural chemicals. On-site disposal of untreated wastes and treated process wastewater discharged to Doane Lake, which leads to the Willamette River. Free product observed in groundwater; a treatment system was installed in 1993.	1940s-1990	Chlorinated pesticides in groundwater; dioxins, metals, chorinated and aromatic solvents	Pesticides (DDT, DDE, DDD).
	13) Gould Inc. Operated a battery-processing facility at the site. Batteries were disposed of on site and into Doane Lake. Two thousand tons of lead-bearing material is piled on-site, while 80,000 tons was buried. About 6.5 million gallons of sulfuric acid was discharged to Doane Lake.	1949-1981	Metals in surface water and sediments of Doane Lake. Metals in groundwater	Lead, arsenic, chromium, and zinc
	14) Elf Atochem North America Operates as a chlorine production facility; also produces sulfuric acid, hydrogen sodium chlorate, sodium hydroxide. Six chemical spills were reported in 1986. Some soil removal actions have occurred. Four NPDES-permitted outfalls discharge to the river. On-site disposal of DDT-manufacturing wastes occurred in the 1940s and 1950s.	1941 to present	DDT in soils; Free product in groundwater.	DDT, PAHs and metals
	15 Reidel Environmental Services Operated a hazardous waste storage facility. The company operated in marine construction and dredging and specialized in marine spill cleanups. Underground storage tanks have also leaked.	1980-1984	Soils and groundwater contaminated with un-specified organic compounds, including PCBs, TPH, VOCs, PAHs	Metals and TBT detected
	16 Willbridge Bulk Fuel Area Operates as a bulk fuel storage facility.	Unknown	Product layers and	PAHs and metals

Table 1. Identified sites at the Willamette River, Portland Harbor site.

Reach (River Mile)	Identified Sites	Period of Operation	Reported Source Contamination	River Sediment Contamination
	Presently used by Shell, Chevron, and Unocal.		dissolved TPH in the groundwater. Metals and DDT also found in the groundwater.	
E (8 — 9.5)	17 Port of Portland-Ship Repair An active ship repair facility with multiple dry docks. The facility has been cited for inadequate cleaning of dry docks prior to submersion and extensive discharge of sandblast grit to the river.	Unknown	PCBs, TBT, PAHs, metals	Sediment beneath drydocks contaminated with metals, TBT, and PCBs.
	18 Gunderson, Inc. Operates as a rail car manufacturing facility. Leaks from degreasing operations underground storage tanks, sandblasting, painting, and salvage yard operations have occurred.	1985 to present	Metals, solvents (TCA), and PCB	TCA, PAHs and metals

Table 2. Contaminants of concern in surface sediment from the lower Willamette River compared to ecological benchmarks.

