FINAL INTERIM FEASIBILITY STUDY REPORT

SAN JACINTO RIVER WASTE PITS SUPERFUND SITE

September 2016

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LIST OF ACRONYMS AND ABBREVIATIONS

1V:3H	1 vertical to 3 horizontal
2H:1V	2 horizontal to 1 vertical
3H:1V	3 horizontal to 1 vertical
5H:1V	5 horizontal to 1 vertical
AOC	Administrative Settlement Agreement and Order on Consent for Removal Action: CERCLA Docket No. 06-12-10
ARAR	Applicable or Relevant and Appropriate Requirements
BAT	Best Available Technology Economically Achievable
BCT	Best Conventional Pollution Control Technology
BERA	Baseline Ecological Risk Assessment
BHHRA	Baseline Human Health Risk Assessment
BMP	Best Management Practice
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
Cfs	cubic feet per second
CMP	Coastal Management Plan
cm/year	centimeters per year
CNRA	Coastal Natural Resource Area
COC	chemical of concern
COPC	chemical of potential concern
CSM	Conceptual Site Model
CWA	Clean Water Act
CY	cubic yard
EAM	Exposure Assessment Memorandum
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
FS	Feasibility Study
FS Report	Feasibility Study for the San Jacinto River Waste Pits Superfund Site
GLO	Texas General Land Office
GRA	General Response Action

HSC	Houston Ship Channel
I-10	Interstate Highway 10
ICs	Institutional Controls
IP	International Paper Company
MCL	Maximum Contaminant Level
MIMC	McGinnes Industrial Maintenance Corporation
mm/year	millimeters per year
MNR	Monitored Natural Recovery
MOU	Memorandum of Understanding
MSL	mean sea level
NAVD88	North American Vertical Datum of 1988
NCP	National Contingency Plan
ng/kg	nanograms per kilogram
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOx	nitrogen oxides
NFIP	National Flood Insurance Program
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRHP	National Register of Historic Places
NRRB	National Remedy Review Board
NSR	net sedimentation rate
OMM	Operations, Monitoring, and Maintenance
OSHA	Occupational Safety and Health Administration
PCB	polychlorinated biphenyl
PRG	protective concentration level
PM	particulate matter
$PM_{2.5}$	fine particle particulate matter
POTW	publically owned treatment works
PPE	personal protective equipment
PRG	Preliminary Remedial Goals
Proposed Plan	proposed remedial action plan for the SJRWP Site
PSCR	Preliminary Site Characterization Report

RACR	Removal Action Completion Report
RAL	remedial action level
RAM	Remedial Alternatives Memorandum
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
RME	Reasonable Maximum Exposure
ROD	Record of Decision
ROW	right-of-way
S/S	solidification and stabilization
Site	San Jacinto River Waste Pits Superfund Site
SJRF	San Jacinto River Fleet
SJRWP	San Jacinto River Waste Pits
SMA	sediment management area
SPME	solid phase micro extraction
SWAC	surface-weighted average concentration
SWPPP	Storm Water Pollution Prevention Plan
TBC	to-be-considered
TCCC	Texas Coastal Coordination Council
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TCDF	2,3,7,8-tetrachlorodibenzofuran
TCEQ	Texas Commission on Environmental Quality
TCMP	Texas Coastal Management Plan
TCRA	time critical removal action
TEQ	toxic equivalents
$TEQ_{DF,M}$	TEQ concentration calculated for dioxin and furan congeners using toxicity equivalency factors for mammals
TES	threatened and endangered species
TMDL	total maximum daily load
TMV	toxicity, mobility or volume
TPDES	Texas Pollutant Discharge Elimination System
TSHA	Texas State Historical Association
TxDOT	Texas Department of Transportation

T&E	threatened and endangered
UAO	Unilateral Administrative Order for Remedial Investigation/Feasibility Study: CERCLA Docket No. 06-03-10
UECA	Uniform Environmental Covenants Act
USACE	U.S. Army Corps of Engineers
U.S.C.	U.S. Code
USDL	U.S. Department of Labor
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Services

EXECUTIVE SUMMARY

This report presents the Feasibility Study (FS) for the San Jacinto River Waste Pits (SJRWP) Superfund Site (Site) in Harris County Texas, and was prepared to evaluate remedial alternatives based on Site conditions described in the Remedial Investigation (RI) Report (Integral and Anchor QEA 2013). The RI Report was prepared on behalf of McGinnes Industrial Maintenance Corporation (MIMC) and International Paper Company (IP) and in response to a Unilateral Administrative Order (UAO) issued by the U.S. Environmental Protection Agency (USEPA), Docket No. 06-03-10.

This FS Report presents remedial alternatives for two areas within the study area perimeter designated by USEPA for purposes of the RI/FS investigation (USEPA's Preliminary Site Perimeter).

One area is located north of Interstate Highway (I-10) where impoundments used for the disposal of paper mill waste (Northern Impoundments) are located. A time critical removal action (TCRA) has been implemented to construct a temporary armored cap to isolate and contain waste in those impoundments. The FS Report presents eight remedial alternatives for the Northern Impoundments (Alternatives 1N, 2N, 3N, 3aN, 4N, 5N, 5aN, and 6N). The alternatives range from continued maintenance of the existing temporary armored cap (Alternative 1N) to full removal of waste and impacted materials (Alternative 6N).

The second area is located on the peninsula south of I-10 to the west of Market Street, where various marine and shipping companies have operations; certain portions of the area of investigation south of I-10 may have been used for disposal of paper mill waste (as well as other wastes) in the 1960s. The remedial alternatives for this area (Alternatives 1S to 4S) address three distinct locations in which subsurface soils contain dioxins at levels above the Preliminary Remediation Goal (PRG) for a hypothetical future construction worker.

The Site and Site History

The SJRWP Site was added to the National Priorities List (NPL) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in 2008. USEPA's Preliminary Site Perimeter encompasses several impoundments and surrounding in-water and upland areas. The impoundments are located on the western side of the San Jacinto River, in Harris County, Texas, north and south of I-10 where I-10 crosses the San Jacinto River. The impoundments were built in the mid-1960s for disposal of paper mill wastes that were barged from the Champion Paper Inc. paper mill in Pasadena, Texas.

Large scale groundwater extraction by others resulting in regional subsidence of land in the vicinity of the SJRWP Site resulted in increased exposure of the contents of the Northern Impoundments to surface waters. The Northern Impoundments were the subject of a TCRA, discussed below, that since its completion in 2011 has temporarily capped and isolated waste material.

The area of investigation south of I-10 is an upland area, and the site of a former impoundment. The impoundment south of I-10 is not currently in contact with surface water. Since the 1960s, a variety of industrial and other activities have taken place on the upland area south of I-10. Most of the peninsula is currently in industrial or commercial use by marine services companies, with some parcels currently unused.

Stabilization and Isolation of the Northern Impoundments

MIMC and IP implemented a temporary cap to stabilize and isolate materials within the Northern Impoundments. The temporary cap was completed in 2011 pursuant to the terms of an Administrative Settlement Agreement and Order on Consent for Removal Action: CERCLA Docket No. 06-12-10 (AOC; USEPA 2010a). It included construction of a temporary armored cap that was designed in accordance with U.S. Army Corps of Engineers (USACE) and USEPA guidelines and capping guidance (USACE 1998; USEPA 2005) (temporary armored cap). The temporary cap also included installation of fencing around the Site, establishment of access controls, and the posting of warning signs.

The temporary armored cap includes layers of armor stone, geotextile and geomembrane and is constructed over an area of approximately 15.7 acres. It was designed and constructed at a cost of more than $9 million. The temporary armored cap was designed to withstand a 100-year storm event with an additional factor of safety to ensure its protectiveness. The storm event defines the depth of water and the currents that the cap armor layer must resist. Although a 100-year event was specified for the temporary cap design, events up to the 500-year storm were evaluated for the FS in order to assess the potential risk of an even larger storm.

Since being completed in July 2011, the temporary armored cap has generally isolated and contained impacted material. However, in July 2012, disruption of a localized area of the armor rock layer of the temporary armored cap occurred, and the geotextile was exposed. This occurred following wet weather in July 2012 and was addressed in accordance with the approved OMM Plan and USACE and USEPA guidance. The affected areas totaled about 200 square feet, or 0.03 percent of the overall area of the temporary armored cap.

The temporary armored cap's design and construction were the subject of a post-construction evaluation by MIMC and IP and a separate assessment by USEPA and USACE (USACE 2013).

Based on this review, the USACE recommending enhancements (e.g., placing additional armor rock and constructing flatter slopes) to further ensure the protectiveness of the temporary armored cap. In January 2014, the Respondents implemented all of the USACE recommendations (Anchor QEA 2014).

Despite implementation of the USACE's recommendations, in December 2015 another area (approximately 22 feet by 25 feet) on the northwest part of the cap was discovered to be deficient in armor rock material. The discovery of the uncapped area did not occur as a result of routine maintenance activities, which had not revealed the lack of armor rock, but was discovered by the USEPA Dive Team in the performance of other tasks at the Site. This deficiency resulted in exposing the underlying paper mill waste material to the San Jacinto River. Sampling of the exposed waste material found that it contained dioxin over 43,000 ng/kg TEQ dioxin. While sampling from the nearby undisturbed areas of the cap did not show elevated levels of waste materials containing dioxins, for an unknown period the paper mill material was in direct contact with surface water. Repairs of this area were completed in January 2016 by installing a geotextile fabric over the area and covering it with armor stone. Additional areas of missing rock were discovered in February and March 2016.

The temporary armored cap, and associated fencing, access controls and signs have been routinely inspected and maintained pursuant to a USEPA-approved Operations, Monitoring, and Maintenance (OMM) Plan. The OMM Plan originally was developed to address conditions that USACE and USEPA cap design guidance expressly presumes could occur post-construction (such as movement of rock cover in localized areas of the cap). However, the OMM Plan had to be modified because the original program of routine inspections failed to identify the cap deficiencies described above. The OMM Plan now requires not only periodic inspections, topographic survey data, bathymetric survey data, manual probing and monitoring following key storm events, but also, more frequent inspections and video surveillance to identify the need for possible cap maintenance and procedures to implement appropriate repair activities (USEPA 2005; USACE 1998).

Remedial Action Objectives and Protective Concentration Levels

Remedial Action Objectives (RAOs) for the Site and Preliminary Remediation Goals (PRGs) for waste material, soil and sediment are risk-based criteria that were developed as part of the RI/FS process. The PRGs are consistent with reasonably anticipated future uses and applicable to the areas north and south of I-10 for which remedial alternatives were developed. The risk-based PRG for dioxin/furan in sediment is 30 ng/kg TEQ (hypothetical recreational fisher, non-cancer Hazard Index (HI) = 1) (EPA, Khoury, Human Health Risk Evaluation and Recommended Sediment Cleanup Level, August 29, 2016). The risk-based PRG for dioxin/furan in waste material is 200 ng/kg TEQ (hypothetical recreational visitor, non-cancer HI = 1) (Anchor QEA, Relative Bioavailability Adjustment Memo, 01/16/2015). Finally, the risk-based PRG for dioxin/furan in soil is 240 ng/kg TEQ (hypothetical construction worker, non-cancer HI = 1) (Anchor QEA, Relative Bioavailability Adjustment, January 16, 2015).

Principal Threat Waste

The NCP establishes an expectation that EPA will use treatment to address the principal threats posed by a site wherever practicable (NCP § 300.430(a)(1)(iii)(A)). In general, Principal Threat Wastes are those source materials considered to be highly toxic or highly mobile which generally cannot be contained in a reliable manner or would present a significant risk to human health or the environment should exposure occur. The "principal threat" concept is applied to the characterization of "source materials" at a Superfund site. At the Site, the northern waste pits contain dioxin/furan over 43,000 ng/kg TEQ, and the Southern Impoundment soils contains dioxin/furan over 50,000 ng/kg TEQ. The northern waste pits maximum dioxin/furan concentration is 215 times higher than the non-cancer hazard based waste material PRG, and the Southern Impoundment maximum dioxin/furan concentration is 208 times higher than its non-cancer hazard based PRG. The non-cancer hazard index for exposure to waste material (recreational visitor scenario) at the Site is 66, which is more than an order of magnitude greater that the acceptable hazard index of 1. Dioxin/furans are highly persistent chemicals and will not breakdown for hundreds of years. While there is considerable uncertainty regarding biodegradation of dioxins/furans, the EPA estimates that, for dioxins that are not exposed to sunlight, the dioxin half-life ranges from 25 to 100 years (https://clu-in.org/contaminantfocus/default.focus/sec/dioxins/cat/Chemistry_and_Behavior/).

The Site is located in the San Jacinto River, which has experienced a number of severe storms and floods in the past. For example, the 1994 flood exceeded the 100-year return period storm, resulted in severe riverbed scour while cutting new channels outside of the river bed, destroyed or damaged thousands of homes, and undermining and rupturing pipelines both inside and outside of the river channel. The 1994 storm crested at 27.09 feet at the Sheldon, Texas gauge located about five miles upstream of the Site. Previous storm resulted in even higher crests of 31.5 feet in 1940 and 32.90 feet in 1929.

Because of the high levels of dioxin/furan, which are over two orders of magnitude higher than the acceptable concentration, and its' highly toxic and persistent nature, there is a significant risk to human health or the environment should exposure occur. With the regular occurrence of severe storms and flooding in the area, there is high level of uncertainty that the waste material can be reliably contained over the long term (Appendix A). Therefore, the dioxin/furan waste at the San Jacinto River Waste Pits Superfund Site is considered a Principal threat waste based on high toxicity or potential mobility.

Remedial Alternatives for Area North of I-10

Remedial technologies presented in this FS Report were subjected to an initial screening process before being developed and included in the final set of remedial alternatives that are discussed in this FS Report. The initial screening process was performed by MIMC and IP pursuant to the UAO for the RI/FS; the EPA subsequently decided to revise and complete the Feasibility Study Report itself. The EPA also entered into an agreement with the USACE to provide additional information and modelling analysis of remedial alternatives for the Site (see Appendix A discussing the USACE's Evaluation of the San Jacinto Waste Pits Feasibility Study Remediation Alternatives, or "Alternatives Evaluation report").

For the area north of I-10, the remedial alternatives focus on containment, treatment, removal, and/or a combination of containment, treatment and removal, together with Institutional Controls (ICs) to achieve a range of post-remedy surface-weighted average concentrations (SWACs). All alternatives recognize the existence of the temporary armored cap.

The alternatives developed and presented in this FS Report for the area north of I-10 include:

- **Alternative 1N – Temporary Armored Cap and Ongoing OMM (No Further Action),**

  Estimated Operation & Maintenance Cost (e.g., inspection, maintenance): $0.4 million
  Estimated Total Present Worth Cost: $0.4 million
  Estimated Construction Time: Construction complete

  Assumes the temporary armored cap would remain in place, together with fencing, warning signs and access restrictions established as part of the temporary cap, and would be subject to ongoing OMM.

- **Alternative 2N – Armored Cap, ICs, Ground Water Monitoring, and Monitored Natural Recovery (MNR)**

  Estimated Operation & Maintenance Cost: $2.0 million
  Estimated Total Present Worth Cost: $2.0 million
  Estimated Construction Time: Construction complete

  Includes the actions described under Alternative 1N and institutional controls in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground or surface water resulting from the waste left in place. Monitoring may also involve collecting and analyzing sediment, tissue, and surface water and evaluating the data.

- **Alternative 3N – Upgraded Cap, ICs, Ground Water Monitoring, and MNR,**

  Estimated Capital Cost: $1.77 million
  Estimated In-Direct and Operation & Maintenance Cost: $2.38 million
  Estimated Total Present Worth Cost: $4.1 million
  Estimated Construction Time: 2 months

  Includes the actions described under Alternative 2N plus additional enhancements to the temporary armored cap. Institutional controls in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River. This alternative will increase the long-term stability of the temporary armored cap consistent with isolation of impacted materials. The Upgraded Cap will use rock sized for the "No Displacement" design scenario, which is more conservative than the "Minor Displacement" scenario used in the temporary armored cap's design. This remedial alternative also includes additional measures to protect the Upgraded Cap from potential vessel traffic (e.g., rock berm). An off-site staging area may be required for management of rock armor materials, similar to that which was utilized during the temporary cap construction. However, the exact location and configuration of the staging area are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 3aN - Enhanced Cap, Protective Pilings, ICs, Ground Water Monitoring, and MNR,**

Estimated Capital Cost: $19.7 million
Estimated In-Direct and Operation & Maintenance Cost: $5.1 million
Estimated Total Present Worth Cost: $24.8 million
Estimated Construction Time: 15 months

Includes enhancements to Alternative 3N suggested by the USACE in an attempt to address the 80% erosion of the Upgraded Cap (Alternative 3N) (see Appendix A), which included substantial erosion of the underlying paper mill waste material. This alternative, 3aN, includes the actions described under Alternative 3N plus additional enhancements to the temporary armored cap recommended by the USACE to create a cap with increased long-term stability. Institutional controls in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

The additional cap enhancements added for this alternative include pre-stressed concrete or concrete filled steel pipe pilings placed 30 feet apart around the perimeter of the cap to protect from barge strikes. The spacing is designed to catch a typical barge, which is 35 feet wide. An additional armor stone cap with a thickness of at least 24 inches would be placed over the armor cap for Alternative 3N. The armor stone would have a median diameter of 15 inches. This additional armor stone would cover 13.4 acres of the 17.1 acre armored cap. Also, a course gravel filter layer would be placed on 1.5 acres of the Northwest Area where there is currently no geotextile under the armor cap. The actual scope and design of the cap enhancements, and additional area needed to construct the required slopes, would be determined in the Remedial Design. This additional weight of rock on top of the waste pits may cause cap settling and/or pushing the waste material out the sides of the cap; the Remedial Design will consider the significance of and design issues related to this.

- **Alternative 4N – Partial Solidification/Stabilization, Upgraded Cap, ICs and MNR,**

Estimated Capital Cost: $11.13 million
Estimated In-Direct and Operation & Maintenance Cost: $3.74 million
Estimated Total Present Worth Cost: $14.8 million
Estimated Construction Time: 17 months

Provides for solidification and stabilization (S/S) of the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's

Preliminary Site Perimeter was used to define the most highly contaminated material. This alternative also includes the actions described under Alternative 3N; however, about 23 percent of the temporary armored cap (2.6 acres above the water surface and 1.0 acre in submerged areas) would be removed to provide for S/S of the most highly contaminated material. Institutional controls in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

About 52,000 cubic yards (CY) of materials with $TEQ_{DF,M}$ that exceeds a concentration of 13,000 nanograms per kilogram (ng/kg), would undergo S/S. After the S/S is completed, the Upgraded Cap would be re-constructed and the same ICs and MNR as in Alternatives 2N and 3N would be implemented. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground or surface water resulting from the waste left in place. An off-site staging area may be required for management of rock armor materials, stabilization reagents and associated treatment equipment. However, the exact location and configuration of the staging area are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 5N – Partial Removal, Upgraded Cap, ICs, Ground Water Monitoring, and MNR,**

  Estimated Capital Cost: $24.86 million
  Estimated In-Direct and Operation & Maintenance Cost: $4.94 million
  Estimated Total Present Worth Cost: $29.8 million
  Estimated Construction Time: 13 months

  Provides for removal of the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter was used to define the most highly contaminated material. The temporary armored cap would be partially removed and the same 52,000 CY of material that would undergo S/S under Alternative 4N would instead be excavated for off-site disposal. After the removal was completed, the Upgraded Cap would be re-constructed and the same ICs and MNR that are part of Alternatives 2N to 4N would be implemented. These institutional controls in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground or surface water resulting from the waste left in place. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. The exact location, configuration, siting and operational impacts, as well as potential delivery restrictions by the receiving facility (e.g., tons per day) are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 5aN - Partial Removal of Materials Exceeding the PRG, Upgraded Cap, ICs, Ground Water Monitoring, and MNR,**

  Estimated Capital Cost: $60.38 million
  Estimated In-Direct and Operation & Maintenance Cost: $9.21 million
  Estimated Total Present Worth Cost: $69.6 million
  Estimated Construction Time: 19 months

  All material beneath the temporary armored cap in any location where the water depth is 10-feet or less and which has a $TEQ_{DF,M}$ at or above the PRG for the waste material for a hypothetical recreational visitor of 200 ng/kg[1] – about 137,600 CY – would be excavated for off-site disposal. Institutional controls in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

  To implement this alternative, about 11.3 acres (72 percent) of the temporary armored cap would be removed to allow for this material to be removed. After excavation of the material, the remaining areas of the temporary armored cap would be upgraded to create an Upgraded Cap.

[1] In defining this alternative, USEPA included an additional requirement that all material exceeding 13,000 ng/kg $TEQ_{DF,M}$, regardless of water depth, would be removed. All locations that exceed 13,000 ng/kg $TEQ_{DF,M}$ are in areas with 10-feet of water or less. Thus, the horizontal boundary defining this alternative (the 10-foot water depth) includes all locations exceeding 13,000 ng/kg $TEQ_{DF,M}$.

Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground or surface water resulting from the waste left in place. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. The exact location, configuration, siting and operational impacts, as well as potential delivery restrictions by the receiving facility (e.g., tons per day) are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 6N – Removal of Waste Materials Exceeding the PRG, MNR, and ICs,**

  Estimated Capital Cost: $77.14 million
  Estimated In-Direct and Operation & Maintenance Cost: $9.83 million
  Estimated Total Present Worth Cost: $87 million
  Estimated Construction Time: 19 months

  This is the same alternative as 6N* evaluated by the USACE (Appendix A). All waste material above the waste material PRG of 200 ng/kg located beneath the temporary armored cap would be removed. Institutional controls in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

  This alternative would involve removal of most of the existing temporary armored cap and the removal of approximately 152,000 CY of waste material. The full removal alternative will utilize Best Management Practices (BMPs) to reduce the re-suspension of sediment. The removal will be completed in stages or sections as appropriate to limit the exposure of the uncovered sections of the waste pits to potential storms. Raised berms, sheet piles, and silt curtains in addition to dewatering and removal in the dry to the extent practicable will be used to reduce the re-suspension and spreading to the removed material. The berms would be armored on the external/river side with armor material removed from the areas that have geotextile present. The design approach for removal and design of BMPs will be determined in the Remedial Design. Residual concentrations of contaminants following excavation and removal will be covered by at least two layers of clean fill to limit intermixing of residual material with the clean fill. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. The exact location, configuration, siting and operational impacts, including severe weather, as well as potential delivery restrictions by the receiving facility (e.g., tons per day) are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

Comparative Evaluation of Alternatives for Area North of I-10

The waste material is highly toxic and may be highly mobile in a severe storm and therefore is considered a Principal Threat Waste. The EPA considers material at the Site with more than 300 ng/kg dioxin to be Principal Threat Waste. This concentration was calculated by multiplying the risk-based sediment PRG of 30 ng/kg (Hazard Index = 1) by a factor of 10 (an order of magnitude). While no threshold level of toxicity or risk has been established to equate to a principal threat, the EPA generally considers source materials with a potential risk that is equal to or greater than an order of magnitude higher than a protective level should be considered a Principal Threat Waste.

In evaluating the Remedial Alternatives, the EPA has considered the location of the Principal Threat Waste materials, either partially submerged within the San Jacinto River (northern impoundments) or on a small peninsula on the San Jacinto River (southern impoundment). The Site is in a river environment that is subject to dramatic change, creating concerns about the protectiveness of leaving Principal Threat Waste in and adjacent to the River, even if contained with an armored cap. The area has a high threat of repeated storm surges and flooding from hurricanes and tropical storms, which, if the material was left in place, could result in a release of hazardous substances. The history of repeated temporary armor cap maintenance to replace missing or eroded armor stone, with flooding that has been less severe than the design 100-year flood, also creates concerns about the long-term permanence of an armored cap.

The two CERCLA Threshold Criteria are that a remedy must 1) provide for overall protection of human health and the environment; and 2) comply with the Applicable or Relevant and Appropriate Requirements (ARARs) identified for the Site. The containment alternatives (2N through 5aN) will only remain protective if they are properly maintained for the length of time (hundreds of years) that the impounded waste retains its toxicity, and assumes that their integrity is not compromised by extreme weather events, barge strikes and/or changes in the river channel which could result in a future release. Alternative 6N best realizes the Threshold Criteria of overall protectiveness because the waste material would be removed and therefore not subject to a potential future release of a significant amount of Principal Threat Waste into the San Jacinto River, although there will be some short term releases of dioxin (estimated by the USACE as between 0.2% and 0.34% of the waste material with Best Management Practices or BMPs) as a result of implementing the full removal alternative.

Alternatives 1N and 2N rely on continued containment of materials exceeding the PRGs within the existing temporary armored cap. These two alternatives each include a requirement, based on the approved OMM Plan, to monitor and maintain the temporary armored cap in accordance with USACE and USEPA guidance to ensure the long-term effectiveness of the cap system.

Alternative 3N includes the features of Alternatives 1N and 2N, together with construction of an Upgraded Cap that exceeds USACE and USEPA design guidance by placing additional armor rock and constructing flatter slopes. In addition, the Upgraded Cap uses larger rock sized for the "No Displacement" design scenario, which more conservative than the "Minor Displacement" scenario used in the temporary armored cap's design. In addition, Alternative 3N includes the construction of a protective perimeter barrier or other measures around the perimeter of the Upgraded Cap to address concerns regarding potential damage from vessel traffic.

The USACE performed evaluations to address the permanence of the existing repaired temporary cap with the proposed modifications outlined in the capping Alternative 3N. Since its completion in July 2011, the armored cap has generally isolated the waste, but has required many repairs and extensive maintenance. The expected long-term releases from capping are very small in the absence of cap erosion or a major disturbance by a barge strike. However, the USACE found that a severe storm could erode a sizable portion of the upgraded Alternative 3N cap. The most severe event simulated was the hypothetical synoptic occurrence of Hurricane Ike (Category 2 hurricane) and the October 1994 flood, with a peak discharge of approximately 390,000 cubic feet per second occurring at the time of the peak storm surge height at the Site. This storm flow is about 8% higher than the river flow during the 1994 storm. Approximately 80 percent (12.5 acres) of the 15.7 acre upgraded Alternative 3N cap incurred severe erosion during the simulated extreme storm. The maximum scour depth in any grid cell within the cap boundary during this potential extreme event was 2.4 feet resulting in erosion and release of the paper mill waste material containing dioxin.

Some localized disturbances of the cap may occur from bearing capacity failures of the soft sediment, gas entrapment by the geomembrane or geotextiles, or barge strikes, requiring maintenance or repair. The USACE believes that the expected releases from these localized disturbances would be very small, much smaller more than releases from removal of the contaminated sediment as predicted for Alternative 6N with enhanced resuspension BMPs, even if these disturbances are not quickly repaired.

The USACE estimated that these issues related to cap permanence might be addressed by additional modifications to Alternative 3N (modifications included in Alternative 3aN), including upgrading the blended filter in the Northwestern Area to control sediment migration into the cap, upgrading the armor stone size with a median size of 15 inches, thickening of the armor cap by an additional 2-feet across most of the waste pits, and installing pilings to protect the cap from barge strikes. However, the USACE report did not consider changing river conditions in its evaluation of the long term permanence of a cap; new channels eroding during flooding as well as changes in channel cross section due to bank erosion, shoreline breaches, etc. during a high flow event caused by a major flood or hurricane is beyond the ability of existing sediment transport models to simulate. In addition, the uncertainty associated with estimates of the effects of some of the potential failure mechanisms, e.g., propwash, stream instability, is very high (USACE 2016b). Finally, even more severe hurricanes (exceeding Category 2) are possible during the hundreds of years that the dioxin waste will remain hazardous. Therefore, there is a high degree of uncertainty regarding the long term permanence of the cap, even with the improvements suggested by the USACE.

Alternatives 1N, 2N, 3N, and 3aN are containment alternatives that provide substantial long-term protectiveness under normal conditions while avoiding environmental impacts applicable to Alternatives 4N, 5N, 5aN and 6N, all of which require disruption of the existing temporary armored cap to conduct stabilization or removal/disposal of impacted materials. However, Alternatives 1N, 2N, 3N, and 3aN do not provide any further treatment or removal of the dioxin/furan Principal Threat Waste. Alternatives 3N and 3aN provide additional long-term protectiveness compared to Alternatives 1N and 2N due to the additional cap enhancements and measures to minimize potential damage to the Upgraded Cap from vessel traffic. Alternative 6N provides the greatest long-term protectiveness and effectiveness because the waste material, except for the residuals, would be permanently removed from the San Jacinto River and there would be no potential for a future release from the Site, and neither would there be any concerns regarding the long term viability and effectiveness of a maintenance program that would have to endure for an extremely long time, or hundreds of years. Alternative 6N also provides for removal of the dioxin/furan Principal Threat Waste, which will be treated for water removal as necessary for transportation and off-site disposal.

In situ capping, as discussed in USEPA and USACE guidance (USEPA 2005; USACE 1998) and in Table 4-1a, is a demonstrated technology that has been selected by USEPA for sediment remediation sites across the United States. However, the Site's location within the San Jacinto River creates an uncertainty regarding the ability of an engineered cap to reliably contain the dioxin waste over the hundreds of years that the dioxin will remain hazardous. The uncertainty comes from the severe storms and floods that have occurred in the area, and the potential for barge strikes to compromise the cap. The potential for barge strikes is heighted because of the increased barge traffic after the completion of the temporary armored cap. In summary, the armored cap is predicted by the USACE to have long-term reliability from scour related processes except under very severe hydrologic and hydrodynamic events. However, the USACE also recognized that the uncertainty associated with estimates of the effects of some of the potential failure mechanisms, e.g., propwash, stream instability, is very high (Appendix A), and that potential changes in the river channel cannot be simulated due to modelling limitations.

Alternatives 4N, 5N, 5aN, and 6N include disruption of the existing temporary armored cap in order to conduct treatment or removal of materials beneath the cap. These alternatives employ design, engineering and operational controls to mitigate the resuspension of impacted waste materials that occurs when using these remedial technologies. Removal technologies have been used at sediment sites listed on Table 4-1b. Alternatives 4N and 5N would stabilize (4N) or remove (5N) materials with $TEQ_{DF,M}$ greater than the level set by USEPA of 13,000 ng/kg. Alternatives 5aN and 6N would remove some (5aN) or all (6N) waste materials that exceed the PRG of 200 ng/kg for a hypothetical recreational visitor. Alternative 4N would stabilize 52,000 CY of the waste material from beneath the temporary armored cap, while Alternative 5N, 5aN, and 6N would remove and dispose of off-site volumes of material ranging from 52,000 CY(Alternative 5N), to 137,600 CY (Alternative 5aN) to 152,000 CY (Alternative 6N). Alternatives 5N, 5aN, and 6N may reduce the amount of long-term OMM associated with the capping and treatment-based alternatives (1N thorough 4N), while 6N would eliminate most OMM except for actions to implement and maintain the MNR and the ICs.

Alternative 3N has an estimated construction duration of 2 months and may require an off-site staging area for armored rock, while Alternative 3aN has an estimated duration of 15 months. Alternatives 4N, 5N, 5aN, and 6N have estimated construction durations ranging from 13 to 19 months. Each of these alternatives would require the establishment, and potential permitting of an off-site facility for sediment and material handling. For Alternatives 5N, 5aN, and 6N, this facility would be utilized for processing and managing removed sediments. The availability and location of an off-site facility could impact the implementability, duration, and costs of these alternatives and are beyond the scope of the FS.

Implementation of Alternatives 4N, 5N, 5aN, or 6N would require removing part of the temporary armored cap and either excavation, dredging, or stabilizing the underlying waste deposits. Stabilization under Alternative 4A is consistent with USEPA's preference for treatment. However, experience at sediment sites indicates that resuspension and release of waste material residuals and dioxins/furans into the water column will likely occur, although to a significantly reduced extent with robust BMPs. Such releases may result in increased fish tissue concentrations of contaminants for several years following completion of dredging (Patmont et al. 2013).

The selection of management practices used in removal operations has a significant impact on the levels of potential waste material releases that the USACE estimates may occur during implementation of a removal alternative. The initial drafts of the FS prepared by MIMC and IP did not use robust BMPs, and therefore overestimated likely releases from removal alternatives in comparison with the Alternative 6N described in this FS. Depending on the selection of BMPs, flooding and high flow conditions during removal operations could significantly increase the erosion of waste material residuals. Releases from flood flows over the containment structure regardless of the removal alternative will be dependent on the height of the containment structure and the flood stage. A sheet pile wall built in and supported by an armored waste pit berm and along the southern shoreline to an elevation of about +10 ft would protect the waste pit excavation from releases from more common floods (e.g., the 25-yr or 50-yr flood stage, Appendix A). Excavation would be performed in the dry to the extent practicable. Removals may be performed in small sections at a time such that the armor stone and geotextile within the small section would be removed, and then the sediment removed and a thin layer of sacrificial fill placed before advancing to the next section and repeating the process. Under these removal operations, it would also be advisable to limit or restrict removal activities to a period when there is a lower probability of tropical storms and flooding conditions. The actual design of protective sheet piles and berms will be determined during the Remedial Design.

BMPs would be successful in mitigating potential resuspension and release. For alternatives 4N, 5N, 5aN, and 6N, a flood may occur during construction. Therefore, these alternatives will include design and construction methodologies to mitigate and reduce the impact of storms during construction.

For short-term effectiveness, Alternatives 1N and 2N are most favorable, followed by Alternative 3N. Short-term effectiveness ranks high for Alternatives 1N and 2N because these alternatives do not entail active construction. Alternative 3N ranks lower, followed by Alternative 3aN, than Alternatives 1N and 2N for short-term effectiveness because it includes active construction considerations such as increased truck traffic, worker safety, water quality, and construction equipment emissions of particulate matter (PM), greenhouse gases, and ozone. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10.

Alternatives 4N, 5N, 5aN, and 6N also involve potential water quality impacts, worker safety risks, and air emission impacts that are estimated to be more than 8 to 20 times greater[1] than for Alternative 3N. Traffic and community impacts for Alternatives 4N, 5N, 5aN, and 6N (measured as truck trips) are estimated to range from 6 to nearly 70 times greater than for Alternative 3N and may not fully account for truck trips associated with operation of an offsite materials management facility. While the removal alternatives are less favorable for short-term effectiveness, Alternatives 4N, 5N, 5aN, and 6N all provide either treatment or removal of Principal Threat Waste, at least for a portion of the waste material. Alternative 4N includes treatment (solidification/ stabilization) for about 25% of the volume of the most highly contaminated portion of the waste. Alternative 5N and 5aN both include partial removal of the most highly contaminated waste, with Alternative 5N accounting for 25% of the volume, and Alternative 5aN accounting for about 2/3 of the waste volume. Alternative 6N includes full removal of the Principal Threat Waste above the cleanup level.

The USACE found that fish tissue contaminant concentrations are directly related to the releases to the water column, but are also related to the entirety of their food sources which are largely impacted by the water column concentrations and releases. Consequently, depending on the BMPs employed and the feeding range of the fish species, fish tissue contaminant concentrations may be dozens of times higher (for Alternative 6N) than existing tissue concentrations for several years before returning to near existing values (Appendix A). The release amount referenced in the Corps' Report, 2 grams of dioxin, or 0.34% of the amount removed, is based on using silt curtains in the Northwestern Area. However, using robust BMPs, including sheet piles in the Northwestern Area, would reduce the release by 40% and therefore reduce the estimated fish tissue increases by 40% as well (Appendix A, Table 12-19).

Construction of any of the proposed Alternatives is not expected to cause any flooding in the vicinity of the Site, and therefore should not require the implementation of any flood control measures during the construction of any of the Alternatives under consideration for the Site.

Comparative Cost Effectiveness of the Alternatives for the Area North of I-10

Costs for the remedial action alternatives range from $0.4 to $87 million. Alternatives 1N and 2N have similar costs, primarily related to long-term OMM of the temporary armored cap. Alternative 3N has a higher cost than Alternatives 1N and 2N as it also includes construction of the Upgraded Cap and a protective barrier to ensure the long-term integrity of the Upgraded Cap. Alternative 3aN has a higher cost than Alternatives 3N as it also includes construction of the Enhanced Cap and an additional protective barrier (pilings) to ensure the long-term integrity of the cap.

Costs for Alternatives 4N, 5N, 5aN, and 6N are higher than for Alternatives 1N, 2N, 3N, and 3aN. This reflects the challenges of establishing and operating an off-site staging and processing area, removal of the temporary armored cap, in situ treatment or excavation and associated engineering controls, the quantity of materials being addressed, the duration of work, and the high cost of transportation and disposal of impacted sediments.

Alternatives 1N, 2N, 3N, and 3aN provide an equal reduction in the dioxins and furans in sediments in the river within USEPA's Preliminary Site Perimeter. For Alternatives 4N, 5N, 5aN, and 6N, the dioxins and furans in sediments in the river are predicted to increase the short-term releases from sediment re-suspension construction-related impacts (e.g., cap removal, disturbance of material below waterline, etc.). Alternatives 5N and 5aN would remove some while 6N would remove all impacted materials with higher dioxin/furan concentrations, but possible impacts from re-suspension during construction could potentially reduce the short-term protectiveness of the remedy. These alternatives are also incrementally and substantially more expensive because of their complexity and duration.

The USACE estimates (Appendix A) that the full removal alternative 6N with BMPs (Alternative 6N* in the USACE Corps Alternatives Evaluation report) including sheet piles in deeper water areas could result in a short-term release to the river of about 0.2% of the contaminant mass due to re-suspension during removal. For the enhanced capping Alternative 3N, no significant short-term release is expected and the cap is expected to be generally resistant to erosion except for very extreme floods, which could erode a sizable portion of the cap. A hypothetical occurrence of both Hurricane Ike and the October 1994 flood with a peak discharge of approximately 390,000 cubic feet per second was modelled. This storm flow is about is about 8% higher than the river flow during the 1994 storm. Approximately 80 percent (12.5 acres) of the 15.7 acre upgraded Alternative 3N cap incurred severe erosion with a release of underlying waste material during the simulated potential extreme storm.

The cost of Alternative 6N ($87 million) is about 21 times more that the cost of the upgraded capping Alternative 3N ($4.1 million), but is about 3.5 times more than the cost of enhanced capping Alternative 3aN ($24.8 million). However, the potential future dioxin release for the temporary cap with the upgrades described for the Upgraded Cap (Alternative 3N) during a future severe storm results in a release of approximately 29% of the dioxin in the waste pits. This modelled future storm erodes much of the cap with a potential release that is over 140 times higher than the short-term release for Alternative 6N using BMPs with sheet piles around all areas (0.2% release). If sheet piles cannot be used in deeper water due to technical reasons, the short–term release would still be much less (0.34%) than the severe storm release (USACE 2016b). The additional cost for Alternative 6N insures that that a future extreme storm will never result in a catastrophic cap failure and release of dioxin to the San Jacinto River.

Remedial Alternatives for Area South of I-10

The area south of I-10 is part of a peninsula on which industrial activity has occurred since at least the early 1960s. In contrast with the area to the north of I-10, the peninsula south of I-10 contains active operations of several shipping and marine industrial services businesses, with the area serving as a transport hub and as a location for barge or ship maintenance, cleaning and painting. Changes in the distribution of materials, locations of soil disturbance and staining, development of buildings or other structures, and evolution of roads and tracks throughout the southern peninsula area, indicate that the peninsula south of I-10 has been a busy industrial community in the decades after disposal of paper mill wastes in the mid-1960s took place.

Three dioxin and furan source types have been identified in soils of the area of investigation south of I-10, only one of which has a fingerprint that is similar to the paper mill wastes contained in the North Impoundments. Another source is from general urban background, such as fuel combustion and other common municipal activities, or specific local sources. A third source type has a fingerprint that is distinct from the other two sources, and affects only soils in the area of investigation on the peninsula south of I-10. The nature and origin of this dioxin and furan source are unknown.

There are no risks to ecological receptors from dioxins and furans in the area of investigation south of I-10. The only risks associated with the disposal of dioxins and furans associated with paper mill wastes in the area of investigation south of I-10 was for a hypothetical future construction worker who might come into contact with the dioxins and furans within the upper 10 feet of soil. The PRG for $TEQ_{DF,M}$ protective of a hypothetical future construction worker for $TEQ_{DF,M}$ was calculated to be 240 ng/kg in soil, and is applicable to the average concentration in a soil column of 10 feet.

Remedial alternatives were developed for the locations in the area south of I-10 where the average $TEQ_{DF,M}$ concentration in the upper 10-feet of soil below grade exceeds the PRG in soil for the hypothetical future construction worker. $TEQ_{DF,M}$ concentrations in the upper 10-feet of soil exceed the PRG with the highest $TEQ_{DF,M}$ concentrations occurring at 5-feet below the ground surface or deeper. Remedial alternatives developed for the area south of I-10 include:

- Alternative 1S – No Further Action
- Alternative 2S – ICs
- Alternative 3S – Enhanced ICs
- Alternative 4S – Removal and Off-site Disposal

The costs for these alternatives are $143,000 (Alternative 1S – No Further Action), $1,024,000 (Alternative 2S – ICs), $1,409,000 (Alternative 3S – Enhanced ICs) and $9.9 million (Alternative 4S – Removal and Off-site Disposal).

Other than Alternative 1S, the remedial alternatives for the area south of I-10 meet both of the CERCLA threshold criteria as established in the NCP: protectiveness and compliance with ARARs. The potentially affected receptor (hypothetical future construction worker) would be protected from exposure to soil with elevated $TEQ_{DF,M}$ concentrations by warnings and restrictions (Alternatives 2S and 3S) or removal of impacted soil (Alternative 4S).

Alternative 4S offers the benefit of permanent removal of impacted soil from the 0- to 10-foot interval. The risk management achieved by ICs is somewhat lower, although with the addition of the physical markers that are part of Alternative 3S the risk management is improved. Alternatives 2S and 3S would not require exposing impacted soil or transporting material off-site and would be simpler to implement. However, the toxic and persistent dioxin waste material would remain susceptible to future flooding in the San Jacinto River. Excavation of impacted soil (Alternative 4S) would introduce short-term risks of exposure on-site and potentially off-site in the event of a release in route to the disposal facility. The cost of Alternative 4S (removal), $9.9 million, is about 7 times the cost of Alternative 3S (enhanced ICs). The additional cost for Alternative 4S insures that that a future extreme storm will never result in a catastrophic erosion of the waste material and release of dioxin to the San Jacinto River. Alternative 4S is the only alternative that provides for treatment or removal of the Principal Threat Waste material.

In summary, Alternative 4S offers an increase in long-term effectiveness by removing the impacted soil; however, there is an increased short-term risk of exposure and potential traffic accidents. Alternatives 2S and 3S mitigate potential risks associated with exposure to soil in the area south of I-10 with reduced short-term exposure risks and at costs commensurate with the potential risk associated with the impacted soil at depth, although with a reduced long term protectiveness.

1 INTRODUCTION

This Feasibility Study (FS) Report was prepared for the San Jacinto River Waste Pits (SJRWP) Superfund Site (Site) (Figures 1-1 and 1-2). The location of U.S. Environmental Protection Agency's (USEPA's) Preliminary Site Perimeter is shown in Figure 1-2. This FS Report builds upon the final Remedial Alternatives Memorandum (RAM), which presented the initial screening of remedial technologies and the development of preliminary remedial alternatives. Additional information on remedial technologies was developed by the U.S. Army Corps of Engineers (USACE) in a report prepared for the EPA: the Evaluation of the San Jacinto Waste Pits Feasibility Study Remediation Alternatives (the Alternatives Evaluation report). This FS Report evaluates remedial alternatives for the SJRWP Site based on the Remedial Action Objectives (RAOs) provided in the RAM and Remedial Investigation (RI) Report (Integral and Anchor QEA 2013), and based on results of the Baseline Human Health Risk Assessment (BHHRA) (Integral 2013b) and Baseline Ecological Risk Assessment (BERA) (Integral 2013a). The Final BERA and BHHRA were submitted to USEPA on May 6, 2013 and May 22, 2013, respectively. The EPA subsequently modified the PRGs for waste material in the northern waste pits, and for soil and waste material in the southern impoundment, based on a memorandum regarding a Relative Bioavailability Adjustment (Anchor QEA, January 16, 2015); and modified the PRG for sediment in a memorandum regarding the Human Health Risk Evaluation and Recommended Sediment Cleanup Level (EPA, August 29, 2016).

1.1 Purpose and Organization of the Report

The FS Report evaluates remedial alternatives for the Site, and is consistent with specific guidance (USEPA 1988). The identification and screening of remedial technologies, which the guidance includes as an element of the FS Report (Table 6-5, USEPA 1988), is discussed in the RAM (Anchor QEA 2012b), as was required by the UAO.

The remainder of Section 1 provides a summary of the regulatory background with respect to the Site. Section 2 provides a summary of Site information as presented in previous documents prepared and submitted in support of the RI/FS process, including a summary of the Site setting and history, the nature and extent of contamination, chemical fate and transport, results of the BERA and BHHRA, and the Conceptual Site Models (CSMs) for the SJRWP Site. The other sections of the FS Report address the following:

- Section 3 identifies the Preliminary Remediation Goals (PRGs) described in the RI Report and identified by USEPA and describes the basis for the remedial action
- Section 4 describes the development of each remedial alternative
- Section 5 provides a detailed and comparative analysis of each remedial alternative

- Section 6 provides the comparative analysis of the remedial alternatives
- Section 7 provides the references

1.2 Regulatory Background

On March 19, 2008, the USEPA listed the SJRWP Site on the National Priorities List (NPL) under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund, due to presence of dioxins and furans (Texas Commission on Environmental Quality [TCEQ] and USEPA 2006, 2008) in soils and sediments at the SJRWP Site. On November 20, 2009, USEPA issued a UAO to IP and MIMC (USEPA 2009a). The 2009 UAO directs IP and MIMC to conduct an RI/FS for the SJRWP Site.

The RI Report was conditionally approved by USEPA on April 4, 2013, and the Final RI Report was submitted to USEPA on May 17, 2013. The FS Report will ultimately lead to a proposed remedial action plan for the SJRWP Site (Proposed Plan). The Proposed Plan will be the subject of public comment, and once the EPA Record of Decision (ROD) is finalized, the comments and a Responsiveness Summary and will be incorporated into the ROD for the Site.

The UAO describes a basic history of the SJRWP Site, but only for the impoundments located on the north side of Interstate Highway 10 (I-10), referred to as the Northern Impoundments. USEPA subsequently required investigation of soil and groundwater in an area to the south of I-10, or "Soil Investigation Area 4" citing historical documents indicating possible waste disposal activities in that area (Figure 1-2). The area of investigation south of I-10 ultimately also included areas adjacent to Soil Investigation Area 4, at locations to the south and west of it, where USEPA required additional soil and groundwater samples.

A time critical removal action (TCRA) was completed in July 2011 in the Northern Impoundments, pursuant to an Administrative Settlement Agreement and Order on Consent for Removal Action: CERCLA Docket No. 06-12-10 (AOC) (USEPA 2010a). The temporary cap generally stabilized and isolated pulp waste and sediments within the original 1966 perimeter berm of the Northern Impoundments, but has required many repairs and extensive maintenance. More information about the temporary cap is provided in Section 2.5.3.

The Respondents to the RI/FS UAO, MIMC and IP, prepared the first draft of this Feasibility Study report under EPA oversight. Following review and comment by the EPA and other Site stakeholders on the draft, a revised draft Feasibility Study was submitted to the EPA in March 2014. Following review of the Respondents' second draft, the EPA decided that it would revise and complete the Feasibility Study report. The EPA requested the assistance of the United States Army USACE to provide additional information for the revised Feasibility Study.

The United States Army USACE 2016 report, the Evaluation of the San Jacinto Waste Pits Feasibility Study Remediation Alternatives (the Alternatives Evaluation Report), was prepared for EPA in order to evaluate and supplement the Feasibility Study work performed by the Respondents. As stated in the Alternatives Evaluation report, the technical assistance provided by the Corps was to assess the remediation alternatives presented in the draft Feasibility Study prepared by the Respondents; identify any other remedial action alternatives, technologies or best management practices (BMPs) that might be appropriate for the Site; evaluate the numerical models used by the Respondents for the Site; and assess the hydraulic conditions in and around the San Jacinto River. To perform these tasks, the USACE used surface water hydrologic, hydrodynamic and sediment transport models appropriate for the Site, including the Corps' LTFATE modeling system. The Corps organized the work into nineteen tasks as identified in the Corps Report.

The Corps Report evaluated the remedial alternatives presented in the draft Feasibility Study report prepared by the Respondents. In addition, the Corps Report identified additional alternatives, including an enhanced version of Alternative 3N, referred to in this Feasibility Study as Alternative 3aN, and Alternative 6N*, a full removal alternative with more robust BMPs than the original Alternative 6N proposed by the Respondents. In this Feasibility Study, EPA has changed the name of the Corps' Alternative 6N* to Alternative 6N, and removed from consideration the Respondents' original full removal alternative as it would result in much higher expected releases.

The Alternatives Evaluation Report provided new information for this Feasibility Study regarding how the TCRA cap would withstand an extreme storm in the area, based on the Corps' modeling. According to the report, the most severe event simulated was the hypothetical synoptic occurrence of Hurricane Ike and the San Jacinto River flooding that occurred in October 1994, with a peak discharge of approximately 390,000 cubic feet per second occurring at the time of the peak storm surge height at the Site. The results during the peak of the storm surge showed that the sections using Armor A (3-inches diameter) were completely eroded, while the sections using Armor D (10-inches diameter) were eroded more than 12 inches in about 33 percent of those sections. The sections using Armor B and C (6-inches diameter) incurred a net erosion of more than 9 inches in about 75 percent of those areas. Overall about 80% of the cap experienced significant erosion with scour reaching approximately 2.4-feet through the cap and into the waste material. The scenario defined above may cause significant erosion of the paper mill waste.

The Corps also states its belief that releases from catastrophic events can potentially be addressed by additional cap improvements, including upgrading the blended filter in the Northwestern Area to control sediment migration into the cap, upgrading the armor stone size to a diameter of 15 inches and adding 2 feet of additional armor stone over the existing cap across the waste pits to minimize the potential for disturbance during very severe hydrologic and hydrodynamic events. These improvements have been incorporated into new Alternative 3aN in this Feasibility Study. However, the Corps did not model the impact of the most severe storm/flooding event simulated with the improvements added to Alternative 3aN. More importantly, future flooding may be even more intense. According to the U.S. National Climate Assessment, flooding along rivers and other areas following heavy downpour and prolonged rains is exceeding the limits of flood protection infrastructure designed for historical conditions.

The Corps Report's evaluation of the containment alternatives is contingent on the continued integrity of the armored cap and is limited by uncertainties in modeling. The USACE acknowledges that the uncertainty inherent in any quantitative analysis technique used to estimate the long-term (500 years or more) reliability of the cap is very high, and the uncertainty associated with estimates of the effects of some of the potential failure mechanisms such as propwash and stream instability, is also very high.