Analyte	Reach A			Reach B			Reach C			Reach D			Reach E			Sediment Guideline	
	Avg.	Max	%> TEL	Avg.	Max	%> TEL	Avg.	Max	%> TEL	Avg.	Max	%> TEL	Avg.	Max	%> TEL	TEL	PEL
Inorganic Substances (mg/kg)		n=35			n=20			n=21			n=42			n=32			
Aresenic	3.63	7	50.0	2.95	7	66.7	3.29	5	0.0	2.67	5	0.0	3.3	16	100.0	5.9	17
Cadmium	0.52	2.2	20.0	0.32	0.5	0.0	0.40	0.6	4.8	0.38	0.7	4.9	0.52	1	34.4	0.596	3.53
Chromium	32.7	50.7	48.6	34.81	42.5	30.0	34.43	41.7	38.1	36.14	50.6	57.1	*38.59*	67.5	50.0	37.3	90
Copper	*44.8*	77	*88.6*	*42.65*	71.1	*75.0*	*42.15*	*59.1*	*76.2*	*43.41*	85.3	*78.6*	*91.45*	543	93.8	35.7	196.6
Lead	29.7	262	14.3	24.3	122	10.0	21.52	36	4.8	20.21	186	4.8	26.75	110	25.0	35	91.3
Mercury	0.066	0.18	2.9	0.062	0.12	0.0	0.100	0.24	19.0	0.062	0.12	0.0	0.115	0.86	9.4	0.174	0.486
Nickel	*28.22*	34	100.0	*28.02*	31	95.0	*28.19*	37	100.0	*28.83*	38.5	97.6	*29.35*	38	100.0	18	35.9
Silver	0.57	1.2	NA	0.77	1	NA	1.14	1.7	NA	0.95	1.4	NA	0.98	1.9	NA	NA	NA
Zinc	*134.4*	373	25.7	99.8	148	10.0	121.8	185	42.9	103.2	212	11.9	*171.6*	539	40.6	123.1	314.8
Polynuclear Aromatic Hydrocarbons (µg/kg)																	
2-Methylnaphthalene	55	490	NA	81	530	NA	4091	44000	NA	12	44	NA	13	36	NA	NA	NA
Naphthalene	92	990	NA	153	1000	NA	8061	130000	NA	17	92	NA	18	110	NA	NA	NA
Acenaphthylene	24	160	NA	24	150	NA	546	3600	NA	11	29	NA	10	0	NA	NA	NA
Acenaphthene	329	7800	NA	350	5000	NA	6407	51000	NA	24	170	NA	20	130	NA	NA	NA
Fluorene	174	3500	NA	183	2100	NA	4366	22000	NA	23	160	NA	23	170	NA	NA	NA
Phenanthrene	***1597***	36000	97.1	***1230***	16000	100.0	***29,416***	170000	100.0	*124*	710	*67.6*	*132*	1200	63.3	41.9	514.9
Anthracene	***2597***	8900	NA	226	2700	NA	5826	26000	NA	27	110	NA	25	160	NA	NA	NA
Fluoranthene	*368*	81000	88.6	*1157*	10000	100.0	***17,000***	110000	85.7	*199*	790	52.4	*209*	1900	43.8	111.3	2354.9
Pyrene	***3415***	87000	97.1	***1199***	12000	100.0	***23,019***	140000	100.0	*211*	770	69.0	*200*	1400	68.8	53	875
Benzo(a)anthracene	***3592***	67000	100.0	*355*	2600	100.0	*7364*	72000	90.5	*81*	310	83.9	*82*	700	66.7	31.7	384.7
Chrysene	***2547***	73000	97.1	*469*	3500	100.0	*9795*	100000	85.7	*118*	340	66.7	*134*	920	56.3	57.1	861.7
Benzo(b)fluoranthene	2832	80000	NA	300	1800	NA	4583	33000	NA	80	300	NA	106	1100	NA	NA	NA
Benzo(k)fluoranthene	3156	76000	NA	329	2300	NA	3102	14000	NA	78	310	NA	83	510	NA	NA	NA
Benzo(a)pyrene	*3605*	94000	100.0	*466*	3700	100.0	*7487*	57000	90.5	*89*	400	84.8	*96*	820	68.8	31.9	782
Indeno(1,2,3-cd)pyrene	2019	50000	NA	282	2300	NA	2963	19000	NA	57	300	NA	56	430	NA	NA	NA
Dibenz(a,h)anthracene	924	25000	NA	78	560	NA	1225	9200	NA	14	74	NA	16	120	NA	NA	NA
Benzo(g,h,i)perylene	1820	44000	NA	340	3100	NA	4973	40000	NA	56	380	NA	50	290	NA	NA	NA

Table 2 cont. Contaminants of concern in surface sediment from the lower Willamette River compared to ecological benchmarks.

Analyte	Reach A			Reach B			Reach C			Reach D			Reach E			Sediment Guideline	
	Avg.	Max.	%> TEL	Avg.	Max.	%> TEL	Avg.	Max.	%> TEL	Avg.	Max.	%> TEL	Avg.	Max.	%> TEL	TEL	PEL
Organotins		n=8			n=6			n=13			n=16			n=18			
Tributyltin (µg/kg)	5260	41830	NA	129	427.2	NA	68	311.5	NA	169	320.4	NA	635	4450	NA	NA	NA
Tributyltin (µg/kg OC)	*477754*	3802727	75.0	*12335*	42720	83.3	*5817*	33495	76.9	*12550*	22886	87.5	*38179*	234211	50.0	1255*	
Pesticides (µg/kg)		n=8			n=3			n=7			n=15			n=5			
DDD	2.81	7.3	28.6	2.43	3.1	0.0	*38.26*	100	87.5	*123.2*	460	92.9	*29.8*	98	33.3	3.54	8.51
DDE	*1.54*	2.7	42.9	0.97	0	0.0	*7.64*	13	100.0	*51.3*	220	100.0	*10.6*	1.7	66.7	1.42	6.75
DDT	3.35	15	NA	4.27	7.2	NA	79.91	320	NA	676.6	3100	NA	21.1	54	NA	NA	NA
PCBs		n=8			n=3			n=9			n=12			n=13			
Total PCBs	19.4	ND	0.0	19.2	ND	0.0	*65.8*	54	100.0	*474.4*	200	50.0	*158.5*	580	80.0	34.1	277.2

NA: Guideline not available

ND: Not detected

*: Guideline for TBT is the Puget Sound screening value, normalized to organic carbon (Weston 1996).

TEL and PEL concentrations are from Smith et al. (1996)

Averages are computed with half the detection limit for below detection samples; values in italic exceed TEL; bold values exceed PEL.

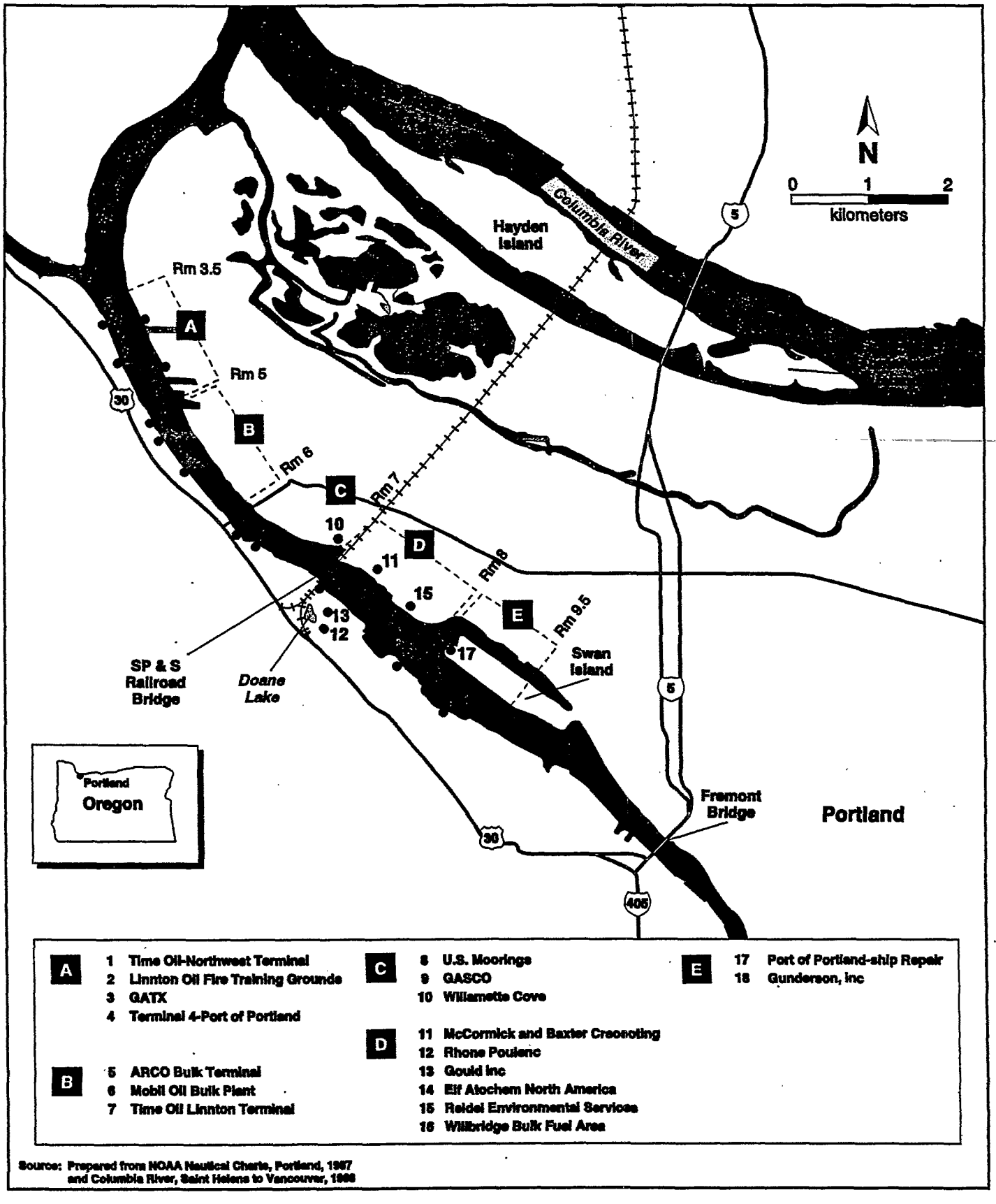

Figure 1. The lower Willamette River study area, divided into river reach sections (lettered) and the individual sites (numbered) within each section.