The Corps Alternatives Evaluation report did not evaluate changing river conditions or stream instability on the containment alternatives. New channels eroding during flooding as well as changes in channel cross section due to bank erosion, shoreline breaches, etc. during a high flow event caused by a major flood or hurricane is beyond the ability of existing sediment transport models to simulate. While changing river conditions may be beyond the ability of current models to simulate, the October 1994 flood provides an example of how flooding can cause major erosion and create water channels outside of the San Jacinto River bed. The largest new channel was cut through the Banana Bend oxbow just west of the Rio Villa Park subdivision, about 2 ½ miles northwest of the Site. This new channel was approximately 510 feet wide and 15 feet deep. A second major channel cut through Banana Bend just north of the channel through the oxbow. Both of these new channels were cut through areas where sand mining had been done before, as is the case in the vicinity of the Site.

The Alternative Evaluation report also provided valuable information on BMPs that can be implemented to improve the performance of the full removal alternative; these BMPs have been incorporated in the new Alternative 6N in this Feasibility Study. However, the 2016 USACE report's evaluation of containment as compared to excavation and removal often focuses on risks which will be reduced and/or eliminated through use of the BMPs it has identified. Several of the USACE's comparisons between containment and removal alternatives use the earlier version of Alternative 6N for the comparison, without BMPs, and therefore higher expected releases of hazardous substances during implementation. The expected releases from the Respondents' original version of Alternative 6N, not using BMPs, were estimated at 3.3% of the total waste to be removed during removal operations; the expected releases from the new Alternative 6N (Alternative 6N* in the Alternatives Evaluation report) are between 0.2% and 0.34% of the waste, depending on whether sheet pile walls can be effectively used in the Northwest Cell.

The USACE Alternatives Evaluation report also indicates that there are no documented cases of any armored cap or armored confined disposal facility breaches. However, there have been many occurrences of breaches and slope failures of armored dikes, jetties, and breakwaters, with some of those structures confining dredged material. In addition, the EPA has estimated that the dioxin contaminated paper mill waste in the impoundments will remain hazardous for hundreds of years; none of the examples cited by the USACE have been in place over 100 years, and many are not in aquatic environments as dynamic as the Site's location in the San Jacinto River.

2 SETTING

This section provides a summary of information gathered concerning physical, chemical, and biological conditions within the USEPA's Preliminary Site Perimeter. This information is intended to provide the reader with an understanding of the SJRWP Site and the human actions, natural processes, and physical properties that may influence the nature and extent of chemicals of concern (COCs) within the USEPA's Preliminary Site Perimeter, and that may influence evaluation of remedial alternatives presented in Sections 4 through 6 of this report. A more comprehensive physical and biological description, as well as more detailed history of the area within the USEPA's Preliminary Site Perimeter, its environmental setting, and land uses are provided in the RI Report (Integral and Anchor QEA 2013).

2.1 Location and History

USEPA's Preliminary Site Perimeter includes several waste impoundments within the estuarine section of the San Jacinto River (SJR), as well as surrounding in-water and floodplains in the upland areas. The impoundments are located on the western side of the San Jacinto River, north and south of I-10 (Figure 1-1). The area within the USEPA's Preliminary Site Perimeter is generally flat with very little noticeable topographic relief across most of the area.

The SJR is a coastal plain estuary. The San Jacinto River Waste Pits are located in a FEMA designated floodway zone, which is essentially the 100-year floodplain for the SJR. The base flood elevation, which is the water surface elevation resulting from a 100-year flood, has been determined by FEMA to be 19 feet (5.8 m) for the waste pits. The low lying Waste Pits are also subject to flooding from storm surges generated by both tropical storms (i.e., hurricanes) and extra-tropical storms. Storm surges generated in the Gulf of Mexico propagate into Galveston Bay and into the Lower SJR

The impoundments were built in the mid-1960s for disposal of paper mill wastes barged from the Champion Paper Inc. paper mill in Pasadena, Texas. These wastes are the source of dioxins and furans present in the impoundments within the USEPA's Preliminary Site Perimeter and have been targeted for remediation. Other sources of dioxins and furans within USEPA's Preliminary Site Perimeter, such as atmospheric inputs, industrial effluents, publicly owned treatment works, and storm water runoff, are discussed in Section 2.5.4; however, the dioxins and furans from the paper mill waste material are distinct from the dioxins and furans from other sources, as demonstrated by the waste "fingerprinting" performed by the EPA. Over time, a variety of actions occurring within and in the vicinity of the USEPA's Preliminary Site Perimeter resulted in actual or potential disturbances to the impoundments, and introduced other sources of dioxins and furans, as well as other COCs into the soils and sediments within the USEPA's Preliminary Site Perimeter.

Large scale groundwater extraction by others, resulting in regional subsidence of land in the vicinity of the SJRWP Site, resulted in increased exposure of the contents of the Northern Impoundments to surface waters. Dredging and sand mining by others within the river and marsh to the west and northwest of the waste pits through the 1990s and early 2000s may have contributed to the exposure. Historical documents indicate that dredging actions also occurred in the river in the vicinity of the upland sand separation area located to the west of the Northern Impoundments (sand separation area) (Figure 1-2). In addition, barge maintenance and cleaning activities conducted on and adjacent to the sand separation area in the mid-1990s by Southwest Shipyards included generation and storage of unspecified hazardous materials and wastes, including residual spent blast sand, paint chips, and rust chips swept from vessels prior to painting, paint drip, and overspray (GW Services 1997).

The peninsula south of I-10 and the area of investigation south of I-10 were characterized by intense industrial activity in the 1980s based on review of historical aerial images (Integral and Anchor QEA 2013). Southwest Shipyards' activities also have impacted areas south of I-10, including the western shoreline of the peninsula south of I-10 (GW Services 1997). Most of the upland area south of I-10 is currently in industrial or commercial use by marine services companies, with some parcels currently unused.

A more detailed discussion of the SJRWP Site history is provided in Sections 5.1 and 6.1 of the RI Report (Integral and Anchor QEA 2013).

2.2 Land Use

The land use types in the area surrounding the USEPA's Preliminary Site Perimeter are shown in Figure 2-1. The land parcels closest to the USEPA's Preliminary Site Perimeter are predominantly commercial/industrial, followed by residential areas. Moving farther from the USEPA's Preliminary Site Perimeter, the amount of residential land use increases. Upstream of the USEPA's Preliminary Site Perimeter, land uses include industrial and municipal activities that may result in releases of dioxins and furans or other COPCs into the San Jacinto River, although these dioxins are distinct from the dioxins in the paper mill waste in the impoundments as discussed in Section 2.5 below.

2.2.1 Recreational and Navigational Use

The RI Report presents information regarding recreational and navigational use of the river and the area within the USEPA's Preliminary Site Perimeter. An advisory regarding the consumption of fish and blue crab exists on the San Jacinto River, including the area within the USEPA's Preliminary Site Perimeter. Sections 3.3.1 and 3.7.3 of the RI Report (Integral and Anchor QEA 2013) discuss surface water use and fishing advisories. Although fishing was reported to have occurred prior to implementation of the temporary cap, there have been no systematic studies of the amount and frequency of fishing that may have occurred within the USEPA's Preliminary Site Perimeter prior to the implementation of the temporary cap. However, the Texas Department of State and Health Services (DSHS) could not identify subsistence fishers in the area of the Site. The completion of the temporary cap resulted in reduced public access to the Northern Impoundment area. Perimeter fencing was installed and warning buoys and signs were placed around the Site. In addition, access to the temporary cap via boat is currently constrained to the north, west, south, and southeast by industrial use and navigational hazards (i.e., submerged sand bars and shallow water). However, affidavits from local fisherman indicate fishing in the vicinity of the Site with sale to local businesses.

The commercial and industrial navigational use of the waterway is generally restricted by shallow depths outside the prescribed channel, as well as other "foul areas" where unidentified hazards are likely to exist. There is no Federally authorized navigation channel in the portions of the river within the USEPA's Preliminary Site Perimeter, and vessel heights are limited in the vicinity of the Site due to clearance limits under the I-10 Bridge. Barge fleeting and mooring occurs in many areas within the USEPA's Preliminary Site Perimeter, including the San Jacinto River Fleet (SJRF) operations near the former sand separation area (Figure 1-2).

2.3 Biological Habitat

The USEPA's Preliminary Site Perimeter is located within a low gradient, tidal estuary near the confluence of the San Jacinto River and the Houston Ship Channel (HSC). The surrounding area includes Lynchburg Reservoir to the southeast and the Lost Lake sediment management area (SMA) west of Lynchburg Reservoir (Figure 2-2). The I-10 freeway reduces the connectivity of habitats in the natural areas to the north and south of the highway, and industrial land use has diminished the habitat value of the uplands and aquatic areas within the USEPA's Preliminary Site Perimeter.

Some upland natural habitat adjacent to the river within the USEPA's Preliminary Site Perimeter remains, consisting primarily of clay and sand that support a variety of forest community types including composites such as loblolly pine-sweetgum, loblolly pine-shortleaf pine, water oak-elm, pecan-elm, and willow oak-blackgum (TSHA 2009). It is reasonable to expect a suite of generalist terrestrial species that are not highly specialized in their habitat requirements and are adapted to moderate levels of disturbance (Integral 2013a). Such species could include reptiles and amphibians (e.g., snakes, turtles), birds (e.g., starlings, pigeons), and mammals common to semi-urban environments (e.g., rodents, raccoons, and coyotes).

Wildlife habitats within the northern portion of USEPA's Preliminary Site Perimeter include shallow and deep estuarine waters, and shoreline areas occupied by estuarine vegetation. A sandy intertidal zone is present along the shoreline throughout much of the USEPA's Preliminary Site Perimeter (Figure 2-2). The tidal portions of the river and upper Galveston Bay provide rearing, spawning, and adult habitat for a variety of marine and estuarine fish and invertebrate species. Species known to occur in the vicinity of the USEPA's Preliminary Site Perimeter include: clams and oysters, blue crab (*Callinectes sapidus*), black drum (*Pagonius cromis*), southern flounder (*Paralichthys lethostigma*), hardhead (*Ariopsis afelis*) and blue catfish (*Ictalurus furcatus*), spotted sea trout (*Cynoscion nebulosis*), and grass shrimp (*Paleomonetes pugio*) (Gardiner et al. 2008; Usenko et al. 2009). An estimated 34-acres of estuarine and marine wetlands are found within the USEPA's Preliminary Site Perimeter (Integral and Anchor QEA 2013).

On the peninsula to the south of I-10, most of the upland is zoned for commercial or industrial use. Minimal habitat is present in the upland terrestrial area within the USEPA's Preliminary Site Perimeter. Demolition of former industrial facilities and current operations in support of barge fleeting and other industrial activities have created a denuded upland with a covering of crushed concrete and sand. The sandy shoreline of this area has scattered riprap, other metal debris, and piles of concrete fragments. The upland vegetation present on the peninsula south of I-10 is primarily low-lying grasses, with a few shrubs and trees adjacent to the shoreline.

A more detailed description of the local ecological system can be found in Section 3.8 of the RI Report (Integral and Anchor QEA 2013) and in Section 3.4 of the BERA (Integral 2013a).

2.4 Physical Description

2.4.1 Waterway Hydrodynamics

The Site is located in the estuarine portion of the lower San Jacinto River where the river begins to transition from a river system to a delta. River conditions have significantly changed with respect to the location of the waste impoundments (Figures 2-4.1 through 2-4.4). These photos clearly show that the river channel has changed over time. These river changes will continue and could cause a catastrophic release of the highly toxic waste materials from the impoundments, if the waste materials remain in place.

The San Jacinto River within the USEPA's Preliminary Site Perimeter is a well-mixed estuarine system. Flow rates and freshwater inputs in the river in the vicinity of the USEPA's Preliminary Site Perimeter are partially controlled by the Lake Houston dam, upstream of the USEPA's Preliminary Site Perimeter. Salinity ranges from 2 to 20 parts per thousand, but may approach 0 parts per thousand during flood conditions (Integral and Anchor QEA 2013). During low-flow conditions when current velocities were dominated by tidal effects, maximum velocities were measured to be about 1 foot per second, with typical velocities of 0.5 feet per second or less during most of the tidal cycle (Integral and Anchor QEA 2013).

Water depths within the USEPA's Preliminary Site Perimeter range from relatively shallow in intertidal areas (3 feet or less) to relatively deep in the main channel of the river (about 30 feet). Flow rates in the San Jacinto River in the vicinity of the Site are partially controlled by the Lake Houston dam, which is located about 16 river miles upstream of the northern impoundments. The average flow in the river is 2,200 cubic feet per second. Floods in the river occur primarily during tropical storms (e.g., hurricanes) or intense thunder storms. Extreme flood events have flow rates of 200,000 cubic feet per second or greater. Floods can cause water surface elevations to increase by 10 to 20 feet or more (relative to average flow conditions).

Tropical weather systems in the region can have tremendous impacts on regional precipitation and hydrology along the Gulf Coast. Heavy precipitation events produce wide variations in the volume of discharge into and out of the San Jacinto River and may significantly affect variations in flow velocities, sediment transport, suspended sediment loads, and water levels. Floods in the river occur primarily during tropical storms, hurricanes, or intense thunder storms. Extreme flood events with flow rates of 200,000 cubic feet per second or greater and water surface elevations increased by 10 feet or more (relative to average flow conditions) could force the river out of its main channel.

Hurricane season runs from June 1 to November 30. Between 1851 and 2004, 25 hurricanes have made landfall along the north Texas Gulf Coast, seven of which were major (Category 3 to 5) storms. Tropical Storm Allison, which hit the Texas Gulf Coast in June 2001, resulted in 5-day and 24-hour rainfall totals of 20 and 13 inches, respectively, in the Houston area, resulting in significant flooding. More recently, Hurricane Rita made landfall in September 2005 between Sabine Pass, Texas and Johnsons Bayou, Louisiana, as a Category 3 storm with winds at 115 miles per hour and it continued on through parts of southeast Texas. The storm surge caused extensive damage along the Louisiana and extreme southeastern Texas coasts. In September 2008, the eye of Hurricane Ike made landfall at the east end of Galveston Island and travelled north up

Galveston Bay, along the east side of Houston. Ike made its landfall as a strong Category 2 hurricane, with Category 5 equivalent storm surge, and hurricane-force winds that extended 120 miles from the storm's center.

In October 1994, heavy rainfall occurred in southeast Texas resulting in the San Jacinto River Basin receiving 15 to 20 inches of rain during a week-long period. One of the largest measurements of stream flow ever obtained in Texas, 356,000 cubic feet per second (cfs), was made on the San Jacinto River near Sheldon on 19 October 1994 at a stage of 27 feet. During the measurement, velocities of water that exceeded 15 feet per second (about 10 miles per hour) were observed. Another storm occurring in 1940 had a river stage height of 31.5 feet at the same Sheldon location. The 100-year flood, which is defined as the peak stream flow having a one percent chance of being equaled or exceeded in any given year, was exceeded at 18 of 43 stations monitoring the area. For those stations where the 100-year-flood was exceeded, the flood was from 1.1 to 2.9 times the 100 year-flood.

The 1994 flooding caused major soil erosion and created water channels outside of the San Jacinto River bed. This flooding caused eight pipelines to rupture and 29 others were undermined at river crossings and in new channels created in the flood plain outside of the San Jacinto River boundaries. The largest new channel was cut through the Banana Bend oxbow just west of the Rio Villa Park subdivision, about 2½ miles northwest of the Site. This new channel was approximately 510-feet wide and 15-feet deep. A second major channel cut through Banana Bend just north of the channel through the oxbow. Both of these new channels were cut through areas where sand mining had been done before, as is the case in the vicinity of the Site. Sonar tests in a 130-foot section south of the I-10 Bridge located adjacent to the Site found about 10 to 12-feet of erosion from the bottom of the river bed (National Transportation Safety Board; Pipeline Special Investigation Report, PB96-917004, 1996).

The San Jacinto River is a very dynamic system, subject to changes in size and flow paths as experienced during the 1994 storm. A series of aerial photographs illustrate this variability. An aerial photograph taken in 1956 (Figure 2-4.1), before the waste pits were established, shows I-10 crossing the river and extensive islands and land to the north. The next photograph, from 1966 (Figure 2-4.2), shows the northern pits located just west of the I-10 Bridge (the pits were built and in operation in the mid–1960s); significant changes to the north can be seen compared to the 1956 photograph. Land erosion and subsidence is evident in the next photograph from 1973 (Figure 2-4.3); the river had carved a new passage to the west of the site since the 1966 photograph. Photographs in the 1990's and later (Figure 2-4.4) show continued loss of land.

The USACE performed an evaluation of the San Jacinto River and the armor cap using hydrodynamic and sediment transport models. In order to evaluate long term protectiveness, these models must predict the river conditions for a very long time because dioxin is extremely persistent in the environment and will remain toxic for hundreds of years. The uncertainty inherent in any quantitative analysis technique used to estimate the long-term performance of the river and cap is very high. Further, changes in the river channel due to bank erosion, shoreline breaches, etc. during a high flow event caused by a major flood or hurricane is beyond the ability of any existing sediment transport model to simulate. The changes that the river has experienced over the last 50 years as described above will likely continue in the future; and these changes are specifically what the current models cannot simulate. Therefore, the model predictions should be considered as having a very limited long term reliability.

Future flooding may be even more intense. According to the U.S. National Climate Assessment, flooding along rivers and other areas following heavy downpours and prolonged rains is exceeding the limits of flood protection infrastructure designed for historical conditions. Sea level rise, storm surge, and heavy downpours in combination with the pattern of continued development in coastal areas are increasing damage to U.S. infrastructure and are also increasing risks to ports and other installations. Because the intensity of future storms and flooding may increase, estimates regarding the ability of a cap (even a cap with increased armoring) to contain the dioxin waste material is highly uncertain.

2.4.2 Riverbed Characteristics and Sediment Transport

A detailed evaluation and analysis of the riverbed and sediment transport processes within the USEPA's Preliminary Site Perimeter was presented in the RI Report, as well as in the Chemical Fate and Transport Modeling Report (Anchor QEA 2012c).

The nature of the sediment bed affects sediment transport processes, as well as chemical distributions. As described in the RI Report, the sediment bed within the USEPA's Preliminary Site Perimeter is composed of approximately 80 percent cohesive (i.e., muddy) and 20 percent non-cohesive (i.e., sandy) sediments (Integral and Anchor QEA 2013). Erosion rate data of cohesive sediment collected in the San Jacinto River indicate that the erodibility of bed sediment decreases with increasing depth in bed (Anchor QEA 2012c). The primary source of sediment to the San Jacinto River and within the USEPA's Preliminary Site Perimeter is suspended sediment in surface waters discharged from the Lake Houston Dam. The average annual sediment load at the dam is approximately 381,000 metric tons (Anchor QEA 2012c).

Sediment stability within the USEPA's Preliminary Site Perimeter may be affected by human activities and natural processes as discussed in the RI Report (Integral and Anchor QEA 2013):

- Near-bed velocities generated by episodes of propeller wash are expected to be higher than those due to tidal and riverine currents in areas of the river that are subjected to vessel operations (e.g., at the SJRF operations area and within the navigation channel). Bed-shear stress due to vessel operations is expected to be higher than bed-shear stress due to natural forces and may have the potential to disturb sediments in these vessel operation areas. Near and above the temporary armored cap where vessel access is constrained (Section 2.2.1), natural forces are expected to provide the dominant bed-shear stress.

- The rate of subsidence has decreased during the last 35 to 40 years, due to controls on groundwater usage within Harris County, but continues as does sea level rise. The combined effect of sea level rise and subsidence is reflected in the 1.97 foot increase in relative sea level rise recorded over the past 100 years in Galveston Bay (Brody et al. 2014). The impact of continued subsidence on the integrity and reliability of the existing cap to prevent any release of contaminated material would be dependent on the long-term rate of subsidence. The latter is not well known and cannot be predicted with any reliability. In general, subsidence and the slow rise in sea level would both result in slightly deeper water depths over the Eastern Cell and Northwestern Area of the cap, but the USACE does not believe that these effects would be substantial enough to affect the tidal, river and wind induced circulation in the SJR estuary. As such, it is not believed that the reliability of the cap would be lessened (Appendix A).

- Sea level rise is projected to continue at a rate of approximately 2 to 3 millimeters per year (mm/year) during the next century, with a total increase in sea level of about 0.5 to 2 feet by the year 2100 (Anchor QEA 2012c).

The stability of the sediment bed is an important factor for considering natural recovery processes and in evaluating remedial alternatives for deeply buried deposits of sediment that might exceed the identified PRGs (discussed in Section 3.1) for the areas within the USEPA's Preliminary Site Perimeter. The net sedimentation rate at the site is 1.3 cm/year ± 0.8 cm/year (Appendix A). Sedimentation rates may change with time if land use restrictions, discharge limitations, or other regulatory developments related to storm water discharge are implemented within the San Jacinto River basin; however, sediment loads from sources located downstream of Lake Houston dam are minimal compared to the load at the dam (Anchor QEA 2012c). Thus, any potential decreases in loads downstream of the dam in the future will have negligible effect on long-term sedimentation within the USEPA's Preliminary Site Perimeter.

2.5 Nature and Extent of COCs

The RI Report (Integral and Anchor QEA 2013) contains a discussion of the nature and extent of COCs north of I-10 (RI Report Section 5.2) and the area of investigation south of I-10 (RI Report Section 6.2). Site conditions have been assessed by EPA based on RI sampling and prior sampling of the Site and the San Jacinto River in the Site area by the University of Houston and the State of Texas. Based on sediment data and the results of the BERA and BHHRA, dioxins and furans were identified as the indicator chemical group for the purposes of the RI/FS (see Appendix C of the RI/FS Work Plan; COPC Technical Memorandum [Integral 2011], and the RAM [Anchor QEA 2012b]). This section discusses the nature and extent of COCs focusing specifically on this chemical group.

The maximum background surface sediment dioxin and furan concentration is approximately 7.2 ng.kg. The average surface sediment dioxin and furan concentration within the Preliminary Site Perimeter, excluding the waste material in the impoundments but including the sand separation area, is 12.5 ng/kg, although levels as high as 198 ng/kg were found. About 190 acres in this area exceed the sediment background (Figure 2-7). Even though the average sediment concentration is 12.5 ng/kg, there are about 43 acres that exceed the sediment PRG of 30 ng/kg (Figure 2-8), discussed in Section 3.1 below.

The dioxins located in the upstream background sediment are distinct from the dioxins in the paper mill waste in the impoundments. There are other sources of dioxin to the San Jacinto River upstream from the Site, and these sources are characterized by different "fingerprint" than the dioxin in the waste pits. The dioxin in sediment upstream of the Site contains a relatively large amount of hepta-chlorinated dioxin (with 6 chlorine atoms per dioxin molecule) and very little tetra-chlorinated dioxin (has 4 chlorine atoms per dioxin molecule) (Figure 2-12). Conversely, the waste pit dioxin contains a relatively large amount of tetra-chlorinated dioxin and very little hepta-chlorinated dioxin (Figure 2-13).

2.5.1 North of I-10

Under baseline conditions, the highest 2,3,7,8-tetrachlorinated dibenzo-*p*-dioxin toxic equivalents (TEQ) concentrations calculated for mammalian receptors using dioxins and furans only ($TEQ_{DF,M}$) in sediment were found in the area of the Northern Impoundments, which corresponds to the area capped by the temporary cap. Outside of the temporary cap, $TEQ_{DF,M}$ concentrations in sediment and soils are significantly lower. Figure 2-3 presents the $TEQ_{DF,M}$ concentrations in surface sediment. As presented, concentrations for each sample are color-coded based on powers of 10 to facilitate identifying areas of similar concentration. Figure 2-4 presents $TEQ_{DF,M}$ concentrations in samples collected from sediment cores. The $TEQ_{DF,M}$ concentrations in sediment are discussed in the context of the PRGs in Section 3.1.

The RI Report also examined concentrations of polychlorinated biphenyls (PCBs) and mercury in the Site soils/sediments. The source evaluation of the area north of I-10 and surrounding aquatic environments presented in Section 5.4 of the RI Report concluded that the PCB concentrations in sediments within the USEPA's Preliminary Site Perimeter, but outside the Northern Impoundments are not highly elevated relative to areas outside of the USEPA's Preliminary Site Perimeter and contribute very little dioxin-like toxicity to the sediment. In addition, because mercury concentrations in the soils on the sand separation area (as shown in Figure 1-2), are higher than they are in the wastes within the Northern Impoundments, the wastes within the Northern Impoundments may not the primary source of mercury in the aquatic environment under investigation.

2.5.2 Area of Investigation South of I-10

Some of the wastes deposited within Soil Investigation Area 4 may have originated from the Champion Paper Inc. paper mill (TDH 1966). As noted in the RI Report, the BHHRA for the area of investigation on the peninsula south of I-10 found no health risks in surface soil to hypothetical trespassers and hypothetical commercial workers above the thresholds considered acceptable by USEPA. For hypothetical future construction workers, exposure scenarios for certain core locations (each assumed to be representative of a potential building site, and assuming excavation or other activities that would disturb the soil) resulted in noncancer and dioxin cancer hazard indices greater than 1. Dioxins and furans, as $TEQ_{DF,M}$ were identified as COCs for the hypothetical future construction worker, based on hypothetical future exposures to the upper 10-feet of soil. At the request of USEPA, risk to a hypothetical future construction worker who could be exposed to the upper 5 feet of soil only was also evaluated, as described in Section 3.1. A description of the risk evaluation assumptions, uncertainties, and data evaluation is provided in the BHHRA (Integral 2013b).

The BERA for the area of investigation south of I-10 identified low risks to terrestrial bird populations from lead and zinc. Lead and zinc were therefore identified as COCs. Soil PRGs were not developed for these metals because of uncertainties associated with the exposure modeling that likely overestimated exposures, and because these two metals are not associated with paper mill waste, but are likely present due to other industrial activities within the area of investigation on the peninsula south of I-10.