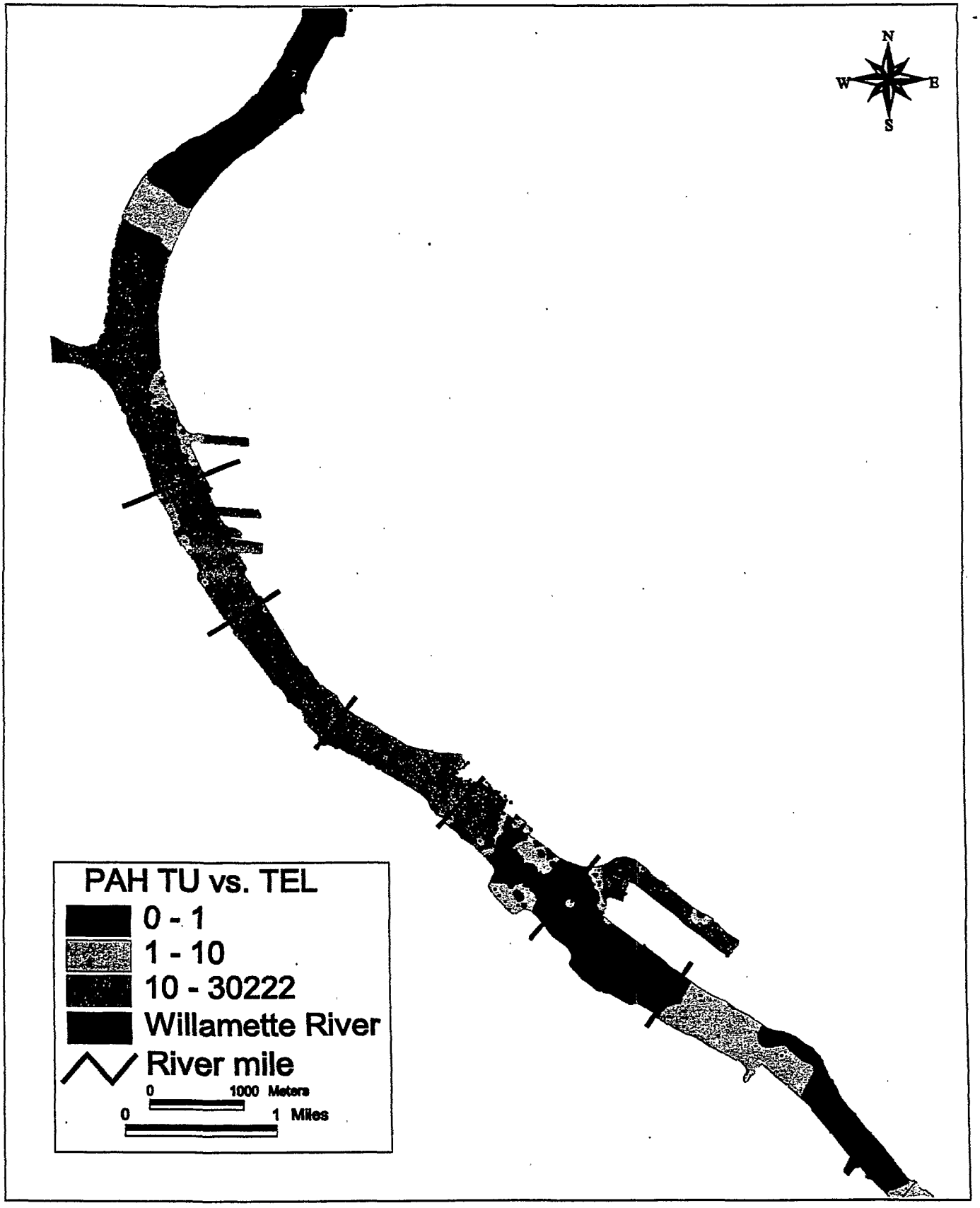

Figure 2. Contours of summed Toxic Units (TU) for five high-weight PAHs, calculated relative to their individual TEL benchmarks, as interpolated from individual sampling stations (•)

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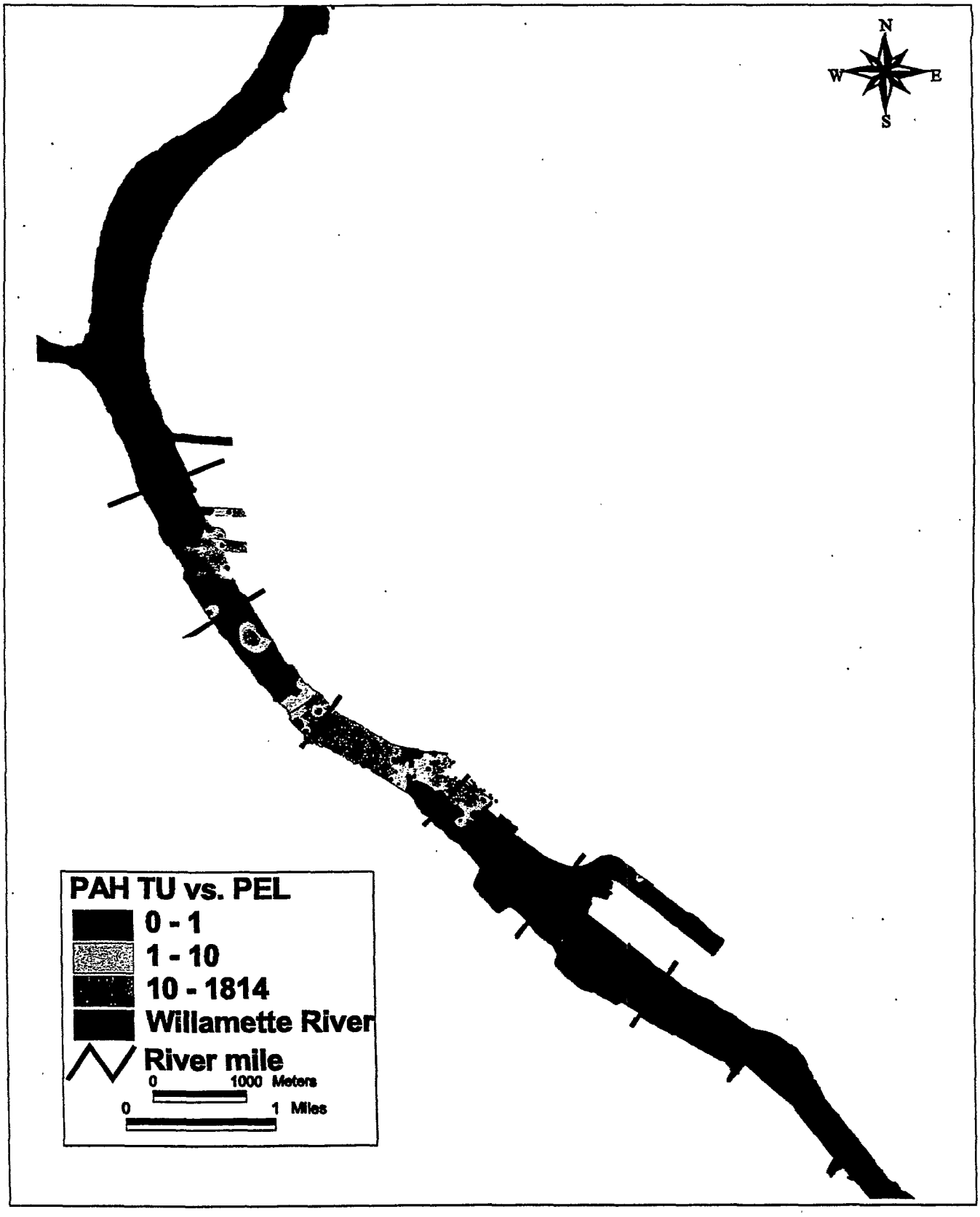