Figure 2-5 presents $TEQ_{DF,M}$ concentrations in surface and subsurface soil in the area south of I-10. The data are discussed relative to the PRG for soil for a hypothetical future construction worker and a hypothetical future commercial worker in Section 3.1. The exposure scenario for the hypothetical future construction worker receptor assumes exposure to a depth-weighted average of $TEQ_{DF,M}$ concentrations throughout a 10-foot soil depth, but the most elevated $TEQ_{DF,M}$ concentrations are found in samples taken at locations several feet below grade. As discussed in the BHHRA and the RI Report, several feet of relatively clean soil isolates the soil with the highest $TEQ_{DF,M}$ concentrations from potential receptors at the surface.

2.5.3 Tissue

Tissue samples were collected from three Site fish collection areas (FCA) (Figure 2-9) in 2010 prior to construction of the temporary cap:

- FCA1 - Downstream of I-10, referred to below as "downstream";
- FCA2 - In the area surrounding the impoundments north of I-10 and the upland sand separation area, referred to as "adjacent to the northern impoundments"; and
- FCA3 - Immediately upstream of the northern impoundments and upland separation area, referred to as "upstream."

Tissue samples were also collected at background locations. Cedar Bayou, a small tributary to the San Jacinto estuary near Morgan's Point, and the lower San Jacinto River estuary, near the mouth of Cedar Bayou and downstream of the Fred Hartman Bridge, served as the background areas for catfish and crabs. Killifish were collected from the upstream background area sampled for sediments (Figure 2-6).

Data for blue crab, hardhead catfish, and Gulf killifish are summarized in Figure 2-10. The maximum detected values and highest mean values of dioxin and dioxin-like polychlorinated bi-phenyl generally were collected from the fish collection area adjacent to the northern impoundments. Compared to background results, the tissue results within the Preliminary Site Area before construction of the temporary cap averaged from about 4.5 times (for hardhead and crab) to 20 times (for killifish) higher than the background levels.

2.5.4 Sediment Background

The sediment background samples include surface sediments (0 to 6 inches) collected in 2010 and 2011 from 29 stations upstream and outside of USEPA's Preliminary Site Perimeter, both within the subtidal zone and in the intertidal zone. All of the upstream sediment sampling locations are shown in Figure 2-6. Background surface sediment $TEQ_{DF,M}$ concentrations range from 0.108 to 6.54 ng/kg, with a mean of 1.17 ng/kg. Aroclors were not detected in background surface sediment. The Reference Envelope Value (statistical background level) for background surface sediment is 7.2 ng/kg dioxin. This background sediment level is less than the dioxin sediment PRG of 30 ng/kg (discussed below), and also less than the dioxin surface-area weighted average sediment concentration (SWAC) of 12.5 ng/kg in the San Jacinto River outside of the temporary cap. Because the background dioxin sediment level is less than the current Site dioxin level, re-contamination of the Site by dioxin from other sources following remediation is not expected.

2.5.5 Prior Actions at the SJRWP Site

As discussed in Section 1.2, a TCRA was implemented, pursuant to an AOC, to stabilize and isolate paper mill waste and sediments within the original 1966 perimeter berm of the Northern Impoundments (Anchor QEA 2011; USEPA 2012c). As presented in the Action Memorandum (USEPA 2010a, Appendix A) for the TCRA, the following removal action objectives for the TCRA were identified:

- Stabilize waste pits to withstand forces sustained by the river.
  - The barrier design and construction must be structurally sufficient to withstand forces sustained by the river including any future erosion and be structurally sound for a number of years until a final remedy is designed and implemented (USEPA 2010a).
  - Technologies used to withstand forces sustained by the river must be structurally sufficient to withstand a storm event with a return period of 100-years until the nature and extent of contamination for the Site is determined and a final remedy is implemented.
- Prevent direct human contact with the waste materials (USEPA 2010a, Appendix A, IV.A.1; Page 9; first paragraph).
- Prevent benthic contact with the waste materials (USEPA 2010a, Appendix A, III.B).
- Ensure that the "actions are consistent with any long-term remediation strategies that may be developed for the Site" (USEPA 2010a, Appendix A, V.A.2).

The TCRA included construction of a temporary armored isolation cap (temporary armored cap), completed in July 2011, that was designed in accordance with USACE and USEPA guidelines. During the design of the temporary cap, the area within the original 1966 perimeter of the

Northern Impoundments was divided into three distinct areas: 1) the Eastern Cell; 2) the Western Cell; and 3) the Northwestern Area (Figure 2-11). In general, the temporary cap design included an armor rock cap placed atop a geotextile bedding layer in all but the Northwestern Area, where an aggregate cap was constructed. Additionally, the Western Cell received treatment through stabilization and solidification (S/S) of approximately 6,000 cubic yards of waste material in the upper 3 feet over a 1.2 acre area. The treatment consisted of mixing in Portland cement at a ratio of 8%. A geomembrane cover layer was then installed prior to armor rock installation. The temporary armored cap is discussed further in Section 4 relative to the remedial alternatives, and shown in the figures from that Section. In addition to capping the Northern Impoundments, the temporary cap upland perimeter was fenced and signage was installed to prevent unauthorized access to the Site. A description of the TCRA implementation is provided in the Removal Action Completion Report (RACR) (USEPA 2012c). Costs for design and implementation of the TCRA were more than $9 million.

The temporary armored cap has been subject to ongoing inspections, monitoring, and maintenance, consistent with USACE and USEPA guidelines and the agency-approved Operations, Monitoring, and Maintenance (OMM) Plan (Appendix N of the RACR, Anchor QEA 2012a). Three separate post-construction survey and monitoring events (conducted in September 2011, January 2012, and April 2012) appeared to confirm the integrity of the temporary armored cap.

During the next inspection, in July 2012, an area along the western berm slope was noted to have areas where cap armor materials had moved down the slope, uncovering a small area of the geotextile layer (approximately 200 square feet, or 0.03 percent of the temporary armored cap footprint). There was no exposure of underlying materials or release of hazardous substances associated with this temporary condition. Consistent with the agency-approved OMM Plan, the Respondents implemented approved maintenance measures that involved grading specific locations to an overall flatter condition by placing additional armor rock over the cap surface in those locations. These maintenance activities were completed in July 2012 and were documented in a completion report that was submitted to USEPA (Anchor QEA 2012d).

Additional maintenance was performed in January 2013, when additional armor stone was placed in other cap areas. As discussed in more detail in Section 4.1.3, sediment caps commonly require localized maintenance during the initial post-construction period, and USACE and USEPA guidance identifies ongoing inspection and maintenance of the type required by the OMM Plan as an integral component in ensuring that sediment caps remain protective over the long-term.

During the post-construction period, the Respondents (Anchor QEA 2013a) and USEPA, in coordination with USACE (USACE 2013), conducted separate evaluations of the temporary armored cap design and construction. The USACE report conclusions are quoted as follows:

1. *Parameterization of the stone size equation. The inputs to the [stone size] equation were not provided. The design velocity from the hydrodynamic model may not account adequately for the slope changes due to limitations in spatial resolution. The factor of safety may not have [been] adequate for the uncertainties in construction, slopes, material gradation, waves, non-uniform flow, flow constrictions and overtopping.*[2]

2. *Slope. The slope of the face of the berm just below the crown was much steeper than the design slope and was not modified prior to capping. For the non-uniform recycled concrete used for Armor Cap B/C, the design slope should have been [1 vertical to 3 horizontal] 1V:3H or flatter to prevent excessive displacement and loss of gravel and sand sized particles.*[3]

3. *Armor cap material gradation. The uniformity of the armor cap material was not specified. The material specifications allowed too much gravel and sand sized particles to be used, which could be eroded from the cap because they did not meet internal stability and retention criteria. Greater uniformity of the armor cap is preferable in the high energy regimes of the cap, particularly the southwestern corner of the berm.*[4]

4. *Repair should ensure that the final surface throughout the repair area and adjacent areas has a slope of 1V:3H or flatter.*

In accordance with these conclusions and recommendations, the Respondents conducted additional cap enhancement work during January 2014. A description of the completed work was provided in the TCRA Cap Enhancement Completion Report (Anchor QEA 2014). This enhancement work was conducted using stone that was larger than the minimum stone size recommended by USACE, in an attempt to provide a more stable and protective cap configuration and exceeding design criteria specified in USACE and USEPA sediment capping design guidance (USACE 1998).

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[2] Note that these input parameters have been provided to USEPA and USACE.

[3] Note that the enhancements completed in January 2014 used natural stone material, placed at the USACE recommended 1V:3H slope.

[4] Note that Armor Rock C, as described in the TCRA RAWP (Anchor QEA 2011), was considered sufficient by USACE for cap enhancement in their report. Armor Rock D, which is even larger than Armor Rock C, was used for the enhancement work completed in January 2014.

In January 2013 five areas in the Eastern Cell of the cap with less than the required armor cover thickness and/or exposed geotextile were identified. In one of those areas there is a need for placement of geotextile fabric in addition to armor stone. The cause of these areas of deficient cap cover is unknown. These areas were repaired in January 2013 with the addition of additional stone and geotextile.

On December 9 and 10, 2015, EPA performed an underwater inspection that identified an area of deficient thickness and/or missing armor cover resulting in exposure of the underlying paper mill waste material to the San Jacinto River. The deficient area is located on the northwestern section of the armored cap where no geotextile was installed. The area is irregularly shaped with dimensions of approximately 22 feet by 25 feet. Some armored rock cover was still present, but coverage was not complete nor was there adequate thickness. The USACE found that the defect area was most probably caused by sinking of the cap over time due to either an improper filter/support layer under the rock cap or unusual decomposition of organic matter under the area (USACE 2016a). Sediment sampling completed in December 2015 identified dioxin/furan in the exposed waste material as high as 43,700 ng/kg TEQ. Maintenance activities to place geotextile and additional rock cover over and extending beyond the deficient area began on December 29, 2015, and were completed on January 4, 2016.

On February 24, 2016, during an extremely low tide, a visual inspection of the cap was performed. A large majority of the Eastern Cell was exposed during this abnormally low tide event. Five small areas (approximately 1 foot by 3 feet at the largest areas) of exposed geotextile with no rock cover were observed in the central part of the Eastern Cell where the cap should have had a one-foot thickness minimum. The cause of these deficient rock areas is unknown, although some of the areas may have been geotextile overlap portions associated with the cap construction. During March 2016 probing of the entire Eastern Cell of the cap to check thickness was completed and identified a number of additional areas of deficient armor cover thickness and/or exposed geotextile. Rock was added to all of these areas in the Eastern Cell in March 2016 to achieve a minimum thickness of one foot.

2.5.5.1 Effectiveness of the Time Critical Removal Action

The TCRA's implementation has generally reduced potential risks from dioxins and furans associated with baseline conditions but has required many repairs and extensive maintenance. However, on one occasion a 500 ft^2 area on the northwest portion of the temporary cap was found to be missing armor stone and paper mill waste with dioxin over 43,000 ng/kg was exposed to the environment for an unknown amount of time. This deficiency was not discovered by the regular inspection program, but instead by a special investigation performed by the EPA Dive Team.

A summary of the instances of missing armor stone and subsequent cap repairs follows:

- July 2012: Approximately 200 square feet (ft2) of stone eroded and geotextile exposed (armor materials had moved down slope). Following EPA approval of the repair plan, additional stone was added to achieve the required cap thickness. Repairs were completed August 3, 2012.

- January 2013: Five areas missing part or all of armor stone with exposed geotextile in some areas of the Eastern Cell. Following EPA approval of a repair plan, additional stone was added to achieve the required cap thickness. Repairs were completed January 30, 2013.

- January 2014: The USACE evaluated the design & construction of the cap and found that improvements were needed, including flatter slopes and larger rock in some areas. Following EPA approval of a repair plan, additional rock was added in accordance with the USACE recommendations, with construction completed on January 13, 2014.

- December 2015: Following an inspection by the EPA Dive Team, approximately 500 ft^2 of cap was missing or deficient in cover (no geotextile present, paper mill waste exposed to the river, waste material concentration measured at 43,700 ng/kg dioxin exposed to river). The EPA ordered repair of this area, and following EPA approval of a repair plan, geotextile & new rock was added to repair the area with construction completed on January 4, 2016.

- February 2016: Missing rock in portions of eastern cell (five areas up to 6 ft^2 each with some exposed geotextile). The EPA ordered repair of this area, and after EPA approval of the repair plan, new rock was added to repair the area with construction completed on March 15, 2016.

- March 2016: Approximately 500 locations in the Eastern Cell were probed to check for cap thickness and eight additional areas of missing rock were found. During repairs, additional areas of missing rock and exposed geotextile were found. Following EPA approval of the repair plan, new rock was added over a total area of 170 ft^2 with construction completed on March 31, 2016.

- June 2016: Following an inspection by the EPA Dive Team, ten areas of missing rock were found in the Western Cell up to 300 ft^2. Following EPA approval of the repair plan, new rock was added to repair the areas with construction completed on June 17, 2016.

The temporary cap was designed to withstand a hundred-year storm, yet the above cases of eroded or missing armor stone all occurred with flooding below the design hundred year storm. In addition, the routine maintenance required by the original OMM plan did not reveal the deficiencies discovered in 2015 and 2016.

The following sections discuss effects of TCRA implementation on sediment, water, and tissue.

2.5.5.1.1 Sediment

Implementation of the TCRA appears to have eliminated, with one known exception, the transport of waste associated COCs from the Northern Impoundments. The effect of the temporary cap on overall sediment quality within the USEPA's Preliminary Site Perimeter was evaluated in the RAM by performing a "hilltopping" evaluation comparing the surface-weighted average concentration (SWAC) of $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter for various prospective remedial action levels (RALs), including SWACs before TCRA implementation and following TCRA completion. As documented in the RAM, the $TEQ_{DF,M}$ SWAC was reduced by more than 80 percent by implementing the TCRA. In addition, on-going natural recovery continues to reduce surface sediment concentrations outside of the temporary cap, as indicated by the long-term chemical fate model simulations presented in Appendix A. However, the simulations did not consider the impact of a dioxin release that may result for a future extreme storm or hurricane, nor the impacts of a barge strike that may breach the cap or other future events that might affect the integrity of the cap.

2.5.5.1.2 Water

Sampling of surface water and porewater with solid phase micro-extraction (SPME) fibers was conducted after construction of the temporary armored cap was completed. The sampling indicated that 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and 2,3,7,8-tetrachlorodibenzofuran (TCDF) were not present in surface water over the temporary armored cap.

2.5.5.1.3 Tissue

Upon completion of the temporary cap construction in July 2011, waste materials in the waste pits were rendered inaccessible, except for the cap deficiencies identified above, for direct contact by humans, benthos, fish, and aquatic dependent wildlife. The completion of the temporary cap construction therefore would be expected to lead to reductions in tissue concentrations in catfish and clams within the USEPA's Preliminary Site Perimeter.

2.5.6 Sources of COCs

The chemical fate and transport modeling, discussed in Appendix A, concluded that ongoing deposition of sediment within the USEPA's Preliminary Site Perimeter may continue to reduce concentrations of dioxins and furans in sediment. However, deposition rates are low in most areas, particularly shallow areas. Further, changes in the river geometry as a result of extreme erosion similar to that which was documented during the 1994 flood may prevent the predicted deposition from occurring. As noted in the RI Report, a number of historical and current sources of dioxins, furans, and other COCs remain as ongoing contributors to COC concentrations present within the USEPA's Preliminary Site Perimeter, although comparison of the paper mill waste in the impoundments with background samples as part of the waste "fingerprinting" analysis indicate that the paper mill waste is the source of the TCDD and TCDF found in the Preliminary Site Perimeter. Other sources of dioxin can be distinguished from the less highly chlorinated dioxin and furan congeners found in the paper mill waste, which contains high concentrations of TCDD and TCDF.

The chemical analyses of groundwater, soils, and sediments presented in both the Preliminary Site Characterization Report (PSCR; Integral and Anchor QEA 2012) and the RI Report demonstrated that other regional sources – such as atmospheric inputs, industrial effluents, publicly owned treatment works, and storm water runoff – contribute other types of dioxins and furans and other COCs (metals, and PCBs) found in the Site area and surrounding aquatic environment. In the area of investigation south of I-10, historical and ongoing industrial marine services are known to contribute chemicals, including COCs for ecological receptors to soils.

In the peninsula south of I-10, soils and subsurface soils contain dioxins and furans from a mixture of sources including paper mill wastes, as well as other background or site-specific sources. The un-mixing analysis for soils collected from the area of investigation south of I-10 indicates that there are three distinctive dioxin and furan source types contributing to the presence of dioxins and furans in soils sampled south of I-10 including one that resembles paper mill wastes, one that resembles background dioxin and furan sources, and a third mixture unique to this area. The dioxin and furan mixture towards the southern end of Soil Investigation Area 4 in shallower soils is consistent with the fingerprint characteristic of paper mill wastes, based on fingerprints of samples collected from within the impoundments north of I-10. In deeper soils at the southern and northern ends of the area of investigation on the peninsula south of I-10, the dioxin and furan mixture describes a different source type that is not observed elsewhere within the USEPA's Preliminary Site Perimeter, and does not appear to match apparent source types in other soils or sediment samples collected from within the USEPA's Preliminary Site Perimeter nor any known anthropogenic source pattern in the USEPA Dioxin Reassessment database (USEPA 2004).

The general spatial distribution of sources that differ from the paper mill wastes in soils suggests that dioxin and furan containing material was deposited into, or on the peninsula south of I-10, at a point in time prior to disposal of paper mill wastes. Finally, outside of Soil Investigation Area 4, the dioxin and furan mixtures are generally dominated by a fingerprint consistent with general urban background sources. The un-mixing analysis demonstrates that paper mill wastes are mostly confined to the area within USEPA's estimated perimeter of the impoundment. Spatial patterns of dioxins and furans and other chemicals within subsurface soils in the area of investigation south of I-10, as well as waste materials (such as paint chips, construction debris, plastics, and asphalt shingles) and chemicals not associated with paper mill wastes, also support the conclusion that wastes other than paper mill wastes have contributed to the presence of more highly chlorinated dioxins and furans in soils in the area of investigation south of I-10 (see RI Report Section 6.6).

2.5.6.1 Bioaccumulation

The data analyses and literature review presented in the Technical Memorandum on Bioaccumulation Modeling (Integral 2010), including evaluation of region-specific multivariate datasets, indicates that the majority of dioxin and furan congeners do not consistently bioaccumulate in fish or invertebrate tissue. This is due to biological controls on uptake and excretion in both fish and invertebrates (Integral 2010). As a result, systematic predictions of bioaccumulation from concentrations of dioxins and furans in abiotic media (both sediment and water) are only possible for tetrachlorinated congeners.

The more highly chlorinated congeners, such as OCDD, appear to have the lowest bioconcentration potential either because they are less bioavailable because of their rapid adsorption to sediment particles (Servos et al. 1989a, 1989b) or because their large molecule size may interfere with transport across biological membranes (Bruggeman et al. 1984; Muir et al. 1986a, 1986b), (ATSDR, Toxicological Profile for Dioxin, 1998). In most vertebrate species, the 2,3,7,8-substituted PCDDs are the congeners which are predominantly retained. If chlorine atoms are present on all 2,3,7,8 positions, the biotransformation rate of PCDDs is strongly reduced, resulting in significant bioaccumulation. In most species the liver and adipose tissue are the major storage sites. (WHO, IARC, 1997).

Analyses presented in the BERA (Integral 2013a) indicated that concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF in the tissues of clams and killifish (which have limited spatial movements) were higher in those clams and killifish taken in proximity to the Northern Impoundments (prior to the temporary cap construction). Consistent with the literature (USEPA 2009b), benthic species (clams and catfish) had higher concentrations of dioxins and furans than predatory fish species, suggesting that concentrations of dioxins and furans are not predicted by position in the food chain, but are accumulated more as a function of proximity to sediment in which dioxins and furans are present. The fact that concentrations in clam tissue correlate reasonably well with concentrations in sediments adjacent to where they were collected reinforces the "proximity hypothesis" in support of the conceptual framework for bioaccumulation of dioxin and furans, outlined in the Technical Memorandum on Bioaccumulation Modeling (Integral 2010).

3 BASIS FOR REMEDIAL ACTION

The basis for undertaking remedial action is to address the potential risks associated with the presence of dioxin and furan containing waste material resulting from historical paper mill waste disposal in the Northern Impoundments, as well paper mill wastes present in the Southern Impoundment south of I-10. This section discusses the development of PRGs, reviews the RAOs established by USEPA for the area within the USEPA's Preliminary Site Perimeter, and reviews the Applicable or Relevant and Appropriate Requirements (ARARs) that have been identified in previous documents.

Dioxin and furans, the primary contaminants of concern at the Site, are classified as probable human carcinogens. Dioxins are highly toxic and can cause reproductive and developmental problems, damage to the immune system, and can interfere with hormones in addition to causing cancer. The human health risk assessment identified non-cancer hazards greater than one for some recreational fisher exposure scenarios (direct exposure to beach areas identified and the ingestion of catfish, clam, or crab from fishing areas identified, Figure 3-1 and Figure 3-2), for some recreational visitor exposure scenarios (direct exposure to the beach areas identified), and for some future construction worker exposure scenarios.

A Baseline Human Health Risk Assessment (human health risk assessment) and Baseline Ecological Risk Assessments (ecological risk assessments) were conducted to estimate the potential for current/future risk or hazard from exposure to contaminants from the Site. The human health risk assessment and ecological risk assessments were conducted to determine potential pathways by which people (human receptors) or animals (ecological receptors) could be exposed to upland or aquatic contamination in waste material, sediment, soil, water, or biota; the amount of contamination receptors of concern may be exposed to; and the toxicity of those contaminants if no action were taken to address contamination at the Site. Some of the human health risk determinations subsequently were modified by the Environmental Protection Agency based on further risk analysis as documented in memoranda included as part of the Site administrative record.

The risk assessments were conducted on the baseline conditions that existed before the installation of the temporary armored cap over the northern waste pits that was completed during a removal action. This temporary cap was built to stabilize the northern waste pits and prevent direct human exposures until a permanent remedy could be selected for the Site. These assessments provide the basis for taking action and identify the contaminants and exposure pathways that need to be addressed by the remedial action.

Hazard quotients greater than one indicate the potential of contaminants of concern (e.g. dioxin) may cause adverse health effects to those that are exposed in the manner specified in the tables. There were no cancer risks above the upper limit of the Environmental Protection Agency's target cancer risk range ($1x10^{-4}$) for all beach areas identified in the human health risk assessment except for Beach Area E, which had an excess cancer risk of 6.6×10^{-4} for a recreational fisher exposed through ingestion and dermal contact with waste material and sediment.

The basis for action at the Site are the unacceptable hazards, determined by the risk assessments, to the recreational fisher (Hazard Index = 65), to the recreational visitor (Hazard Index 66), and to the construction worker (Hazard Index = 46). The three tables below provide more information on these hazards. For the recreational fisher and the recreational visitor, risk assessments were done for areas both north and south of I-10. For the construction worker, the risk assessment applies to the area south of I-10.

Non-Cancer Hazards for a Recreational Fisher

Chemical	Primary Target Organ	Non-Cancer Hazard Quotient: Incidental Ingestion of Sediment	Dermal Contact with Sediment	Consumption of Fish or Shellfish	Exposure Route Total
Scenario 1A: Direct Exposure Beach Area A; Ingestion of Catfish from Fish Collection Area 2/3					
Dioxins and dioxin-like Polychlorinated Bi-Phenyls	Reproductive/Developmental	0.0006	0.0016	1.8	1.8
Scenario 2A: Direct Exposure Beach Area B/C; Ingestion of Catfish from Fish Collection Area 2/3					
Dioxins and dioxin-like Polychlorinated Bi-Phenyls	Reproductive/Developmental	0.0081	0.0229	1.8	1.8
Scenario 3A: Direct Exposure Beach Area E; Ingestion of Catfish from Fish Collection Area 2/3					
Dioxins and dioxin-like Polychlorinated Bi-Phenyls	Reproductive/Developmental	16	47	1.8	65
Scenario 3B: Direct Exposure Beach Area E; Ingestion of Clam from Fish Collection Area 2					
Dioxins and dioxin-like Polychlorinated Bi-Phenyls	Reproductive/Developmental	16	47	0.27	64
Scenario 3C: Direct Exposure Beach Area E; Ingestion of Crab from Fish Collection Area 2/3					
Dioxins and dioxin-like Polychlorinated Bi-Phenyls	Reproductive/Developmental	16	47	0.008	63
Scenario 4A: Direct Exposure Beach Area D; Ingestion of Catfish from Fish Collection Area 1					
Dioxins and dioxin-like Polychlorinated Bi-Phenyls	Reproductive/Developmental	0.0027	0.0076	1.8	1.8
Note: Polychlorinated Biphenyls - PCBs Dioxins – see Glossary					

Non-Cancer Hazards for a Recreational Visitor

Chemical	Primary Target Organ	Non-Cancer Hazard Quotient				Total
		Incidental Ingestion of Sediment	Incidental Ingestion of Soil	Dermal Contact with Sediment	Dermal Contact with Soil	
Scenario 3: Direct Exposure Beach Area E						
Dioxin	Reproductive/ Developmental	17	0.03	49	0.0021	66
Note: Dioxin – 2,3,7,8-tetrachlorodibenzo-p-dioxin toxicity equivalent quotient						

Non-Cancer Hazards for a Future Construction Worker

Chemical	Primary Target Organ	Non-Cancer Hazard Quotient		Total
		Incidental Ingestion of Soil	Dermal Contact with Soil	
Scenario DS-1: Direct Exposure to Surface and Subsurface Soils				
Dioxin	Reproductive/Developmental	9.6	0.49	10
Scenario DS-2: Direct Exposure to Surface and Subsurface Soils				
Dioxin	Reproductive/Developmental	44	2.2	46
Scenario DS-4: Direct Exposure to Surface and Subsurface Soils				
Dioxin	Reproductive/Developmental	32	1.6	34
Scenario DS-5: Direct Exposure to Surface and Subsurface Soils				
Dioxin	Reproductive/Developmental	2.2	0.11	2.3
Note: Dioxin – 2,3,7,8-tetrachlorodibenzo-p-dioxin toxicity equivalent quotient				

Baseline risks to ecological receptors associated with the wastes in the impoundments north of I-10 are the result of exposures to dioxins localized to the immediate vicinity of the impoundments. Baseline ecological risks include reproductive risks to mollusks from dioxin, but primarily in the area that surrounds the former waste impoundments north of I-10, and low risks of reproductive effects in individual mollusks in sediments adjacent to the upland sand separation area, but not to populations of mollusks. Baseline risks include moderate risks to individual birds like the killdeer or spotted sandpiper whose foraging area could regularly include the shoreline adjacent to the impoundments north of I-10, but low risk to populations because of the low to moderate probability that individual exposures reach effects levels. Baseline risks include risks to individual small mammals with home ranges that include areas adjacent to the impoundments such as the marsh rice rat, but low to negligible risks to small mammal populations because of the moderate probability that exposures will reach levels associated with reproductive effects in individuals, and because small mammals reproduce rapidly. Baseline risks to benthic macroinvertebrate communities and populations of fish, birds, mammals, and reptiles resulting from the presence of metals, bis(2-ethylhexyl) phthalate, Polychlorinated Bi-Phenyls, carbazole, and phenol on the Site are negligible. Risks to fish populations from all chemicals of potential concern are negligible.