Figure 3. Contours of summed Toxic Units (TU) for five high-weight PAHs, calculated relative to their individual PEL benchmarks, as interpolated from sampling stations (•)

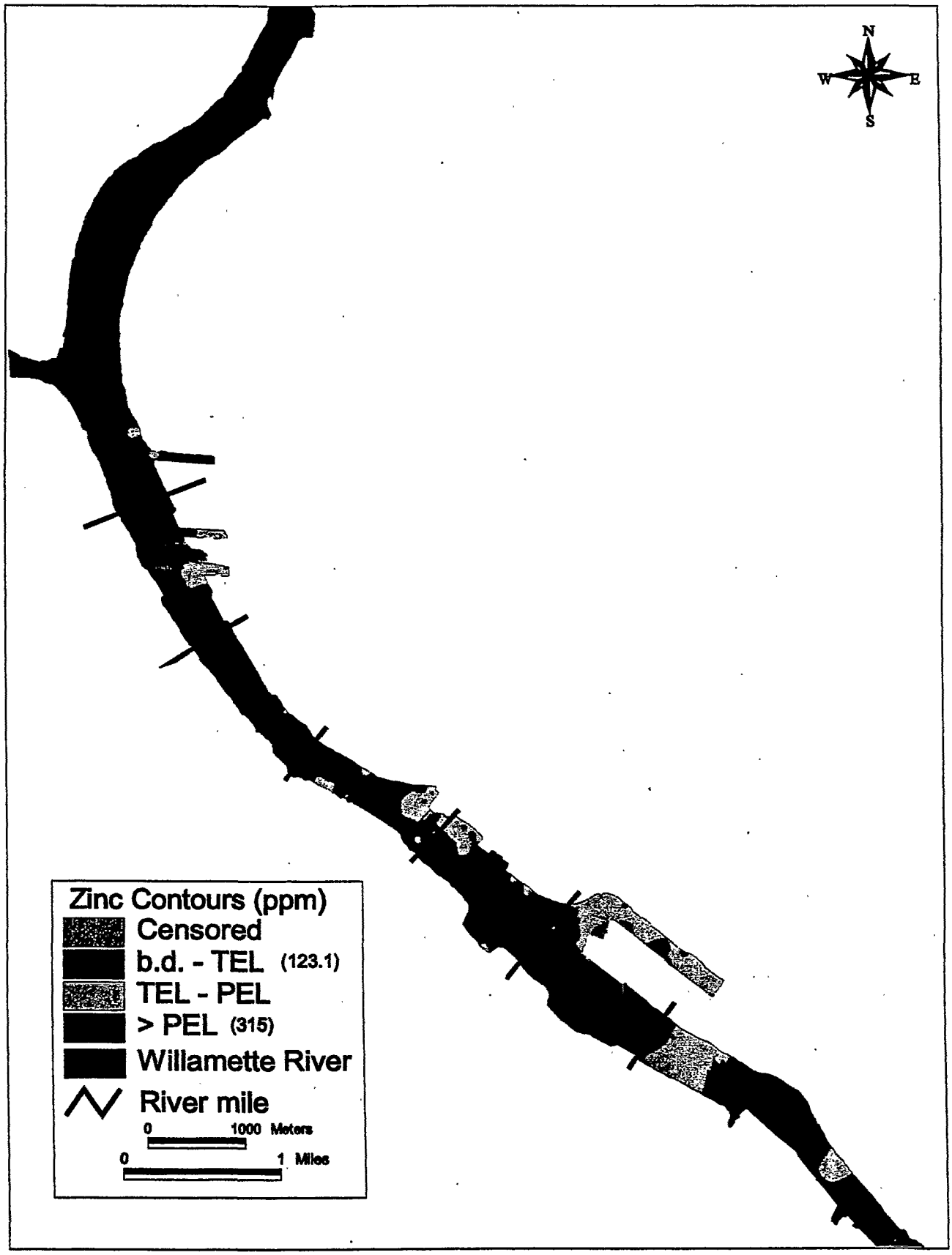

Figure 4. Contours of Zn concentrations, as interpolated from individual sampling stations (•) scaled to Zn sediment benchmarks