There are negligible risks to populations of wading birds represented by the great blue heron, and to populations of diving birds like the neotropic cormorant. There are negligible risks to populations of terrestrial mammals such as the raccoon. There are low to negligible risks to individual terrestrial insectivorous birds like the killdeer from exposure to zinc, and negligible risks to populations of such birds. Although the upper bound of estimated daily intakes of zinc by individual killdeer is about equal to conservative effects thresholds, the exposure estimate is influenced by the use of generic models to estimate zinc concentrations in the foods of the killdeer, and this model likely overestimates ingested tissue concentrations, resulting in overestimates of exposure and risk. The highest exposures of killdeer to zinc occur outside of the northern impoundment perimeter, and background exposures less than 30 percent were lower than on the Site. In addition, the low probability of individual exposures exceeding effects levels indicates low risk to populations. There are also low to negligible risks to individual terrestrial insect eating birds from exposure to dioxins. The ecological risk assessments identified risk to ecological receptors as summarized in the tables below.

Ecological Risks

Receptor of Concern	Feeding Guild	Contaminant of Concern	Baseline Risk Identified
Benthic Macroinvertebrates			
Mollusks	Filter feeders	2,3,7,8-TCDD	Reproductive risks to mollusks (primarily in the area which surrounds the waste impoundments)
Individual mollusks	Filter feeders	2,3,7,8-TCDD	Low risks of reproductive effects (sediments adjacent to the upland sand separation area)
Birds			
Spotted sandpiper	Invertivore (probing)	Dioxin	Low risk to populations
Killdeer	Invertivore (terrestrial)	Dioxin	Low risk to populations
Mammals			
Marsh rice rat	Omnivore	Dioxin	Low to negligible risk to populations
Note: 2,3,7,8-TCDD – 2,3,7,8-tetrachlorodibenzo-p-dioxin Dioxin – toxicity equivalent quotient for 2,3,7,8-tetrachlorodibenzo-p-dioxin calculated using toxicity equivalent factors for mammals			

3.1 *Recommended Preliminary Remediation Goals*

The RAOs are focused on remedial measures applicable to waste material, sediments and soils within the USEPA's Preliminary Site Perimeter to reduce potential exposure pathways to humans and ecological receptors. Therefore, the PRGs utilized in the development of remedial alternatives are those developed for waste materials, soils and sediments. All of the PRGs used in the evaluation of alternatives were approved by USEPA, and are based on $TEQ_{DF,M}$ concentrations that are protective of human health, based on the Reasonable Maximum Exposure (RME) scenario for the subject hypothetical receptors.

Based on consideration of reasonable potential future uses within the USEPA's Preliminary Site Perimeter, three PRGs were developed for use in the FS Report for evaluation of the remedial alternatives of waste materials, sediments and soils. The reasonable potential future users within the USEPA's Preliminary Site Perimeter used in the development of alternatives include hypothetical recreational fisher and hypothetical recreational visitor for waste materials, sediments, and hypothetical construction and hypothetical commercial workers for soils. The Texas Department of State Health Services was unable to identify any subsistence fishing uses, so a PRG for that scenario was not developed.

PRGs were not developed for total PCBs. Concentrations of PCBs in waste materials, soils and sediments were either significantly correlated with concentrations of dioxins or were generally below detection limits; the PCB sediment patterns may correlate with dioxins because the two chemical groups have low solubility, tend to bind to organic carbon, are persistent, and behave similarly in aquatic environments. Therefore, no remedial action objective was developed for PCBs because remediation of material contaminated with dioxins will also remediate the co-located polychlorinated bi-phenyls. Also, the estimated lifetime cancer risks for all receptors from exposures to total PCBs and arsenic did not exceed the upper bound of the cancer risk of $1x10^{-4}$ that USEPA regards as acceptable, as is outlined in the Exposure Assessment Memorandum (EAM) and the BHHRA. An evaluation of PCBs and mercury concentrations in soils/sediments was presented in the RI Report, and it was concluded that the PCB concentrations are not highly elevated and contribute very little dioxin-like toxicity. The elevated mercury concentrations in the soils on the sand separation area are higher than in the wastes within the Northern Impoundments, indicating that elevated mercury concentrations are not related to paper mill waste. Therefore, the evaluation of remedial alternatives is focused on the risk-based PRGs for $TEQ_{DF,M}$.

The PRGs are as follows:

- The risk-based PRG for sediment outside the footprint of the temporary armored cap, 30 ng/kg TEQs, is based on exposure to dioxins and furans by a hypothetical recreational fisher for a noncancer hazard quotient equal to 1[2]. Figures 3-1 and 3-2 present $TEQ_{DF,M}$ concentrations in surface and subsurface waste material, respectively, outside the footprint of the temporary armored cap. This PRG is also protective of the Site ecological risks.

- The risk-based PRG for waste material within the footprint of the temporary cap, 200 ng/kg TEQs, is based on the recreational visitor potential exposure scenario and a noncancer hazard quotient equal to 1. Figures 3-3 and 3-4 present $TEQ_{DF,M}$ concentrations in surface and subsurface waste material, respectively, within the footprint of the temporary armored cap relative to this PRG.

- The risk-based PRG For waste material and soil in the area south of I-10, 240 ng/kg TEQs, was derived based on the reasonable maximum exposure scenario for a hypothetical future construction worker using a noncancer hazard quotient equal to 1. The development of the PRG considers exposure to soil through the total depth interval (0- to 10-feet) to which a hypothetical future construction worker could be exposed.

For the river areas outside of the temporary armor cap, the surface area–weighted average dioxin concentration (SWAC) in sediment just south of the waste pits is 16.1 ng/kg, and the SWAC in sediment located adjacent to and upstream of the waste pits, including the sand separation area, is 11.2 ng/kg. The average SWAC for sediment within the Preliminary Site Perimeter, including both upstream and downstream areas, is 12.5 ng.kg. Because the average dioxin concentrations in sediment both upstream and downstream of the waste pits, including the sand separation area, are significantly less than the 30 ng/kg PRG for sediment, active remediation of the sediment outside of the waste pits is not required. Using an average dioxin concentration for the sediments outside the impoundments is appropriate because of the movement and range of the aquatic organisms that may be exposed to the dioxins in the sediment. While dioxin has been found in excess of the 200 ng/kg in the sand separation area, these levels are found only in the subsurface sediment as deep as six feet, and the 200 ng/kg PRG is based on direct surface contact with waste materials. To date, two subsurface sediment sample results over 300 ng/kg (maximum 349 ng/kg) were found in the sand separation area, but based on other samples, the EPA does not believe these two results are representative and additional sampling may be conducted there during the Remedial Design.

[2] The noncancer $TEQ_{DF,M}$ PRG is always lower than the PRG for the cancer endpoint for any given media and exposure scenario, and is therefore the more conservative PRG.

3.2 *Remedial Action Objectives*

The RAOs discussed in this section were established to support the initial development and refinement of Preliminary Remediation Goals (PRGs) during the RI/FS process and inform USEPA's selection of final remediation goals (or final clean-up levels) in the ROD.

The RAOs provided the first step in the process to define the chemicals and media to be addressed by the cleanup. The RAOs address specific exposure pathways and receptors, and provide the basis for defining PRGs. The RAOs for the areas within the USEPA's Preliminary Site Perimeter are provided below.

RAO 1: Prevent releases of dioxins and furans from the former waste impoundments to sediments and surface water of the San Jacinto River.

RAO 2: Reduce human exposure to dioxins and furans from consumption of fish by remediating paper mill waste and sediments affected by paper mill waste to appropriate cleanup levels.

RAO 3: Reduce human exposure to dioxins and furans from direct contact with paper mill waste, soil, and sediment by remediating affected media to appropriate cleanup levels.

RAO 4: Reduce exposures of benthic macroinvertebrates to paper mill waste-derived dioxins and furans by remediating sediment to appropriate cleanup levels.

In the area of investigation south of I-10, the hypothetical future construction worker scenario indicated the potential for risk above thresholds considered acceptable by USEPA, due to exposure to dioxins and furans in the upper 10-feet of the soil columns.

3.3 *Applicable or Relevant and Appropriate Requirements*

The development and evaluation of remedial alternatives, as presented in Section 5 of this document, includes an assessment of the ability of the remedial alternatives to address ARARs of environmental laws and other standards or guidance to-be-considered (TBC). Table 3-1 provides a summary of potential ARARs and TBCs that are considered in this FS Report. The list in Table 3-1 includes certain citations that are not applicable to the USEPA's Preliminary Site Perimeter to document the rationale for eliminating these regulations, standards, or guidelines from consideration. Many of the ARARs and TBCs in Table 3-1 are relevant to only some of the remedial alternatives, but all of the requirements that may be relevant to any of the remedial alternatives are identified in the list.

After a remedy is selected, a detailed review of ARARs specific to the selected remedial action will be conducted and included in the Design Analysis Report for the selected action. No federal, state, or local permit is required for response action conducted entirely onsite, but substantive technical requirements of the ARAR must be met.

The ARARs in Table 3-1 can be broken out into three different categories, although some ARARs may belong to more than one of these categories:

- Chemical-specific requirements
- Location-specific requirements
- Performance, design, or other action-specific requirements

Chemical-specific ARARs are typically the environmental laws or standards that result in establishment of health- or risk-based numerical values. When more than one of these chemical-specific ARARs are applicable to site-specific conditions, a remedial alternative should generally comply with the most stringent or conservative ARAR. Chemical specific ARARs presented in Table 3-1 include Clean Water Act (CWA) criteria and State water quality and waste standards. The development of PRGs within the USEPA's Preliminary Site Perimeter considered chemical-specific ARARs, as well as other generally accepted benchmarks for protection of human health and the environment.

Location-specific ARARs include restrictions placed on concentrations of hazardous substances or the implementation of certain types of activities based on the location of a site. Some examples of specific locations include floodplains, wetlands, historic places, land use zones, and sensitive habitats. Location-specific ARARs presented in Table 3-1 include the Rivers and Harbors Act, Coastal Zone Management Act, and Federal Emergency Management Agency/National Flood Insurance Program regulations.

The action-specific ARARs are generally technology or activity-based limitations or guidelines for management of pollutants, contaminants, or hazardous wastes. These ARARs are triggered by the type of remedial activity selected to achieve the RAO and these requirements may indicate how the potential alternative must be achieved. Action-specific ARARs presented in Table 3-1 include CWA water quality certifications (Section 401) and discharges of dredged and fill material (Section 404), Clean Air Act, Endangered Species Act (ESA), and other wildlife protection acts.

The following sections discuss ARARs that have the most significance to the evaluation of remedial alternatives for the USEPA's Preliminary Site Perimeter. Action-specific ARARs do not apply to all of the remedial alternatives. For example, requirements for waste management and hazardous materials transportation are most significant for remedial alternatives that involve removal of waste material, and would not apply at all to remedial alternatives that do not include removal of material from within the USEPA's Preliminary Site Perimeter. The types of actions that would trigger compliance with these requirements are also discussed.

3.3.1 Water Quality and Water Resources

3.3.1.1 Section 303 and 304 of the Clean Water Act and Texas Surface Water Quality Standards

Section 303 of the CWA requires states to promulgate standards for the protection of water quality based on Federal water quality criteria. Federal water quality criteria are established pursuant to Section 304. Texas Surface Water Quality Standards are relevant to the evaluation of short-term and long-term effectiveness of the remedial alternatives. The State of Texas has identified the Texas Surface Water Quality Standards as potential ARARs for this Site.

Substantive compliance with these ARARs for remedial alternatives involving removal of wastes will be achieved using:

- Best Management Practices (BMPs) incorporated into the design to support water quality and attainable use standards for this section of the San Jacinto River. These BMPs include the use of protective berms (either raised or constructed), sheet pile walls within the berms to strengthen and seal the berms and to aid dewatering, establish the top elevation of walls to provide protection from larger floods (i.e., 50-year return period floods), armoring the external side of the berms with removed armor cap material to control erosion, removing the armored cap and geotextile/geomembrane and waste material in the dry to the extent practicable, and silt fences to manage re-suspension.

- Installing the sheet pile walls at the top of the berms would provide more support for the wall, facilitate sealing joints between the sheet piles above the berm, and reduce the potential leakage through the wall and berms since the wall would not be exposed to the water column except during very high flow conditions. Excavation and backfilling in the dry will eliminate potential resuspension and residuals losses.

- To manage potential upland runoff, plastic sheeting would be used to cover any required upland stockpiles, and other erosion control measures to be described in the plans and specifications of the final remedy.

- To reduce the waste material residuals having a high concentration of contaminants, a clean-up pass would be included in the removal plan to reduce the future exposure. Additionally, a multi-layer residuals cover would be placed in two lifts to limit intermixing of residuals with the fill so that the bioactive zone would be clean following remediation and would yield less diffusive flux than the existing temporary cap without a geomembrane. The specific design of the residuals cover, including armoring where appropriate, will be determined during the Remedial Design.

- During the course of construction activities suspended waste materials will accumulate within the enclosed area; however, considering the brackish nature of the site water flocculation and settling will maintain relatively low concentrations of total suspended solids, probably a concentration of less than 250 mg/L, within the enclosure. Upon removal of the sheet pile, this waste material laden water may be released allowing transport of contaminants offsite. At a minimum, it is suggested to allow time for particulates to settle after construction activities cease prior to sheet pile removal, the vast majority of the suspended solids should settle within a day. Flocculants may also be used to promote settling and create dense, strong flocs that would settle in minutes. Furthermore, dispersal of activated carbon may be used to adsorb dissolved contaminants. Once deposited on the bottom, the carbon would continue to treat contaminants on the surface.

- Water quality monitoring, performed as described in the Water Quality Monitoring Plan that will be developed to detect potential impacts on water quality and trigger the implementation of additional BMPs or an interruption of construction if necessary.

3.3.1.2 Section 401 Water Quality Certification of the Clean Water Act as Administered by Texas

Section 401 requires that the applicant for Federal permits obtain certification from the appropriate State agency that the action to be permitted will comply with State water quality standards. Although environmental permits are not required for on-site CERCLA response actions, the selected remedy will incorporate elements to comply with State water quality standards. Consultation with the TCEQ may be necessary to confirm that the final design of the selected alternative meets the substantive requirements of Section 401 of the CWA.

Documentation of substantive compliance with this ARAR would include:

- Coordinating with TCEQ regarding the information required in the Section 401 "Tier

2" Water Quality Certification questionnaire and incorporating agency feedback in the design, if needed.

- Providing documentation of the consultation to USEPA.

3.3.1.3 Section 404 and 404 (b)(1) of the Clean Water Act

Section 404 requires that discharges of fill to waters of the United States serve the public interest. In selecting a remedial alternative including discharge of fill, USEPA would be required to make the determination that the placement of materials into the San Jacinto River serves the public interest as necessary to remediate source material from within the USEPA's Preliminary Site Perimeter.

The area within the USEPA's Preliminary Site Perimeter includes wetlands in the area north of I-10, and a plan will need to be established that addresses the requirements (to the extent practicable) of Section 404 and 404(b)(1). The Respondents previously prepared a report on potentially jurisdictional waters of the U.S. (including wetlands) (Anchor QEA 2010; Anchor QEA 2011) as part of the TCRA implementation in compliance with the 1987 USACE Wetlands Delineation Manual and Interim Regional Supplement to the USACE Wetland Delineation Manual: Atlantic and Gulf Coastal Plan Region. A supplemental draft 404(b)(1) report may need to be prepared for consideration by USEPA depending on the nature of the selected remedy.

Specific BMPs anticipated to be included in construction actions, to minimize the impacts of discharges of fill into the water, include:

- The use of armored berms, sheet piles, and silt curtains and debris booms around in-water work areas
- The use of upland erosion controls such as plastic covering of stockpiles
- The use of silt fencing around upland areas
- Construction of a stable upland haul route capable of handling construction traffic without creating ruts that would develop into a source of turbid water
- Monitoring and maintenance during construction to ensure these BMPs are functioning as designed

3.3.1.4 Texas Pollutant Discharge Elimination System

Within the State of Texas, the National Pollutant Discharge Elimination System (NPDES), which demonstrates compliance with Section 402 of the CWA, is administered by TCEQ and referred to as Texas Pollutant Discharge Elimination System (TPDES). To demonstrate substantive compliance with TPDES, the following measures will be taken:

- The contractor will be required to prepare a Storm Water Pollution Prevention Plan (SWPPP) in accordance with the general permit requirements of TXR150000 (the TPDES permit for construction activities).

- The contractor will be required to implement appropriate monitoring during construction.

3.3.1.5 Rivers and Harbor Act and Texas State Code Obstructions to Navigation

The USEPA's Preliminary Site Perimeter is within a navigable waterway, and the State of Texas regulates the obstruction of navigable waters within the State involving the construction of structures, facilities, and bridges or removal and placement of trees that would obstruct navigation (Riddell 2004). The State of Texas considers land within the bed and banks of rivers to be public and requires access for the public to such areas. With the exception of the TCRA Site, which is required to be restricted to minimize the potential for disturbance of the temporary armored cap by vehicular traffic or vandalism, the remedial alternatives will not limit public access.

Documentation of compliance with this ARAR would entail documenting, with State concurrence, the extent to which a remedial alternative would affect navigability of the San Jacinto River in the vicinity of the USEPA's Preliminary Site Perimeter.

3.3.2 Protected Species Requirements

This section addresses requirements of the ESA, the Fish and Wildlife Coordination Act, the Bald and Golden Eagle Protection Act, and the Migratory Bird Treaty Act. The area within the USEPA's Preliminary Site Perimeter surrounds a section of a major highway including an overpass; however, the USEPA's Preliminary Site Perimeter is upstream of Galveston Bay, which provides rearing, spawning, and adult habitat for numerous marine and estuarine fish and invertebrate species including blue crab, drum, flounder, oysters, spotted sea trout, and shrimp. Sea turtles, including the Federally listed green, hawksbill, Kemp's Ridley, leatherback, and loggerhead turtles occasionally enter Galveston Bay to nest and feed

National Oceanic and Atmospheric Administration (NOAA 2010a). The National Marine Fisheries Service (NMFS) includes the ESA-listed sea turtles in Trust resources, but these turtles are not likely to be present within the USEPA's Preliminary Site Perimeter. The design and overall goal of the remedial action is to improve habitat conditions through the anticipated reduction of potential exposure to COCs.

To address concerns regarding presence of protected species, the Respondents retained a qualified biologist to conduct a threatened and endangered species (TES) survey. The TES survey led to a determination that there is no likely presence of protected species and their habitat within the USEPA's Preliminary Site Perimeter (Anchor QEA 2010a).

Further documentation of compliance with the protected species requirements would include:

- Incorporation of BMPs into the design to prevent or minimize incidental construction-related releases that could potentially impact protected species off-site.

- Pursuant to CERCLA Section 121(e) and USEPA policy, consultation with the U.S. Fish and Wildlife Services (USFWS) and NMFS is needed to confirm that the implementation of the proposed remedy will have no effect on listed species or habitat.

3.3.3 Coastal Zone Management Act and Texas Coastal Management Plan

Federal agency activities that have reasonably foreseeable effects on any land or water use or natural resource of the coastal zone (also referred to as coastal uses or resources and coastal effects) must be consistent to the maximum extent practicable with the enforceable policies of a coastal State's Federally approved coastal management program (NOAA 2010b). The Texas General Land Office (GLO) administers the Texas Coastal Management Consistency certification process.

Substantive compliance with the certification would be demonstrated by:

- Evaluating the effects of the proposed remedy on critical areas (if any) and associated criteria including no net loss of critical area functions and values.

- Evaluating the remedy for compliance with the Texas Coastal Zone Management Consistency Determination and policies identified in the application for Consistency with the Texas Coast Management Program.

- Supporting the USEPA's consultation with the Galveston District USACE and Texas GLO.

3.3.4 Floodplain

The construction of any of the proposed Alternatives is not expected to cause any flooding in the vicinity of the Site, and therefore should not require the implementation of any flood control measures during the construction of any of the Alternatives under consideration for the Site (Appendix A).

3.3.5 Cultural Resources Management

No historic properties eligible for listing in the National Register of Historic Places (NRHP) are recorded within the USEPA's Preliminary Site Perimeter (Anchor QEA and Integral 2010a).

3.3.6 Noise Control Act

Noise abatement may be required if actions are identified as a public nuisance. Due to the temporary cap being bounded by water on three sides and adjacent to a highway overpass on the fourth side and the industrial activities in the area south of the I-10, noise from the construction activity is unlikely to constitute a public nuisance. If necessary, BMPs would be implemented to reduce the noise levels. If materials are delivered to or removed from the project area by truck, noise greater than 60 decibels in close proximity to sensitive receptors (schools, residential areas, hospitals, and nursing homes) will be avoided. Truck routes will be selected to avoid sensitive receptors to the extent possible.

3.3.7 Hazardous Materials Transportation and Waste Management

Remedial alternatives 5N, 5aN, 6N, and 4S (presented in Section 4) include removal and transportation of waste materials to an off-site disposal facility. Off-site disposal would also be required for limited quantities of waste, such as used personal protective equipment (PPE) and any debris or vegetated materials required to be removed during clearing and grading activities, associated with all of the remedial alternatives except for no further action. The contractor will be required to package any hazardous materials in appropriate containers and label containers in accordance with Texas Department of Transportation (TxDOT) requirements. The development of remedial alternatives anticipates that all disposal will be at a permitted landfill facility. If an off-site facility needs to be established for dewatering waste material or transloading waste from barges to trucks or rail cars, it may require a solid waste permit.

4 DEVELOPMENT OF REMEDIAL ALTERNATIVES

4.1 Remedial Technologies Screening

The RAM (Anchor QEA 2012b) identifies General Response Actions (GRAs) and provides initial screening of remedial technologies. In addition, the RAM describes the development of a set of preliminary remedial alternatives for the area north of I-10 to achieve a range of post-remedy SWACs. Subsequent to development of the RAM, the range of remedial alternatives was modified to include those that are described in this FS Report. The following supplemental information regarding GRAs is provided in the specific context of the final set of remedial alternatives considered in this FS Report.

4.1.1 Institutional Controls

ICs are administrative measures that are implemented to mitigate risks or to protect the integrity of engineered controls. ICs include "Proprietary Controls," which are restrictions placed on the use of private property, "Governmental Controls," which include restrictions on the use of public resources, "Enforcement Tools" that may be imposed by an agency to compel certain actions, and "Informational Devices," which include notices about the presence of contamination or fishing advisories.

Governmental controls, enforced by state or local government, may include bans on harvesting fish or shellfish, zoning restrictions, ordinances, statutes, building permits, or other restrictions. Zoning may be used by local governments to designate land use for specific purposes. Government ordinances or permits may also restrict or control land uses, and outline specific requirements before authorizing certain activities (e.g., building codes, drilling permit requirements). Some local ordinances place controls on access to or use of certain areas within a property.

Proprietary controls are based on real property law (EPA 2000). Enforceability of proprietary controls should be evaluated under applicable (state) law. Some proprietary controls are enforceable upon execution, others upon the sale or transfer of property. Examples include easements, covenants, and conservation easements. Easements are rights over the use of another's property, and include negative easements which limit uses that would otherwise be lawful. Access easements are sometimes used to ensure current and future property owners allow property access to operate, monitor, or maintain ECs or ICs. Covenants are agreements between the landowner and others connected to the land. They are typically used to establish an IC when property is transferred to another party. Use restrictions/ statutes/ environmental covenants are state statutes that provide owners of a contaminated property with authority to establish use restrictions. Conservations easements are state statutes that establish easements to conserve property or natural resources. Enforcement and permit tools include permits, administrative orders, and consent decrees which are enforceable by state or federal agencies. Most enforcement agreements are binding on only the signatories and do not bind subsequent owners. Examples include administrative orders which are issued by an environmental regulatory agency directing property owners to perform (or not perform) certain actions. Consent decrees document an administrative or judicial court's approval of the settlement of an enforcement case filed in court. These typically specify actions to be taken (or not to be taken) by the settling parties. Permits are implemented by an environmental regulatory agency and may require compliance with a statutory or regulatory provision that may impact the reuse of the property.

Informational devices provide information to the public about risks from contamination and generally are not legally enforceable. Informational devices include deed notices, state registries of hazardous waste sites, and advisories. Deed notices are filed in public land records with the property deed that provide information about potential health risks from contamination left on the property. Advisories warn the public of potential risks associated with using contaminated land surface water or groundwater, generally issued by public health agencies.