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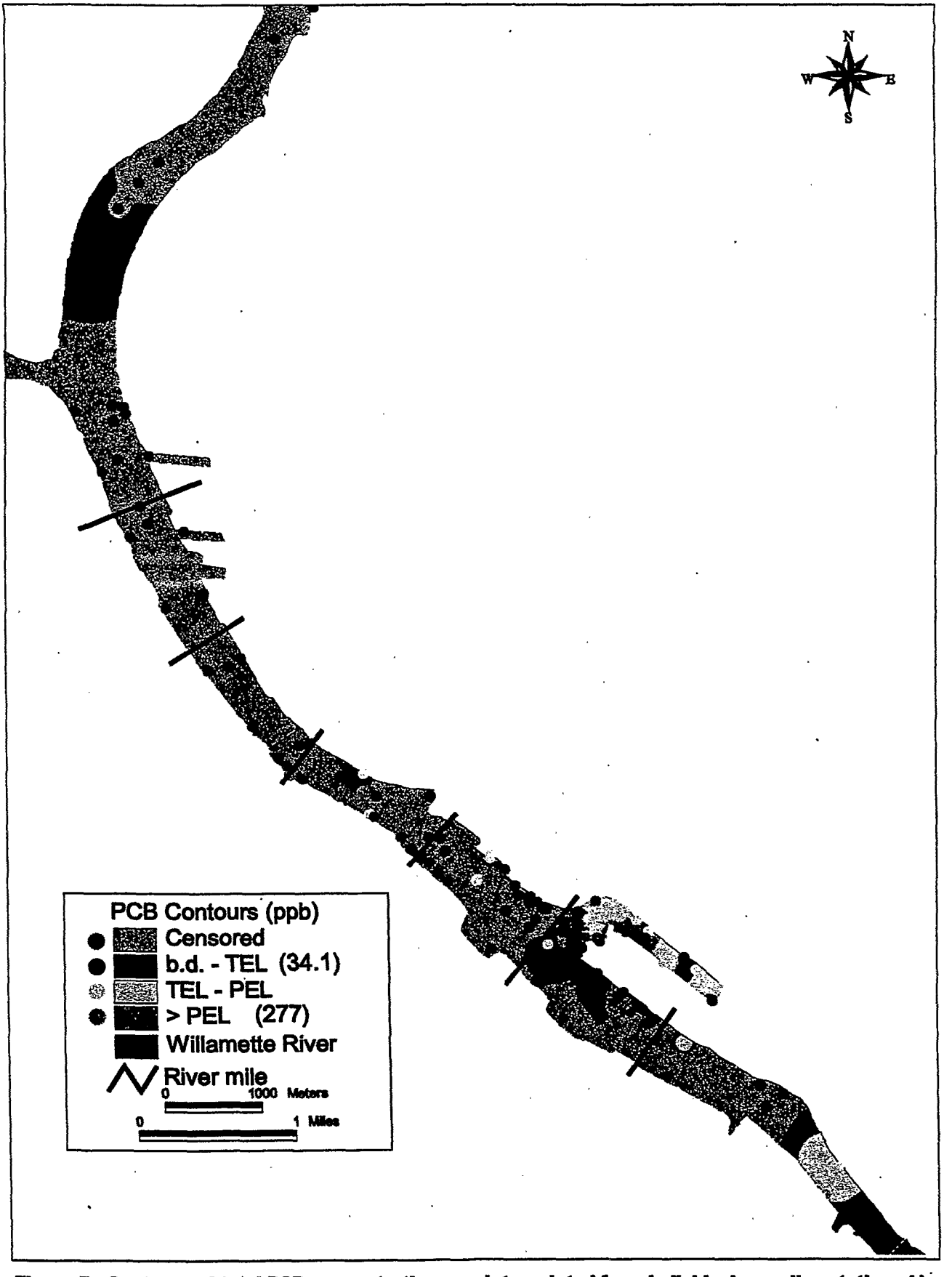