In addition to the legal mechanisms mentioned above, the Uniform Environmental Covenants Act (UECA) is a model statute that can be adopted into law by each individual state or territory. The UECA provides legal framework to create, modify, enforce and terminate a valid real estate instrument (environmental covenant or IC) to restrict use of contaminated real estate or impose obligations under state law and precluded the application of traditional common law doctrines that might otherwise hinder the validity or enforcement of ICs adopted under state property law or other mechanisms. The UECA provides a legal mechanism to ensure LUCs can be readily found, maintained, and enforced over time.

Layering of ICs, using different types of ICs at the same time may enhance protectiveness. Applying ICs in series may help ensure both short- and long-term effectiveness. Using ICs in conjunction with physical barriers to limit access is also recommended.

The three most common types of ICs at sediment sites include fish consumption advisories and commercial fishing bans, waterway use restrictions, and land use restriction/structure maintenance agreements. Fishing advisories, restrictions or bans on fishing (including shell fishing) are typical ICs. Commercial fishing bans are government controls that ban commercial fishing for specific species or sizes of fish or shellfish (EPA 2005). Rather than a complete ban, advisories may be placed on certain locations and types of fishing. Advisories inform the public that they should not consume fish from an area or should limit the number of fish meals consumed over a specific time period. Advisories and bans are usually established by state departments of health and can be administered through signs, pamphlets or other outreach materials. Warning signs should be in the language of the local community including new immigrants, and require periodic inspection and maintenance. Monitoring, enforcement and communication with local or state authorities are required. Consumption advisories are not enforceable controls and may have variable effectiveness. Surveys of anglers are often helpful to evaluate whether they consume the fish they catch and whether restrictions are effective. EPA's Fish Advisory Program compiles a national listing of fish advisories through its Office of Science and Technology.

Institutional controls may also be needed to protect the integrity of the remedy. Land use restrictions may be needed at near-shore or upland sites to limit or eliminate construction activities, digging or other activities that may disturb the contaminated materials. A deed restriction or notice may be adequate for an upland property, but for in-water remedies, restrictions may be more difficult due to ownership issues. Nearshore areas can, in some cases, be privately owned out to the end of piers. If privately owned, traditional ICs such as proprietary controls or enforcement tools can be considered. Federal, state and local laws place restrictions on and require permits for dredging, filling, or other construction activities in the aquatic environment. ICs may also be implemented through coordination through existing permitting processes.

Restrictions on vessel traffic to establish no-wake zones or restrictions against anchoring may be necessary to protect a cap. Restrictions on easements for installation of utilities and other in-water construction may also be needed, and should be placed on navigational charts. Navigational buoys or warning flags can be used to help warn boaters (ASTSWMO 2009). Changing the navigation status of a waterway may also be necessary. De-authorization or re-authorization of federally authorized navigation channels to a different width or depth would be required. The state may have authority to change harbor lines or the navigation status.

In general, the following ICs would be implemented where the waste material, soil, or sediment exceeds its PRG and does not allow for unlimited use and unrestricted access:

- Deed restrictions would be applied to parcels in which the dioxin concentrations exceed the relevant PRG.

- Notices would be attached to deeds of affected properties to alert potential future purchasers of the presence of dioxin concentrations exceeding the PRG.

- As a result of the long term persistence of dioxin, it is anticipated that the institutional controls will be essentially permanent measures.

The ICs for all northern area alternatives except Alternative 1N include establishing limitations on dredging and anchoring within the footprint of the temporary armored cap. Limitations on dredging and anchoring would be established by requesting that the U.S. Coast Guard District Commander establish a regulated navigation area. The intent of Alternative 6N is full removal of all materials exceeding the PRGs potentially allowing for less restricted future use of the property. However, if waste material residuals leave a layer of material exceeding PRGs, ICs will be needed for Alternative 6N, including a no-wake zone to protect the residuals cover. Additional measures are required to alert future property owners of the presence of subsurface materials exceeding PRGs and management requirements for any excavated soils or waste material exceeding the PRGs. For the northern nearshore areas and the upland area of the southern impoundment, the ICs would include land use restrictions against construction, excavation, or other disturbances that may expose contamination. The ICs would be established using proprietary controls such as covenants to alert future landowners of the potential risks and restrictions. The ICs would be needed until such time as resulting concentrations are shown to be acceptable.

The Texas Department of State Health Services has issued a fish advisory for the Houston Ship Channel and San Jacinto River below the Lake Houston Dam. This advisory recommends that children and women of childbearing age do not eat any fish or crab, and adult men and women past childbearing age should only consume one fish or crab meal per month. This advisory is expected to stay in place following remediation of the Site.

4.1.2 Monitored Natural Recovery

MNR is a remedy for contaminated sediment that typically uses ongoing, naturally occurring processes to contain, destroy, or reduce the bioavailability or toxicity of contaminants in sediment. MNR is technically and administratively implementable at the Site. The River at the location of the Site is generally depositional in nature, and MNR of dioxins and furans is a natural process that occurs when clean sediment particles are deposited over contaminated materials within the Site. Decreases in surface sediment concentrations were documented for all dioxin and furan congeners between 2005 and 2010 datasets within the Site in the Chemical of Potential Concern Technical Memorandum (Integral 2011). There would not be any short- or long-term impacts related to the implementation of the remedial action for MNR. MNR would entail periodic sampling and an analytical program that would be implemented to monitor the progress of natural recovery. However, deposition in the area of the Site is uneven, and there is the potential for high erosion events. For that reason, sampling would be conducted at a representative range of locations and at appropriate time intervals to allow trends in concentrations to be assessed and evaluate the effectiveness of the MNR. The scope of the MNR sampling and analysis, and any adaptive management actions that could be taken as a result of the MNR assessment, would be determined during the Remedial Design.

4.1.3 Treatment

Treatment processes are screened and discussed in the RAM (Anchor QEA 2012b). Treatment alternatives considered in this FS include S/S of waste materials, soils and sediments with a reagent such as Portland cement. S/S was successfully performed during the temporary cap construction on a portion of the Western Cell materials. For costing purposes, the FS assumes a treatment reagent and dosage concentration similar to that which was used during the temporary cap construction, or 7 to 8 percent by weight Portland cement (USEPA 2012c).

To accomplish S/S, physical removal of the existing temporary armored cap materials, as well as the overlying surface waters will be required prior to mixing the reagent. This FS Report assumes that treatment areas in the Eastern Cell that are normally inundated would need to be surrounded by a sheet pile wall, and the water drawn down prior to initiating S/S. The sheet pile system used would need to be robust to withstand differential water levels inside and outside the treatment cell. Sheet pile walls can be overwhelmed during major storm and flood events in the river, however these risks could be mitigated through the design of the sheet pile wall enclosure. Finally, given the physical constraints of the Site, an off-site materials management facility is anticipated to be necessary for temporary stockpiling of cap materials, treatment reagents, and associated machinery to implement the S/S.

Several treatment technologies, including thermal (incineration and in-pile thermal desorption) and chemical (solvated electron technology and base catalyzed decomposition) processes, were also considered for use at the Site but were not included in a remedial alternative.

Incineration of dioxin contaminated material requires high temperatures (in excess of 1200°F) of sufficient residence time (30 to 90 minutes) (USEPA 1998a). Air mixed with the volatilized organic contaminants undergoes an oxidation reaction to form carbon dioxide and water vapor. Incomplete oxidation of contaminants may produce other harmful byproducts if sufficient temperatures and residence times are not achieved; however, operating conditions (temperatures, residence times, contaminant inflow, and excess air flow) are carefully controlled to maximize the destruction of contaminants and minimize the generation of products of incomplete combustion (PICs). Any portion of the material that cannot be incinerated (fly ash) is removed from the system; off-gases are captured and treated by a scrubber system prior to atmospheric release. Both the ash material produced and the off-gas released from the incinerator system are assessed for contaminant content. To be permitted, an incinerator facility must meet local, state, and federal requirements for emissions standards. This technology can be applied both on-site with a portable incinerator and off-site at a dedicated facility. Prior to transportation off-site, it is likely that the dredged material would require dewatering. Dewatering improves handling; controls costs of transport, treatment, and disposal; and reduces the risk of releasing contaminants. Incineration is capable of removing dioxins from contaminated media and chemically altering the dioxin to harmless constituents. Incinerators operating in compliance with environmental permits have been shown to effectively and safely treat waste material, soil, sediment, and debris contaminated with dioxin and related compounds. The RAM included consideration of incineration as a component of disposal. At the time the RAM was developed, it was unclear whether there were landfill facilities that would accept dredged or excavated material from the Site. Subsequent to submittal of the RAM and the Draft FS Report, two landfill facilities were tentatively identified that indicated materials from the Site could potentially be disposed of at these locations without incineration. Therefore, further consideration of incineration as a component of disposal has been screened out in this Feasibility Study Report.

In-Pile Thermal Desorption technology uses a heated negative pressure environment to treat contaminated soils and sediments. Excavated material is placed in piles or "cells" for treatment. Each "cell" is constructed above ground with a foundation, containment berms, insulating walls and cover, and treatment wells. Thermal desorption is a slow process, requiring months to treat a batch of sediment. If the selected remedy includes removing a significant volume of sediment, using thermal desorption would require the use of a large amount of land either to house multiple treatment piles or to stage sediment awaiting treatment. Because of the large space requirement, a temporary thermal desorption facility would need to be established off-site and would need to obtain operating permits. For smaller volumes of sediment, the cost of siting a treatment facility would not be warranted. Thermal desorption was not retained because incineration would provide a more implementable thermal treatment option for a roughly similar cost.

The Solvated Electron TechnologyTM (SET) is an ex situ chemical dehalogenation treatment process. The process involves mixing the contaminated soil or sediment with a solvated electron solution (alkali metal or alkaline earth metal mixed in liquid anhydrous ammonia) in a treatment vessel. Chlorine is removed from the chlorinated organic molecules, leaving the parent contaminant molecule (non-chlorinated dioxin in this case) and metal salts, such as sodium chloride. The vessel is then heated using hot water or steam to remove the ammonia for reuse. Based on the available information, the SET chemical dehalogenation treatment technology is not currently available for full-scale implementation in the United States. As a result, this process option was not retained for further evaluation.

Base-catalyzed decomposition (BCD) is another ex situ technology that has been applied in the United States and countries around the world. The patent holder of this technology in the United States is the USEPA. This treatment technology requires pre-treatment via thermal desorption to remove the contaminants from the soil/sediment matrix by volatilization. The volatilized contaminants pass through a condenser and are fed into a liquid tank reactor along with sodium hydroxide and a carrier oil. The mixture is then heated for 3 to 6 hours to temperatures above 326°C. The oil is tested post-treatment and the carbonaceous residues formed from the reaction are removed from the mixture; the carrier oil can then be reused for subsequent treatment applications. The soil and sediment treated via thermal desorption can be reused as fill material. Based on the available information, the BCD treatment technology is not currently available for full-scale implementation in the United States. As a result, this process option was not retained for further evaluation.

4.1.4 Containment

As described in the RAM, to the extent that containment is a component of the remedy, the containment would be designed, monitored, and maintained in accordance with USACE and USEPA capping guidance (USACE 1998. Ground water monitoring may be required to assure that a containment remedy would be successful in confining all dissolved phase contaminants within the containment area.

In situ capping, as discussed in USEPA guidance (USEPA 2005) is a demonstrated technology that has been selected by USEPA for sediment remediation sites across the United States (USACE 1998). Compared to removal-focused approaches, in situ capping has a disadvantage in that caps require monitoring and maintenance to ensure their protectiveness. Table 4-1a presents a summary of projects where capping was a component of the remedy.

The existing temporary armored cap was designed in accordance with USEPA and USACE capping guidance (USACE 1998). As described in the TCRA Removal Action Work Plan (Anchor QEA 2011) and required by the TCRA AOC, the armor rock was designed to withstand a 100-year storm event with an additional factor of safety to ensure its long-term protectiveness. The storm event defines the depth of water and the currents that the cap armor layer must resist. In addition to the 100-year event, storms with 5- and 10-year return intervals were also considered during the temporary cap design because it was recognized that more frequent storms could present more critical design conditions; for these more frequent storms, the water depth at the Site would be lower, which could result in higher shear stresses on the cap compared to a less frequent storm like the 100-year design event.

Cap design occurs with requirements for OMM in mind. Since being completed in July 2011, the temporary armored cap and associated fencing, access controls and signs have been routinely inspected and maintained by Respondents pursuant to a USEPA-approved OMM Plan. The OMM Plan was developed to address conditions that USACE and USEPA cap design guidance expressly presumes could occur post-construction (such as movement of rock cover in localized areas of the cap). The OMM Plan requires periodic monitoring and monitoring following key storm events to identify the need for possible cap maintenance, followed by appropriate repair activities (USEPA 2005; USACE 1998). The OMM Plan has been modified in an attempt to timely identify conditions not revealed by the original periodic monitoring and maintenance program, including the cap deficiencies discovered in 2015 and 2016..

Cap protection from future barge or other vessel operations in the temporary armored cap area would be assessed and detailed during the Remedial Design phase. For purposes of FS cost development, a conceptual submerged perimeter rock berm has been included as a protective perimeter barrier for the alternatives that include the Upgraded Cap to further ensure the long-term protectiveness of the cap by reducing potential for vessel impacts. Further, Alternative 3aN includes additional perimeter protection from barge strikes by adding protective pilings around the cap. Finally, given the physical constraints of the Site, an off-site staging area is anticipated to be necessary for temporary stockpiling of cap materials, similar to that which was utilized during construction of the temporary cap.

Capping is considered to be highly compatible with the temporary armored cap in accordance with the TCRA Removal Action Objectives (USEPA 2010a, Appendix A, V.A.2), because the existing temporary cap would not need to be disturbed to implement this remedial action.

4.1.5 Removal

Sediment removal has been the most frequent cleanup method used by the Superfund program at sediment sites. Excavation or dredging has been selected as a cleanup method for contaminated sediment at more than 100 Superfund sites (USEPA 2005). One of the advantages of removing contaminated sediment from the aquatic environment often is that, if it achieves cleanup levels for the site, it may result in the least uncertainty about long-term effectiveness of the cleanup, particularly regarding future environmental exposure to contaminated sediment. Removal of contaminated sediment can minimize the uncertainty associated with predictions of sediment bed or cap stability and the potential for future exposure and transport of contaminants. Another potential advantage of removing contaminated sediment is the flexibility it may leave regarding future use of the water body. Methods such as MNR and capping frequently include institutional controls (ICs) that limit water body uses (USEPA 2005). Table 4-1b includes a list of representative projects where dredging has been chosen as the remedy. This Site would involve the removal of paper mill waste material, not contaminated sediment, but the Site has some similarities to these projects because the Northwest area and portions of the Eastern Cell are submerged. However, the majority of the waste material should be able to be excavated in the dry using BMPs.

Alternatives that involve full or partial removal of the temporary armored cap and excavation of impacted material from beneath the cap and in other locations all involve excavation and dredging to some extent. Virtually all dredging projects result in some degree of resuspension, release, and residuals. (USEPA 2005, Sections 6.5.5 (resuspension and releases) and 6.5.7 (residuals); NRC 2007; USACE 2008; Bridges et al. 2010). However, the use of BMPs, including sheet piles and excavation in the dry where possible, would eliminate or greatly reduce resuspension.

Operational and engineering controls (rigid barriers) would be used to the extent practicable to mitigate these potential releases. Further, the use of raised, armored berms to support the sheet piles would allow excavation in the dry in the Western Cell and portions of the Eastern Cell, and prevent localized scour adjacent to the barrier.

Residuals would be managed by backfilling the removed material footprint, or by placement of a clean sediment cover or engineered cap over the footprint. For purposes of this FS Report, it has been assumed that backfill and capping would be used to manage residuals for removal-based alternatives that do not achieve the PRG. The design of the residuals cover would be developed during the Remedial Design, but will likely include at least two layers of clean fill to prevent intermixing with the waste material residuals, and may include armoring where appropriate to protect the residuals cover.

Without the use of robust BMPs, including excavation in the dry, there likely would be increased dredging releases. Table 4-2 presents a summary of dredging release case studies, which report dredge releases from two to four percent of the contaminant removed. However, for Alternative 6N, which uses raised armored berms, sheet piles, and excavation in the dry for a majority of the material removed, etc., the USACE estimates that resuspension would be at least an order of magnitude less, or 0.2 percent; this estimated release amount could increase to 0.34% if sheet piles are determined to be impracticable for use in the Northwest area.

The estimated construction durations for the removal-based alternatives range from 13 months to 19 months. If a major storm or flood were to occur during construction of a removal-based remedy, any BMPs that may be instituted to control resuspension releases under normal flow conditions may be overwhelmed. In these circumstances, releases of disturbed wastes to the river that are exposed as a result of construction activities may be exacerbated. It will be necessary to develop a contingency plan as part of the Remedial Design to minimize any releases in the event of a major storm or flood. Finally, given the physical constraints of the Site, an off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill.

Upland excavations for the area of investigation south of I-10 would be accomplished with conventional earthwork equipment (excavators, dozers, loaders, etc.). Considerations related to upland excavations include maintaining stable sidewalls, and managing water for those excavations that must be performed below the groundwater table.

To maintain stable sidewalls, the excavation may be sloped to a stable angle of repose if space permits, or shoring could be used. Earthwork safety guidelines generally require any excavation deeper than 5-feet to have sloped or shored sidewalls, as provided for in 29 CFR 1926.651 and 1926.652 (Occupational Safety and Health Administration [OSHA] 2014).

Excavation water controls could include ditches and sumps, well point systems, or deep wells. The dewatering effluent may need to be treated prior to disposal or shipped to licensed facility depending on the quality of the water. The selection of appropriate dewatering technology and decisions about dewatering effluent treatment are remedial design elements.

4.1.6 Disposal

The RAM included consideration of incineration as a component of disposal. At the time the RAM was developed, it was unclear whether there were landfill facilities that would accept material removed from the Site. Subsequent to submittal of the RAM and the Draft FS Report, two landfill facilities were tentatively identified that indicated materials from the SJRWP Site could potentially be disposed of at these locations without incineration. Thus, further consideration of incineration as a component of disposal has been screened out in this FS Report.

The waste material will be treated as required for transportation and disposal at a permitted waste disposal facility determined during the Remedial Design. Transportation would be in compliance with applicable requirements and permanently managed in a permitted landfill cleared by the EPA's regional offsite rule contact. Treatment may include dewatering and stabilization with Portland cement or other suitable material as determined during the Remedial Design.

Given the limited upland space available adjacent to the temporary cap, an off-site facility with water access would be necessary to unload barges and process removed waste material prior to shipment to the landfill. The off-site facility would need to accommodate stockpiles for armor rock and removed material, and would need space to accommodate a waste material drying process (conceptually envisioned to be mixing in a drying reagent for this FS Report). The off-site facility would also need to accommodate any water treatment and disposal determined necessary during remedial design. Some operations, such as water treatment, could also be barge mounted. Finally, the off-site facility would need access to regional transportation infrastructure such as heavy-duty roads or rail.

Even with ready access to the regional transportation infrastructure, off-site disposal has posed a bottleneck for some sediment remediation projects (Anchor Environmental and Windward Environmental 2005; Anchor QEA 2009). The daily capacity of the landfill facility to receive material, and/or the daily capacity of the transportation infrastructure to accommodate a new waste stream can be limited. The durations presented in this FS Report have assumed there are no transportation or landfill bottlenecks, and that these facilities can receive material at the same rate as it is excavated or dredged. To the extent that any disposal bottlenecks occur, this would increase the overall duration of removal-based alternatives, exacerbating community, traffic, and safety impacts.

4.2 Assembly of Remedial Alternatives

The preliminary remedial alternatives were modified subsequent to submittal of the RAM. The most significant reason for the modifications was that PRGs for waste material, sediment and soil (as described in Section 3.1) had not been developed when the RAM was prepared. Based on a comparison of $TEQ_{DF,M}$ concentrations in waste material, sediment and soil to the PRGs, areas of affected waste material, sediment and soil potentially subject to remedial action have been identified and are discussed in the descriptions of the remedial alternatives in the following subsections. Remedial alternatives were developed for the FS for the areas north and south of I-10. The remedial alternatives for the area north of I-10 are:

- **Alternative 1N – temporary armored cap and Ongoing OMM (No Further Action)**, which assumes the temporary armored cap would remain in place, together with fencing, warning signs and access restrictions established as part of the TCRA, and would be subject to the ongoing OMM program. The estimated cost of this alternative is $0.4 million.

- **Alternative 2N – Armored Cap, ICs, Ground Water Monitoring, and Monitored Natural Recovery (MNR),** which includes the actions described under Alternative 1N, institutional controls in the form of deed restrictions and notices to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. This alternative is estimated to cost $2.0 million.

- **Alternative 3N – Upgraded Cap, ICs, Ground Water Monitoring, and MNR,** which includes the actions described under Alternative 2N plus additional enhancements to the temporary armored cap, many of which have already been implemented during the work performed in January 2014, consistent with the USACE recommendations. Institutional controls in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

  This alternative will increase the long-term stability of the temporary armored cap (Upgraded Cap) and meet or exceed USACE design standards. This alternative also includes additional measures to protect the Upgraded Cap from potential vessel traffic (i.e. a protective perimeter barrier). This alternative would require an estimated 2 months of construction at an estimated cost of $4.1 million. An off-site staging area would likely be required for management of rock armor, similar to that which was utilized during the temporary cap construction. However, the exact location and configuration of the off-staging area are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 3aN** - **Enhanced Cap, Protective Pilings, ICs, Ground Water Monitoring, and MNR**, which includes enhancements to address the 80% erosion of the Upgraded Cap with Alternative 3N (See Appendix A of the Feasibility Study), and substantial erosion of the underlying paper mill waste material in modelling of a future severe storm. This alternative, 3aN, includes the actions described under Alternative 3N plus additional enhancements to the temporary armored cap recommended by the USACE.to create a cap with increased long-term stability. Institutional controls in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

The additional cap enhancements added for this alternative include pre-stressed concrete or concrete filled steel pipe pilings placed 30 feet apart around the perimeter of the cap to protect from barge strikes. The spacing is designed to catch a typical barge, which is 35 feet wide. An additional armor stone cap with a thickness of at least 24 inches would be placed over the armor cap for Alternative 3N. The armor stone would have a median diameter of 15 inches. This additional armor stone would cover 13.4 acres of the 17.1 acre armored cap. Also, a course gravel filter layer would be placed on 1.5 acres of the Northwest Area where there is currently no geotextile under the armor cap. The actual scope and design of the cap enhancements, and additional area needed to construct the required slopes, would be determined in the Remedial Design. This additional weight of rock on top of the waste pits may cause cap settling and/or pushing the waste material out the sides of the cap; the Remedial Design will consider the significance of the design issues related to this.

- **Alternative 4N – Partial Solidification/Stabilization, Upgraded Cap, ICs, Ground Water Monitoring, and MNR,** provides for solidification and stabilization (S/S) of the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter was used to define the most highly contaminated material. This alternative includes the actions described under Alternative 3N; however about 23 percent of the temporary armored cap (2.6 acres above the water surface and 1.0 acre in submerged areas) would be removed and about 52,000 cubic yards (CY) of materials beneath the cap with $TEQ_{DF,M}$ that exceeds a concentration of 13,000 ng/kg, would undergo S/S. After the S/S is completed, the Upgraded Cap would be constructed. Institutional controls in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

  This alternative would require an estimated 17 months of construction to complete and is estimated to cost $15 million. An off-site staging area may be required for management of rock armor, stabilization reagents and associated treatment equipment. However, the exact location and configuration of the off-staging area are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 5N – Partial Removal, Upgraded Cap, ICs, Ground Water Monitoring, and MNR,** provides for removal of the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter was used to define the most highly contaminated material. Under this alternative the temporary armored cap would be partially removed and the 52,000 CY of material that would undergo S/S under Alternative 4N would instead be excavated and treated as required for off-site disposal. After the removal was completed, the Upgraded Cap would be constructed and the same ICs and monitoring that are part of Alternatives 2N to 4N would be implemented. Institutional controls in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

  This alternative would require an estimated 13 months of construction at an estimated cost of $30 million. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. The exact location, configuration, siting and operational impacts, as well as potential delivery restrictions by the receiving facility (e.g., tons per day) are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 5aN - Partial Removal of Materials Exceeding the PRG, Upgraded Cap, ICs, Ground Water Monitoring, and MNR,** in which all material beneath the temporary armored cap in any location where the water depth is 10-feet or less and which has a of $TEQ_{DF,M}$ 200 nanograms per kilogram (ng/kg) or greater[5] – about 137,600 CY – would be excavated and treated as required for off-site disposal. To implement this alternative, about 11.3 acres (72 percent) of the temporary armored cap would be removed to allow for this material to be removed. After excavation of the material, the remaining areas of the temporary armored cap would be enhanced to create a Upgraded Cap, and the same ICs and monitoring that are part of the preceding alternatives would be implemented. Institutional controls in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of

[5] In defining this alternative, USEPA included an additional requirement that all material exceeding 13,000 ng/kg $TEQ_{DF,M}$, regardless of water depth, would be removed. However, all locations that exceed 13,000 ng/kg $TEQ_{DF,M}$ are in areas with 10-feet of water or less. Thus, the horizontal boundary defining this alternative (the 10-foot water depth) includes all locations exceeding 13,000 ng/kg $TEQ_{DF,M}$.

buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

This alternative would require an estimated 19 months for construction and has an estimated cost of $69.6 million. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. The exact location, configuration, siting and operational impacts, as well as potential delivery restrictions by the receiving facility (e.g., tons per day) are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 6N – Full Removal of Waste Materials Exceeding the PRG, ICs, and MNR** in which all waste material above the PRG of 200 ng/kg in the waste pits would be removed. This would involve removal of most of the existing temporary armored cap and the removal of 152,000 CY of material, which would be treated as required for off-site disposal. The area where waste material has been removed would then be covered with two layers of clean fill and the clean fill would be armored where necessary. Institutional controls in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

  The monitoring program will be designed during the Remedial Design, but may include the collection of fish, sediment, surface water, and ground water samples and evaluation of the data. This alternative would require an estimated 19 months of construction at an estimated cost of $87 million. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. The exact location, configuration, siting and operational impacts, as well as potential delivery restrictions by the receiving facility (e.g., tons per day) are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

The remedial alternatives for selected locations within Soil Investigation Area 4 south of I-10 are:

- Alternative 1S – No Further Action
- Alternative 2S – ICs

- Alternative 3S – Enhanced ICs
- Alternative 4S – Removal and Off-site Disposal

A brief description of the primary elements for each alternative is provided in the remainder of this section, and Tables 4-3 and 4-4 provide a summary of material quantities and durations associated with each of the alternatives. Note that the footprint and assumptions for each alternative are based on the available RI data. Data gaps potentially exist that would need to be addressed during remedial design depending on the selected remedial alternative. For example, to the extent that the selected alternative includes solidification, laboratory bench scale testing would be performed during remedial design to select reagent types and dosages for solidification. Alternatively, if the selected alternative includes removal, additional data would be collected during remedial design to refine the delineation of work areas, and to understand whether changes have occurred in sediment bed concentrations due to shipping activities in the area of the SJRF operations (e.g., from propeller wash).