Figure 5. Contours of total PCB concentrations, as interpolated from individual sampling stations (•) with both scaled to PCB sediment benchmarks

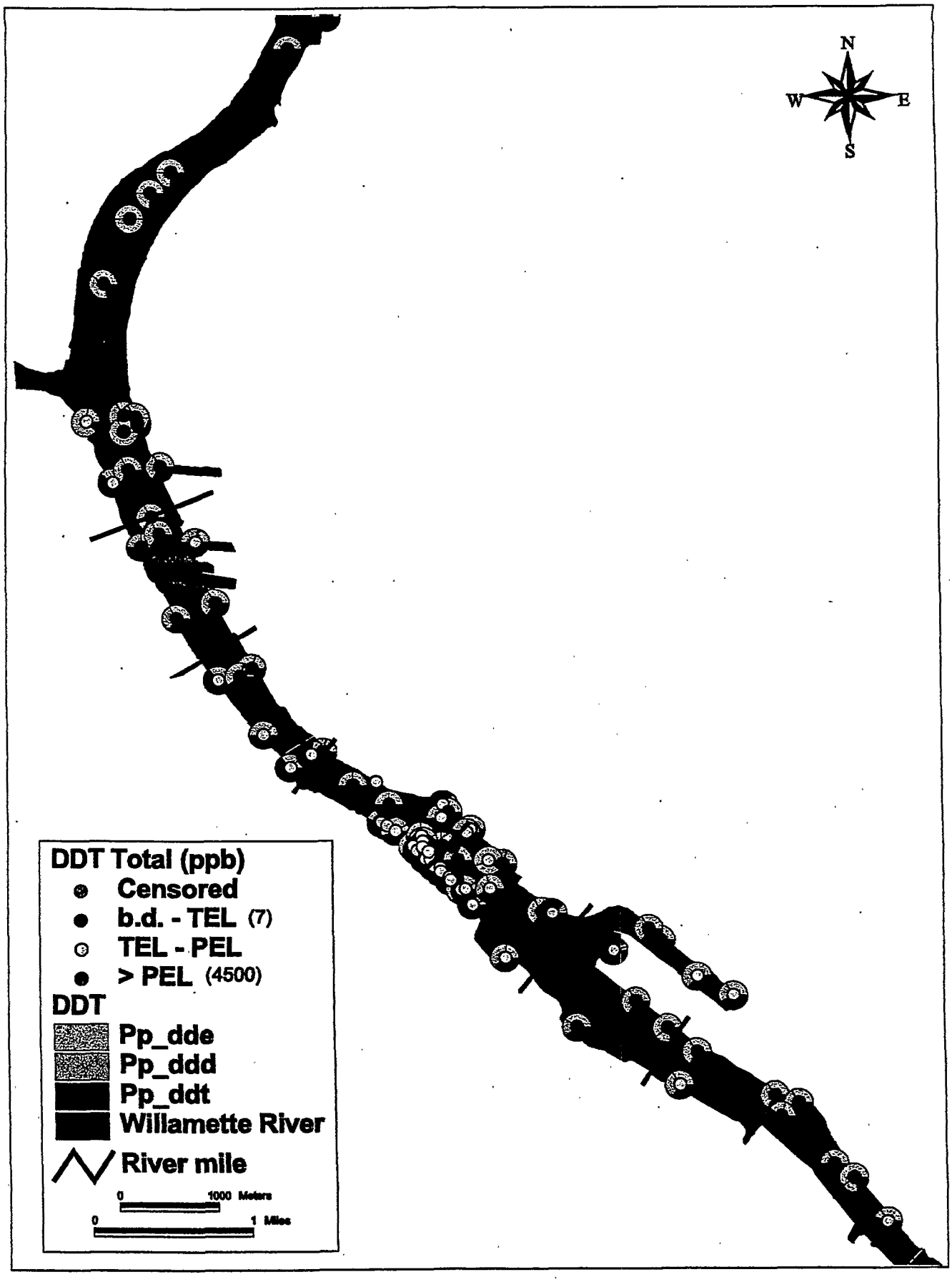

Figure 6. Relative proportions of total DDT compunds (DDT,DDD, DDE) overlayed with tDDT concentrations scaled to tDDT benchmarks