Following the general descriptions of alternatives provided in Sections 4.3 and 4.4 for the areas north and south of I-10, respectively, Section 5 provides a detailed evaluation of the remedial alternatives with consideration of criteria required by the NCP, 40 CFR Section 300.430(e)(9). Those criteria addressed include overall protection, compliance with ARARs, long-term effectiveness, reduction of toxicity, mobility or volume (TMV), short-term effectiveness, implementability and cost. Two additional criteria, State acceptance, and community acceptance, are not addressed. USEPA Region 6 Clean and Green Policy (USEPA 2009c) was also considered in the development of all of the alternatives.

4.3 Remedial Alternatives for the Area North of I-10

4.3.1 Alternative 1N – Temporary Armored Cap and Ongoing OMM (No Further Action)

This alternative serves as the baseline of comparison for the other remedial alternatives. The NCP requires the development and evaluation of a No Further Action alternative (40 CFR 300.430(e)(6)). As described in Section 2, the TCRA included capping the Site, selected stabilization of near surface soils in the Western Cell, installing a security fence, and posting warning signs. The temporary armored cap was selected following a USEPA-approved TCRA alternatives evaluation, and was designed in accordance with USEPA and USACE cap design guidance (USACE 1998) to provide containment under a variety of storm conditions, up to the 100-year storm event specified by USEPA. It was constructed at a cost of $9 million. In accordance with this guidance, an OMM plan was developed that was reviewed and approved by USEPA. Periodic inspections continue to be conducted to assess the integrity of the temporary armored cap. The temporary armored cap has been further enhanced in accordance with the recommendations made by USACE (USACE 2013). Additional details on the history of the design and monitoring of the temporary armored cap are provided in Section 2.5.3.

Under this alternative, the controls installed as part of the TCRA and as a result of the TCRA reassessment would remain in place and no additional remedial action would be implemented. Since the temporary cap remedy was an early action that successfully reduced dioxin/furan exposure within the area by more than 80 percent (Anchor QEA 2012b) and additional work to enhance the temporary armored cap has since been completed, labeling Alternative 1N as the "No Action Alternative" is not accurate. However, under USEPA RI/FS (USEPA 1988), because the temporary cap construction was completed prior to the review of the array of potential remedies under the FS, the existing temporary cap remedy for procedural purposes is designated as being the "No Action" alternative. However, under this "No Action" option, the temporary armored cap would remain in place and would be subject to ongoing inspection and maintenance performed in accordance with the USEPA-approved OMM Plan.

In the San Jacinto River area surrounding the temporary cap (Preliminary Site Perimeter), including the sand separation area, the $TEQ_{DF,M}$ SWAC for sediment following completion of the temporary cap is approximately 12.5 ng/kg (Anchor QEA 2012b), which is well below the PRG for the hypothetical recreational fisher (30 ng.kg) or the hypothetical recreational visitors (200 ng/kg). No surface soil/sediment samples outside the temporary armored cap and within the Preliminary Site Perimeter have a $TEQ_{DF,M}$ concentration exceeding the waste material PRG of 200 ng/kg (Figure 3-1). The only sediment samples outside of the limits of the temporary armored cap with $TEQ_{DF,M}$ concentrations exceeding the PRG for hypothetical recreational visitors of 200 ng/kg are two subsurface sediment samples collected north of I-10 from one location (SJNE032, refer to Figure 2-4) near the sand separation area.

This alternative includes ongoing OMM of the Armored Cap, which includes inspection and periodic maintenance. The estimated cost of this alternative is $0.4 million (Appendix C).

4.3.2 Alternative 2N – Armored Cap, Institutional Controls and Monitored Natural Recovery

This alternative includes all of the elements discussed under Alternative 1N, plus ICs, Ground Water Monitoring, and MNR. ICs in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the Preliminary Remediation Goal for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River. Under this remedial alternative, the following ICs would be implemented:

- Restrictions on dredging and anchoring would be established to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the sand separation area.
- Public notices and signage around the perimeter of the Site would be maintained or provided, as appropriate.

A periodic sampling and analytical program would also be implemented to monitor the progress of natural recovery and to insure that no contaminated ground water is migrating away from the site. The estimated cost for this alternative is $10.3 million (Appendix C).

4.3.3 Alternative 3N – Upgraded Cap, Institutional Controls, Ground Water Monitoring, and Monitored Natural Recovery

This alternative includes the actions described under Alternative 2N plus additional enhancements to the temporary armored cap to create the Upgraded Cap. This alternative will increase the long-term stability of the temporary armored cap consistent with isolation of impacted materials. ICs in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

Cost estimates for this alternative also include additional measures to protect the Upgraded Cap from potential vessel traffic in the form of a protective perimeter barrier. In concept for this FS Report, these measures would include construction of a 5-foot high submerged rock berm outside the perimeter of the Upgraded Cap, in areas where vessels could potentially impact the cap. This concept was prepared as an FS-level assumption and would be more fully developed during the Remedial Design.

The temporary cap was constructed to provide immediate containment of the materials in the Site. As required in USEPA's Action Memorandum for the TCRA (USEPA 2010a, Appendix A), the containment method was chosen to be compatible with the final remedy and meet applicable design criteria for degree of safety. As with any design, the degree of safety can be increased. For the temporary cap, that would involve flattening the slopes of the existing temporary cap by adding additional armor rock material to enhance the effectiveness and permanence of the temporary cap remedy by increasing the degree of safety for the armor rock design to create the Upgraded Cap.

The temporary armored cap was originally designed with an armor layer to provide containment of waste materials exceeding the PRG in the Northern Impoundments, as well as layers of geotextile and geomembrane. Armor materials were sized using a factor of safety of 1.3, which is greater than the suggested minimum factor of safety of 1.1 (USACE 1998) to provide additional protection of the temporary armored cap against catastrophic failure. In January 2014, further enhancements were made to the temporary armored cap in accordance with USACE recommendations (USACE 2013). To conduct the enhancement, the Respondents placed additional armor rock along the central and southern berms to flatten the slopes to 3 horizontal to 1 vertical (3H:1V), using rock sizes that meet or exceed USACE design criteria. The Upgraded Cap adds further robustness to the enhanced temporary armored cap design by using an even higher factor of safety of 1.5 for sizing the armor stone, and by flattening submerged slopes from 2 horizontal to 1 vertical (2H:1V) to 3H:1V and flattening the slopes in the surf zone from 3H:1V to 5 horizontal to 1 vertical (5H:1V), including areas that were enhanced by the Respondents in January 2014. In addition, the Upgraded Cap uses larger rock sized for the "No Displacement" design scenario. However, there is high degree of uncertainty on whether the implemented and planned cap upgrades in Alternative 3N will provide permanent isolation of impacted materials. The 2016 USACE Alternatives Evaluation Report that modelled Alternative 3N did not consider changing river conditions in its evaluation of the long term permanence of a cap; new channels eroding during flooding as well as changes in channel cross section due to bank erosion, shoreline breaches, etc. during a high flow event caused by a major flood or hurricane is beyond the ability of existing sediment transport models to simulate. Such changes occurred during the 1994 storm. In addition, the uncertainty associated with estimates of the effects of some of the potential failure mechanisms, e.g., propwash, stream instability, is very high (USACE 2016b). Finally, even more severe hurricanes that exceed Hurricane Ike, which was used in modelling, are possible (Hurricane Ike was a Category 2 hurricane). The modelling performed by the USACE of a hypothetical synoptic occurrence of Hurricane Ike and the October 1994 flood; the modelling estimated that approximately 80% of the upgraded Alternative 3N cap incurred erosion during the simulated extreme storm. The possibility that a more severe storm will occur are increased given the hundreds of years that the dioxin waste will remain hazardous. Therefore, there is a high degree of uncertainty regarding the long term permanence of the cap, even with the improvements suggested by the USACE.

The anticipated extent of the additional rock that would be placed during construction of a Upgraded Cap is shown in Figures 4-1 and 4-2, and would entail construction of 5H:1V slopes along the central, western and southern berms, and 3H:1V slopes over the submerged portion of the Northwestern Area, requiring placement of approximately 3,400 CY of armor rock.

Based on the production rates that were realized during the temporary cap construction, the duration of construction for this alternative is estimated to be 2 months (Table 4-3). During construction of the temporary cap, obtaining access to the work area from the uplands was a demonstrated challenge; construction of Alternative 3N will require that access from the uplands be obtained, and obtaining such access could be a challenge again. In addition, an off-site, river-side material staging area would be required to load the armor rock onto a barge for placement on the temporary armored cap. There are limited river-side facilities upstream of the I-10 Bridge that can be accessed by heavy construction equipment. Because of the limited clearance height of the I-10 Bridge, downstream river-side facilities have the disadvantage that the size of equipment that can traverse between the work area and the off-site staging area would be limited by I-10 bridge clearance.

This alternative is estimated to require 750-hours of heavy equipment operations, resulting in greenhouse gas, PM, and ozone-generating emissions, and 260 truck trips causing greenhouse gas, PM, and ozone-generating emissions, as well as traffic impacts. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. Equipment and vehicle emissions of hydrocarbons and nitrogen oxides lead to the generation of smog, including ozone, which is a particular concern in Harris County which has been classified by USEPA as a "severe" non-attainment area for the 1997 8-hour ozone standard and a "moderate" non-attainment area for the 2008 8-hour ozone standard. Moreover, Harris County has not yet been classified for the 2012 fine particle particulate matter ($PM_{2.5}$) annual National Ambient Air Quality Standard (TCEQ 2013).

Using construction worker injuries and fatality rates published by the U.S. Department of Labor (USDL 2011), Alternative 3N is estimated to result in nearly 0.15 lost time injuries, and approximately 0.0006 fatalities as a result of construction. Although both of these safety statistics are below 1.0, they are useful for comparison purposes to the safety-related issues of the other alternatives. Further discussion of this comparison is provided in Section 6. Worker safety issues would be addressed during remedial design, and measures would include, at a minimum, development of detailed health and safety plans to help mitigate these risks.

The cost of this alternative is estimated to be $4.1 million (Appendix C).

4.3.3a Alternative 3aN – Upgraded Cap, Protective Pilings, ICs, Ground Water Monitoring, and MNR

This alternative includes the actions described under Alternative 3N plus additional enhancements suggested by the USACE. The additional enhancements are added to address the potential 80% erosion of the Upgraded Cap with Alternative 3N (Appendix A), and substantial erosion of the underlying paper mill waste material in a potential future severe storm that may occur with the cap design included under Alternative 3N. Cost estimates for this alternative also include additional measures to protect the Upgraded Cap from potential vessel traffic in the form of protective pilings. This alternative will increase the long-term stability of the temporary armored cap. ICs in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

For costing purposes, the additional cap enhancements added for this alternative include pre-stressed concrete or concrete filled steel pipe pilings placed 30 feet apart around the perimeter of the cap to protect from barge strikes. The spacing is designed to catch a typical barge, which is 35 feet wide. An additional armor stone cap with a thickness of at least 24 inches would be placed over the armor cap for Alternative 3N. The armor stone would have a median diameter of 15 inches. This additional armor stone would cover 13.4 acres of the 17.1 acre armored cap. Also, a course gravel filter layer would be placed on 1.5 acres of the Northwest Area where there is currently no geotextile under the armor cap. The actual scope and design of the cap enhancements, and additional area needed to construct the required slopes, would be determined in the Remedial Design. This additional weight of rock on top of the waste pits may cause cap settling and/or pushing the waste material out the sides of the cap; the Remedial Design will consider the significance of and design issues related to this. Monitored Natural Recovery would be used to achieve the PRG for sediment in the Sand Separation Area and the Texas Surface Water Quality Standard in the San Jacinto River.

The temporary armored cap was originally designed with an armor layer to provide containment of waste materials exceeding PRGs in the Northern Impoundments, as well as layers of geotextile and geomembrane. The armor materials were sized using a factor of safety of 1.3, which is greater than the suggested minimum factor of safety of 1.1 (USACE 1998) to provide additional protection of the temporary armored cap against catastrophic failure. In January 2014, further enhancements were made to the temporary armored cap in accordance with USACE recommendations (USACE 2013). The Alternative 3aN Enhanced Cap adds robustness to the enhanced temporary armored cap design by flattening submerged slopes from 2 horizontal to 1 vertical (2H:1V) to 3H:1V and flattening the slopes in the surf zone from 3H:1V to 5 horizontal to 1 vertical (5H:1V), including areas that were enhanced by the Respondents in January 2014.

As stated in the discussion of Alternative 3N, the USACE 2016 Alternative Evaluation report did not consider changing river conditions in its evaluation of the long term permanence of a cap; new channels eroding during flooding as well as changes in channel cross section due to bank erosion, shoreline breaches, etc. during a high flow event caused by a major flood or hurricane is beyond the ability of existing sediment transport models to simulate. Such changes occurred during the 1994 storm. In addition, the uncertainty associated with estimates of the effects of some of the potential failure mechanisms, e.g., propwash, stream instability, is very high (USACE 2016b). Even more severe hurricanes that exceed Hurricane Ike, which was used for modelling, are possible (Hurricane Ike was a Category 2 hurricane). While the USACE speculated that increasing the median diameter of the rock used in the armor cap, as proposed in Alternative 3aN, would reduce the amount of scour that occurred during the extreme hypothetical storm (the synoptic occurrence of Hurricane Ike and the October 1994 storm), this was not modelled. The possibility that a more severe storm will occur are increased given the hundreds of years that the dioxin waste will remain hazardous especially given changing climate conditions (Melillo, et. al. Eds, 2014, Third National Climate Assessment, 2014). Therefore, there is a high degree of uncertainty regarding the long term permanence of the cap, even with the improvements (Alternative 3aN) for an enhanced cap.

The duration of construction for this alternative is estimated to be 15 months (Table 4-3). The implementability issues discussed for Alternative 3N also apply to Alternative 3aN, with increased truck loads, emissions, and worker safety issues in relation to the increased construction required for this Alternative. An off-site, river-side material staging area would be required to load the armor rock onto a barge for placement on the temporary armored cap. There are limited river-side facilities upstream of the I-10 Bridge that can be accessed by heavy construction equipment. Because of the limited clearance height of the I-10 Bridge, downstream river-side facilities have the disadvantage that the size of equipment that can traverse between the work area and the off-site staging area would be limited by I-10 bridge clearance.

The cost of this alternative is estimated to be $24.8 million (Appendix C).

4.3.4 Alternative 4N – Partial Solidification/Stabilization, Upgraded Cap, Institutional Controls, Ground Water Monitoring, and Monitored Natural Recovery

This remedial alternative provides for solidification and stabilization (S/S) of the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter was used to define the most highly contaminated material. The extent of the area for partial S/S was defined, based on sediment and soil chemistry results presented in the RI Report, as the Western Cell and a portion of the Eastern Cell that is currently covered by the temporary cap. Based on the analysis of sediment core samples presented in Figure 2-4, the maximum depth of S/S in the Western Cell would be to approximately 10-feet below the current base of the temporary armored cap and on average approximately 5-feet below the current base of the temporary armored cap in the Eastern Cell and Northwestern Area. An Upgraded Cap as described in Alternative 3N is also included in this remedial alternative. ICs in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

Figure 4-3 presents a plan view of the partial S/S remedial alternative. Figure 4-4 presents a cross section of this remedial alternative to give a typical representation of the depth of S/S.

S/S treatment could be accomplished using large-diameter augers or conventional excavators, similar to those that were used to treat portions of the sediment in the Western Cell during the TCRA. Both technologies are discussed in the RAM. Before treating the sediment, the affected portions of the temporary armored cap armor rock would need to be removed and stockpiled for reuse, if possible, or washed to remove adhering sediment and disposed in an appropriate upland facility. The geotextile and geomembrane would need to be removed and disposed of as contaminated debris. S/S reagents, such as Portland cement, would be delivered to the project work area, stockpiled, and mixed with sediment, as needed, to treat the sediment in situ. Submerged areas to be stabilized would need to be isolated from the surface water with sheet piling and mostly dewatered prior to mixing with treatment reagents using conventional or long reach excavators in a fashion similar to the S/S work completed during the TCRA. For FS purposes, a sheet pile enclosure with a top elevation 2-feet above typical mean higher high water, or 3.5-feet North American Vertical Datum of 1988 (NAVD88), has been assumed. Following completion of the S/S operation in submerged areas the sheet pile enclosure would be removed. Finally, the Upgraded Cap, as described in Alternative 3N, would be constructed, including replacement of the armor rock layer geomembrane and geotextile over the S/S footprint, and the measures described in Section 4.3.3 to protect the Upgraded Cap from vessel traffic would be implemented.

The estimated footprint of this alternative is approximately 2.6 acres in the Western Cell and 1.0 acre of submerged sediment spanning the Eastern Cell and the Northwestern Area (Figure 4-3). Based on the horizontal and vertical limits identified for this alternative, a total of approximately 52,000 CY of waste material would be treated.

Using production rates similar to that achieved during the TCRA, this alternative has an estimated construction duration of 17 months (Table 4-3). As with Alternative 3N, access to the work area from the uplands will be required and could be a challenge, and an off-site staging area would be necessary to manage the materials generated during removal of the temporary armored cap, and to stockpile and load the new armor rock materials to be placed for construction of the Upgraded Cap. Compared to Alternative 3N, this off-site facility would need to be larger because of the need to manage the Armor Cap rock that is removed.

This alternative is estimated to require 5,450-hours of heavy equipment operations, and approximately 1,600 truck trips causing higher greenhouse gas, PM, and ozone-generating emissions and traffic impacts than the previous three alternatives. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10.

Alternative 4N is estimated to result in more than one lost time injury, and approximately 0.004 fatalities as a result of construction. Worker safety issues would be addressed during remedial design, and measures would include, at a minimum, development of detailed health and safety plans to help mitigate these risks. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

The cost of this alternative is estimated to be $14.8 million (Appendix C).

4.3.5 Alternative 5N – Partial Removal, Upgraded Cap, Institutional Controls, Ground Water Monitoring, and Monitored Natural Recovery

This remedial alternative provides for removal of the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter was used to define the most highly contaminated material. The lateral and vertical extent and volume of sediment removed under this alternative is the same as the sediment to be treated as described in the previous section for Alternative 4N and is depicted on Figures 4-5 and 4-6. About 52,000 CY of material would be excavated and treated as required for off-site disposal. Construction of a Upgraded Cap, ICs, and MNR, as described in Alternative 3N, are also included in this remedial alternative.

ICs in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

To mitigate potential water quality issues, submerged areas would need to be isolated using berms, sheet piles, and/or turbidity barrier/silt curtains prior to excavating sediment. Upland areas would not need to be isolated with sheet piling, but the excavation would require continuous dewatering and may need to be timed to try to avoid high water and times of year when storms are most likely.

Excavated sediment would be dewatered and potentially treated to eliminate free liquids prior to transporting it for disposal. Effluent from excavated sediment dewatering would need to be handled appropriately, potentially including treatment prior to disposal. Following completion of the excavation, the work area would be backfilled to replace the excavated sediment and then the Upgraded Cap would be constructed, including replacing the armor rock layer above the excavation footprint and the geomembrane and geotextile layers.

The construction duration for this alternative is estimated to be 13 months (Table 4-3). This alternative is estimated to require almost 7,000-hours of heavy equipment operations and more than 9,300 truck trips causing higher greenhouse gas and PM, ozone generating emission, and traffic impacts as compared to the previous four alternatives.

As with Alternatives 3N and 4N, access to the work area from the uplands will be required and could be a challenge. An off-site facility would need to be identified and secured to manage materials removed (including dewatering, transloading, and shipping) and to stockpile and load imported armor rock. Given the nature of the material being managed at the facility, locating a suitable property and willing landowner could be difficult.

Off-site transport of materials for disposal presents a risk for spills and accidents, which could result in exposure of these materials to the general public. Alternative 5N is estimated to result, on average, in more than 1 non-fatal lost time injury, and approximately 0.006 fatalities as a result of construction. Worker safety issues would be addressed during remedial design, and measures would include, at a minimum, development of detailed health and safety plans to help mitigate these risks. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

The cost of this alternative is estimated to be $29.8 million (Appendix C).

4.3.6 Alternative 5aN – Partial Removal of Materials Exceeding the PRG, Upgraded Cap, Institutional Controls and Monitored Natural Recovery

For this removal alternative, the PRG for waste materials for a hypothetical recreational visitor (200 ng/kg $TEQ_{DF,M}$) was considered for the area within the temporary armored cap which is either above the water or where the water depth is 10 feet or less. As an additional criterion, locations exceeding 13,000 ng/kg $TEQ_{DF, M}$ are also included regardless of water depth; however, all samples exceeding 13,000 ng/kg $TEQ_{DF,M}$ are located in areas where the water depth is 10 feet or less. About 137,600 CY would be excavated and treated as required for off-site disposal. ICs in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to protect the integrity of the armored cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

The lateral and vertical extents of the removal under this remedial alternative are presented in Figures 4-7 and 4-8. As with the Alternatives 4N and 5N, the existing temporary armored cap (consisting of cap rock, geomembrane and geotextile) which currently isolates and contains impacted material would need to be removed prior to beginning excavation work.

This alternative also includes an engineered barrier to manage water quality during construction. In shallow water areas (water depths up to approximately 3 feet), this barrier would be constructed as an earthen berm, extending to an elevation at least 2 feet above the high water elevation in consideration of wind-generated waves and vessel wakes. The berm would be limited to a total height of 4 to 5 feet above the existing mudline for constructability reasons: as the berm height increases, the base width increases and it can be challenging to efficiently construct taller berms because they become wider at their base than the reach of a typical excavator. In areas with water depths deeper than about 3 feet, the berm would transition into a sheet pile barrier around the work area. Figure 4-7 depicts the approximate limits where the earthen berm and sheet pile barriers could potentially be constructed.

Work would be conducted in the wet. Excavated sediment would be offloaded, dewatered and stabilized at a dedicated offloading location, as necessary, to eliminate free liquids for transportation and disposal. Following removal of impacted sediment, the area from which sediments are removed would be covered with a residuals management layer of clean cover material. In the deeper water areas of the Site where removal is not conducted, the existing temporary armored cap would be maintained.

This alternative entails removal of approximately 137,600 CY of waste material from the waste pits, which would require a relatively large offloading and sediment processing facility to efficiently accomplish the work. As with Alternative 5N, the challenges with locating such a facility could be significant and are magnified because a larger site would potentially be needed to manage the greater volume of material removed (including dewatering, transloading, and shipping) and to stockpile and load imported armor rock. Alternative 5aN is estimated to have a construction duration of 19 months (Table 4-3).

This alternative is estimated to require approximately 15,665 hours of heavy equipment operations and over 12,855 truck trips, resulting in higher greenhouse gas and PM, ozone generating emissions, and traffic impacts as compared to the previous five alternatives. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. Off-site transport of materials for disposal presents a higher risk for spills and accidents compared to Alternative 5N, which could result in exposure of these materials to the general public. Using an additive drying amendment such as lime or Portland cement could result in fugitive dust emissions at the offloading/processing area, however measures would be implemented to control dust.

Alternative 5aN is estimated to result in approximately 3 lost time non-fatal injuries, and approximately 0.01 fatalities as a result of construction. Worker safety issues would be addressed during remedial design, and measures would include, at a minimum, development of detailed health and safety plans to help mitigate these risks.

The cost of this alternative is estimated to be $69.6 million (Appendix C).

4.3.7 Alternative 6N – Full Removal of Waste Materials Exceeding the PRG, Institutional Controls, and Monitored Natural Recovery

For the full removal alternative, the hypothetical recreational visitor exposure scenario was considered for area north of I-10. The PRG for waste materials for protection of the hypothetical recreational visitor is a $TEQ_{DF,M}$ concentration of 200 ng/kg. The lateral and vertical extents of the removal under this remedial alternative are presented in Figures 4-9 and 4-10. This would involve removal of most of the existing temporary armored cap and the removal of 152,000 CY of material, which would be treated as required for off-site disposal. The work area would be isolated with best management practices (BMPs) to reduce resuspension releases to the maximum extent practicable. Best management practices may include raised/armored berms, sheet piles, excavation procedures including excavation in the dry where practicable, and/or with turbidity barrier/silt curtains. Containment structures to reduce resuspension would consist of berms and sheet pile walls or caissons to an elevation of about +10 NAVD88 (protection from 25-year or 50-year flood stage, Appendix A). If performing excavation of the waste materials in the dry, the top of the berms would preferably be no lower than +5 NAVD88 (protection from 5-year or 10-year flood stage, Appendix A). The specific BMPs and their design and application will be determined during the Remedial Design. ICs in the form of deed restrictions and notices would be implemented to place restrictions on dredging and anchoring to prevent disturbance of any residuals and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

As with the partial removal alternatives, cap rock, geomembrane and geotextile from the existing temporary armored cap, which currently isolates and contains impacted material, would need to be removed prior to beginning excavation within the waste pits. Similarly, upland excavation could require dewatering to allow excavation of impacted sediment in relatively dry conditions. Excavated sediment would be further dewatered and stabilized at the offloading location, as necessary, to eliminate free liquids for transportation and disposal. Some operations, such as water treatment, could be barge mounted. Following removal of the waste material, the area from which sediments are removed would be covered with two residuals management layers of clean sediment to reduce intermixing.

This alternative entails removal of approximately 152,000 CY of waste material from the waste pits, which would require a relatively large offloading and sediment processing facility to efficiently accomplish the work, which would require barge unloading, sediment re-handling, dewatering, stockpiling, transloading, and shipping to the off-site landfill facility. Additional activities would include management and disposal of dewatering effluent, including treatment if necessary.

Alternative 6N is estimated to have a construction duration of 19 months (Table 4-3). The monitoring program will be designed during the Remedial Design, but may include the collection of fish, sediment, and surface water samples and evaluation of the data. Similar to the issues described for Alternatives 5N and 5aN, locating an adjacent facility with sufficient space and availability for more than a year of use for staging, offloading, and waste processing is considered to be a challenge to the implementability of Alternative 6N.

This alternative is estimated to require approximately 11,800 hours of heavy equipment operations and approximately 13,300 truck trips, resulting in higher greenhouse gas and PM, ozone generating emissions, and traffic impacts as compared to the Alternatives 1N through 5N. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and air emissions related to the presence of I-10. Off-site transport of materials for disposal presents a higher risk for spills and accidents compared to Alternative 5N, which could result in exposure of these materials to the general public. However, transportation of hazardous substances with the appropriate controls in place to prevent spills is a commonplace activity at Superfund sites. Using an additive drying amendment such as lime or Portland cement could result in fugitive dust emissions at the offloading/processing area, however, measures would be implemented to control dust as determined during the Remedial Design.

Alternative 6N is estimated to result in more than 3 lost time non-fatal injuries, and approximately 0.01 fatalities as a result of construction. Worker safety issues would be addressed during the Remedial Design, and measures would include, at a minimum, development of detailed health and safety plans to help prevent and mitigate these risks.

The cost of this alternative is approximately $87 million (Appendix C).

4.4 Remedial Alternatives for the Area South of I-10

4.4.1 Alternative 1S – No Further Action

This alternative serves as the baseline of comparison for the other remedial alternatives. The NCP requires the development and evaluation of this alternative (40 CFR 300.430(e)(6)). Under this remedial alternative for the area of investigation south of I-10, impacted soil would remain in place and no steps would be taken to alert future landowners or construction workers of the presence, at depth, of $TEQ_{DF,M}$ concentrations exceeding the PRG for soil. The estimated cost for this alternative, is $0.

4.4.2 Alternative 2S – Institutional Controls and Ground Water Monitoring

The PRG for soil for the hypothetical future construction worker is based on exposure assumptions that include contact with the soil interval from the surface to 10 feet below grade.

The BHHRA concluded that there are no unacceptable risks associated with surface soil (soil from 0 to 6 inches below ground surface). The arithmetic mean of $TEQ_{DF,M}$ concentrations in surface soil is 13.3 ng/kg, which is well below the soil screening level (51 ng.kg) that allows for unlimited use and unrestricted exposure. The highest $TEQ_{DF,M}$ concentration observed in surface soil, 36.9 ng/kg (Sample SJSB023, refer to Figure 2-5), is also below this soil screening level.

This alternative would apply to locations in the area south of I-10 where the average $TEQ_{DF,M}$ concentration in the upper 10-feet of soil below grade exceeds the risk-based PRG for soil for the hypothetical future construction worker (240 ng/kg).

Under this remedial alternative, the following ICs would be implemented:

- Deed restrictions would be applied to parcels in which the depth-weighted average $TEQ_{DF,M}$ concentrations in upper 10-feet of soil exceed the soil PRG for a hypothetical future construction worker (Figure 4-11).

- Notices would be attached to deeds of affected properties to alert potential future purchasers of the presence of waste and soil with $TEQ_{DF,M}$ concentrations exceeding the soil PRG.

The estimated cost for this remedial alternative is $1.02 million (Appendix C).

4.4.3 Alternative 3S – Enhanced Institutional Controls and Ground Water Monitoring

This remedial alternative would incorporate the ICs identified in Section 4.4.2 and add physical features to enhance the effectiveness of the ICs. The physical features would include bollards to define the areal extent of the remedial action areas at the surface and a marker layer that would alert workers digging in the area that deeper soil may be impacted. Figure 4-11 shows the locations of the remedial action areas south of I-10.

Implementation of this remedial alternative may include the following steps:

- Removing up to 2 feet of surface soil.
- Temporarily stockpiling the soil on-site.
- Placing the marker layer (such as a geogrid or similar durable and readily visible material) at the bottom of the excavation.
- Returning the soil to the excavation and re-establishing vegetative cover.
- Placing bollards at the corners of the remedial action areas.

The duration of construction for this remedial alternative is estimated to be 1 month (Table 4-4). This alternative is estimated to require approximately 160 hours of heavy equipment operations, resulting in greenhouse gas, PM, and ozone-generating emissions. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. Alternative 3S is estimated to result in 0.015 lost time injury and 0.0001 fatalities as a result of construction. The estimated cost for this remedial alternative is $1.4 million (Appendix C).

4.4.4 Alternative 4S – Removal and Off-site Disposal

This remedial alternative involves excavation and replacement of soil in the three remedial action areas shown in Figure 4-11. Soil would be removed within these areas to a depth of 10 feet below grade. Implementation of this remedial alternative would require dewatering (groundwater lowering) to allow excavation of impacted soil in relatively dry conditions and may need to be timed to try to avoid high water and periods when storms are most likely. Excavated soil would be further dewatered, as necessary, and potentially treated to eliminate free liquids prior to transporting it for disposal. Effluent from excavation and subsequent dewatering would need to be handled appropriately, potentially including treatment prior to disposal. Excavated soil would be disposed of at an existing permitted landfill, the excavation would be backfilled with imported soil, and vegetation would be re-established. Pavement on Market Street adjacent to Remedial Action Area South 1 (Figure 4-11) would be repaired.

An existing building (an elevated frame structure) and a concrete slab within Remedial Action Area South 3 (Figure 4-11) would need to be demolished and removed prior to excavating the underlying soil. These features would be replaced, if necessary.

The removal volume (50,000 CY) was calculated assuming a conservative excavation side slope of 2 horizontal to 1 vertical. Transportation and disposal costs were estimated assuming that all of the excavated material would be transported to a licensed landfill for disposal. During remedial design, potential cost savings associated with segregating clean soil and using it as backfill may be explored.

Appropriate containment and controls for dust and runoff would be provided for any soil stockpiles or soil amendment areas that may be required. Trucks would be inspected and decontaminated, as necessary, before they would be released from the site to avoid tracking soil from the work site onto public roads.

The duration of construction for this remedial alternative is estimated to be 7 months (Table 4-4). This alternative is estimated to require approximately 900 hours of heavy equipment operations and more than 7,000 truck trips, resulting in greenhouse gas and PM, and ozone-generating emissions. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. Alternative 4S is estimated to result in 0.088 lost time injury and 0.0004 fatalities as a result of construction. The estimated cost for this remedial alternative is $9.9 million (Appendix C).

5 DETAILED ANALYSIS OF REMEDIAL ALTERNATIVES

As discussed in Section 4, the detailed evaluation of remedial alternatives is based on consideration of the following criteria, as required by the NCP, 40 CFR Section 300.430(e)(9):

1. Overall protectiveness of human health and the environment
2. Compliance with ARARs
3. Long-term effectiveness and permanence
4. Reduction of toxicity, mobility or volume through treatment
5. Short-term effectiveness
6. Implementability
7. Cost
8. State/Support Agency acceptance
9. Community acceptance

The first two criteria, overall protectiveness and compliance with ARARs, are identified as threshold criteria in 40 CFR Section 300.430(f). Remedial alternatives must satisfy the threshold criteria to be selected as the final remedy, although ARAR waivers may be considered in some circumstances. The next five criteria are identified as primary balancing criteria. The comparative analysis considers the anticipated performance of the remedial alternatives relative to these balancing criteria. The final two criteria, identified as modifying criteria, are considered by USEPA in preparing the ROD based on consultation with the State environmental agency and public comments received in response to the FS Report and the proposed plan. Item 39 of the Statement of Work attached to the UAO states that the modifying criteria are not to be considered in the comparative analysis in this FS Report. Information related to the modifying criteria are therefore not provided in this section.

The first seven criteria, as presented in 40 CFR 300.430(f), are briefly defined below:

- *Overall protectiveness of human health and the environment* is an evaluation of whether the remedial alternative can adequately protect human health and the environment. This may be expressed as an assessment of whether the remedial alternative addresses all of the RAOs, which are identified and described in Section 2.

- *Compliance with ARARs* is an evaluation of whether the remedial alternative addresses or can be implemented in compliance with all of the ARARs, which are identified in Table 3-1. Section 121 (d) of CERCLA and NCP §300.430(f)(1)(ii)(B) require that remedial actions at CERCLA sites at least attain legally applicable or relevant and appropriate Federal and State requirements, standards, criteria, limitations which are collectively referred to as "ARARs," unless such ARARs are waived under CERCLA section 121(d)(4) and NCP §300.430(f)(1)(ii)(C).

- *Long-term effectiveness and permanence* is an evaluation of the ability of the remedial alternative to reliably maintain protection of receptors.

- *Reduction of toxicity, mobility or volume through treatment* is an evaluation of the degree to which treatment or recycling of affected media is used to reduce the TMV of contaminated media, particularly principal threats.

- *Short-term effectiveness* is an evaluation of both the time required for the remedial alternative to achieve full protection and the degree to which potential risk to human health and the environment is increased during implementation of the remedy, considering measures that may be used to mitigate short-term risks until cleanup levels are achieved. The short-term effectiveness evaluation also includes an evaluation of the sustainability of the remedial alternative in conformance with the USEPA Region 6 Clean and Green Policy (USEPA 2009c).

- *Implementability* is an evaluation of the technical and administrative feasibility of a remedy from design through construction and operation. Factors such as availability of services and materials, administrative feasibility, and coordination with other governmental entities are also considered. Technical factors include consideration of whether the remedial alternative involves the use of well demonstrated technologies, readily available equipment and materials, and whether any physical conditions of the project work area may impede implementation. Administrative factors include consideration of whether implementation of the remedial alternative might be impeded by the need to obtain approvals from nearby landowners or public agencies.

- *Cost* is an evaluation of construction and long-term operation, maintenance, and monitoring costs. A present-worth cost analysis is typically used to evaluate the total cost of remedial alternatives. Both CERCLA and the NCP, require that remedies be cost-effective (42 U.S. Code [U.S.C.] §9621(a); 40 CFR §300.430(f)(1)(ii)(D)): "Each remedial action selected shall be cost-effective" (40 CFR §300.430(f)(1)(ii)(D)). Cost-effectiveness is defined as "costs are proportional to its overall effectiveness." (40 CFR §300.430(f)(1)(ii)(D)). Pursuant to the USEPA's 1999 guidance, A Guide to Preparing Proposed Plans, Records of Decision, and Other Remedy Selection Documents, "cost-

> effectiveness is concerned with the reasonableness of the relationship between the effectiveness afforded by each alternative and its costs compared to other available options." Moreover, "if the difference in effectiveness is small but the difference in cost is very large, a proportional relationship between the alternatives does not exist" (Federal Register 1990). These proportionality requirements were reiterated by USEPA in the above-cited guidance. The present costs presented below are based on a 7% discount rate.

This section describes the individual analyses for each of the alternatives for the areas north and south of I-10. Table 5-1 summarizes the key discussion points from this section for each of the evaluation criteria for area north of I-10. Table 5-2 summarizes the same information for the area south of I-10.

5.1 Area North of I-10

5.1.1 Alternative 1N – Temporary Armored Cap and Ongoing OMM (No Further Action)

5.1.1.1 Overall Protection of Human Health and the Environment

This alternative will only remain protective if it is properly maintained for the length of time (hundreds of years) that the impounded waste retains its toxicity, and its integrity is not compromised by extreme weather events, barge strikes and/or changes in the river channel which could result in a future release. As discussed in Section 2.5, for the area north of I-10 the temporary cap resulted in capping and isolation of all sediment samples with $TEQ_{DF,M}$ concentrations exceeding the applicable soil PRG, except for those located within a small area of subsurface sediment near the sand separation area (located to the northwest of the waste pits). Based on data from the RI study, the subsurface sediment near the sand separation area is isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the sediment PRG for hypothetical recreational fisher.

5.1.1.2 Compliance with ARARs

Alternative 1N would not result in construction impacts or other changes to baseline conditions that would trigger any action-, chemical-, or location-specific ARARs identified in Table 3-1. Under these post-TCRA conditions, there are no documented exceedances of surface water quality standards within the USEPA's Preliminary Site Perimeter due to the presence of dioxins and furans from the impoundments.

5.1.1.3 Long-Term Effectiveness

Alternative 1N would not affect long-term residual risks nor would it affect or enhance the reliability of existing controls. The long-term effectiveness of this remedial alternative was evaluated considering the potential for natural forces or human activity to expose the waste material or sediment with $TEQ_{DF,M}$ concentrations that exceed the applicable risk-based PRGs. Sediment in the vicinity of the sand separation area is stable and net sedimentation in this area is expected to provide continued isolation at this buried location; however, propeller wash from tug boat operations, or severe flooding and/or storms could disturb these sediments. Monitoring will be required to determine sedimentation is occurring.

The dioxin within the waste pits was generally isolated from potential receptors by the temporary cap, but the temporary cap has required many repairs and extensive maintenance. Examples include, in December 2015, an area of missing rock that was found by the EPA Dive Team. This area was not identified by the regular inspections that had been done since the temporary cap construction was completed. Dioxin at 43,000 ng/kg was under water exposing the environment and potential receptors to the dioxin. Repairs to this area were completed in 2016. Other instances of thin or absent rock cover were identified in 2012, 2013, and in 2016. No flood since the cap was constructed in 2011 has exceeded a 100-year return period design flood.

Work implementing USACE 2013 recommendations to enhance the cap's long-term stability was completed in January 2014. This remedial alternative does not include alerting future landowners of the temporary cap to the potential risks associated with activities that may involve exposing the capped sediment, and does not include placing restrictions on dredging or anchoring at the temporary cap. The protection provided by the temporary armored cap would be continued through long-term monitoring and maintenance, which will be required for as long as the dioxin/furan represents an unacceptable risk should exposure occur. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. Dioxins and furans are persistent contaminants that will not readily break down. While there is much uncertainty regarding how long the waste materials will represent an unacceptable risk should exposure occur, however, the EPA estimates that, for dioxins that are not exposed to sunlight, the dioxin half-life ranges from 25 to 100 years.

5.1.1.4 Reduction of Toxicity, Mobility or Volume

Alternative 1N would not include additional reduction of TMV through treatment. However, it is important to note that sediment in the Western Cell was treated with

Portland cement during the temporary cap construction for equipment access that also reduced the mobility of the waste material. Over the long-term, ongoing deposition may result in declines in surface sediment concentrations. Natural deposition is expected to cover the site; however, deposition rates are low in most areas, particularly shallow areas. Further, should the river geometry change as a result of extreme erosion that was documented during the 1994 flood, then the predicted deposition may not occur.

In addition, disturbance from propeller wash due to activities from barge operations in the San Jacinto River could cause locally greater erosion than that modeled during flood events depending on the water depth, the size of the vessel, and the duration of vessel operations. Such disturbance could cause changes in concentration of $TEQ_{DF,M}$ in the area of erosion and its vicinity. Alternative 1N does not include measures to protect against barge strikes. Sediment in the footprint of the temporary armored cap is generally isolated from exposure at the surface by layers of geotextile, geomembrane, and cap rock except for areas in the underwater portions of the northwest part of the cap, for example, that do not contain geotextile or geomembrane.

5.1.1.5 Short-Term Effectiveness

There are no short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative.

5.1.1.6 Implementability

There are no technical or administrative implementability issues associated with this remedial alternative. Monitoring the temporary armored cap, which is required under the USEPA-approved OMM Plan and is part of this remedial alternative, should not pose implementability challenges.

5.1.1.7 Cost

The estimated cost associated with this remedial alternative is $0.4 million (Appendix C) for temporary armored cap construction and for implementing the existing OMM Plan for the temporary armored cap, signs, buoys and fencing. Costs include monitoring, maintenance events, and USEPA 5-year reviews as described in Appendix C, and are based on access to the Site being available from the river and through the TxDOT right-of-way (ROW). Long term monitoring events will be required for as long as an unacceptable risk from the dioxin/furan remain.

5.1.2 Alternative 2N – Armored Cap, Institutional Controls, Ground Water Monitoring, and Monitored Natural Recovery

5.1.2.1 Overall Protection of Human Health and the Environment

This alternative will only remain protective if it is properly maintained for the length of time (hundreds of years) that the impounded waste retains its toxicity, and its integrity is not compromised by extreme weather events, barge strikes and/or changes in the river channel which could result in a future release. This remedial alternative would achieve the RAOs through a combination of ICs, MNR, ground water monitoring, and existing engineering controls. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River. As noted in Section 5.1.1, the temporary armored cap is protective of human health and the environment in the near term. Waste material and sediment with $TEQ_{DF,M}$ concentrations exceeding the applicable PRGs are isolated from potential receptors by the temporary armored cap or by sediment with $TEQ_{DF,M}$ concentrations below the PRGs. ICs would be used to:

- Alert property owners of the presence of subsurface materials exceeding PRGs.
- Describe the need for protective equipment and training if excavation of subsurface materials exceeding PRGs is required in the waste pit footprint.
- Describe requirements for the management of any excavated soil or sediment exceeding PRGs.
- Describe the need to restore the temporary armored cap following any disturbance.
- Establish limitations on dredging and anchoring within the footprint of the temporary armored cap by requesting, in accordance with 33 CFR 165.5, that the U.S. Coast Guard District Commander establish a regulated navigation area.

Affected sediment near the sand separation area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the PRG, may be further isolated by deposition of additional sediment through ongoing natural recovery processes. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. Monitoring of sediment conditions in this area would be performed to confirm that deposition of new sediment was continuing to maintain surface $TEQ_{DF,M}$ concentrations below the PRG for hypothetical recreational visitors. The MNR plan would include methods for assessing whether deposition or erosion were occurring at monitoring stations between monitoring events. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place. The actual scope and timeline of monitoring would be determined in coordination with USEPA during remedial design and during implementation of the monitoring program over the years.

5.1.2.2 Compliance with ARARs

Alternative 2N would involve a minimal amount of physical activity for the implementation of ICs (e.g., landowner notifications; restrictions on dredging and anchoring) and ongoing implementation of existing engineering controls. For the same reasons presented in the ARAR compliance discussion under Alternative 1N (Section 5.1.1.2), due to the minimal amount of active construction involved, Alternative 2N is also expected to generally meet the substantive requirements of the ARARs presented in Section 3.4.

5.1.2.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative is primarily derived from the temporary cap completed in 2011 and the ICs that would help protect the integrity of the cap. Long-term effectiveness is also provided by the layers of surface soil and sediments with concentrations below PRGs and the monitoring that would confirm the continued deposition of clean sediment isolating the affected sediment outside of the footprint of the temporary armored cap. Long-term simulations conducted with the fate and transport model indicate the surface sediment concentrations averaged over the USEPA's Preliminary Site Perimeter are predicted to decline by a factor of 2 over an approximate 10- to 15-year time period (see Appendix A); monitoring would be conducted to verify actual reductions in sediment concentrations.

The long-term effectiveness of this alternative is dependent on the continued integrity of the armored cap. The dioxin within the waste pits was generally isolated from potential receptors by the temporary cap, but the temporary cap has required many repairs and extensive maintenance. Examples include, in December 2015, an area of missing rock that was found by the EPA Dive Team. This area was not identified by the regular inspections that had been done since the temporary cap construction was completed. Dioxin at 43,000 ng/kg was under water exposing the environment and potential receptors to the dioxin. Repairs to this area were completed in 2016. Other instances of thin or absent rock cover were identified in 2012, 2013, and in 2016. No flood since the cap was constructed in 2011 has exceeded a 100-year return period design flood. Other concerns with long-term effectiveness include those associated with Alternative 1N: disturbance of the cap from propwash, barge strikes, storms, flooding, and/or changes in the river channel.

Risk reduction is achieved by the temporary armored cap and the clean soil and sediment layers, which protect against exposure through the applicable potential pathways, and by the use of ICs and monitoring to verify that the isolation layers remain effective. Monitoring and maintenance will be required for as long as the dioxin/furan represents an unacceptable risk should exposure occur. Dioxins and furans are persistent contaminates that will not readily break down. While there is much uncertainty regarding how long the waste materials will represent an unacceptable risk should exposure occur, however, the EPA estimates that, for dioxins that are not exposed to sunlight, the dioxin half-life ranges from 25 to 100 years. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

5.1.2.4 Reduction of Toxicity, Mobility or Volume

There is no additional reduction of TMV due to treatment associated with this remedial alternative beyond that which was achieved during the temporary cap construction. As noted in Section 5.1.1.4, some waste material in the Western Cell was treated during the TCRA, contributing to the reduction of mobility.

5.1.2.5 Short-Term Effectiveness

There are no short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative. The remedy would achieve full protection in the waste pits immediately. As additional clean sediment continues to be deposited in aquatic areas within the USEPA's Preliminary Site Perimeter, $TEQ_{DF,M}$ concentrations in the near surface sediment interval may continue to decline and the buried sediment near the sand separation area with $TEQ_{DF,M}$ concentrations exceeding the PRG may be further isolated from potential receptors. Ongoing deposition may result in declines in surface sediment concentrations, however, deposition rates are low in most areas, particularly shallow areas. Further, should the river geometry change as a result of extreme erosion similar to that which was documented during the 1994 flood, then the predicted deposition may not occur.

5.1.2.6 Implementability

There are no technical implementability issues associated with this remedial alternative. Alternative 2N would involve a minimal amount of physical activity for the implementation of ICs (e.g., landowner notifications; restrictions on dredging and anchoring) and on-going implementation of existing engineering controls. Monitoring would involve collecting and analyzing sediment samples and evaluating the data, which are routine procedures for qualified environmental consultants and laboratories. Establishing ICs is routine; there are no anticipated administrative implementability issues associated with this remedial alternative.

5.1.2.7 Cost

The estimated present worth cost associated with this remedial alternative is $2.0 million (Appendix C). The capital costs for this remedial alternative are associated with preparation of sampling plans, deed restrictions and notices, and a soil management plan. The long-term costs are for collecting and analyzing environmental samples, evaluating the data, preparing reports to document MNR, conduct of 5-year reviews by USEPA, and future monitoring and maintenance of the temporary armored cap, as described in Appendix C. The cost estimate for this alternative assumes available access to the Site by water from a location along the river and by land through the TxDOT ROW. The actual number of monitoring events will be determined during the Remedial Design.

5.1.3 Alternative 3N – Upgraded Cap, Institutional Controls, Ground Water Monitoring and Monitored Natural Recovery

5.1.3.1 Overall Protection of Human Health and the Environment

This alternative will only remain protective if the cap is properly maintained for the length of time (hundreds of years) that the impounded waste retains its toxicity, and its integrity is not compromised by extreme weather events, barge strikes and/or changes in the river channel which could result in a future release. This remedial alternative would achieve the RAOs through a combination of active remedial construction, monitoring and cap maintenance, MNR addressing additional sediment deposition and implementation of ICs. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data.

The active component will include construction of further enhancements to the temporary armored cap beyond the approved temporary armored cap constructed in 2011 and the enhancement work performed in January 2014. Additional enhancements will include adding additional armor rock to the cap, which will further flatten the slopes, and measures to construct a protective perimeter barrier to protect the Upgraded Cap from vessel traffic. The Upgraded Cap would be designed for a 500 year flood event, and meet or exceed USACE and USEPA cap design criteria. The alternative includes, in concept, the construction of a submerged rock berm as the protective perimeter barrier. Cap monitoring, inspections and maintenance, as needed, would be incorporated into the final remedy to ensure the long-term effectiveness of the remedy.

MNR would address the affected sediment near the sand separation area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the sediment PRG and may be further isolated by deposition of additional clean sediment as described in Appendix A. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

For purposes of MNR, monitoring of sediment conditions in this area would be performed to confirm that deposition of new sediment was continuing to maintain $TEQ_{DF,M}$ concentrations in surface sediments below the PRG for protection of hypothetical recreational visitors. The MNR plan would include methods for assessing whether deposition or erosion were occurring at monitoring stations between monitoring events. The actual scope and timeline of monitoring would be determined in coordination with USEPA during remedial design.

ICs would be used to:

- Alert property owners of the presence of subsurface materials exceeding PRGs
- Describe the need for protective equipment and training if excavation of subsurface materials exceeding PRGs is required in the footprint of the Upgraded Cap
- Describe requirements for the management of any excavated soil or sediment exceeding PRGs
- Describe the need to restore the cap or clean cover soil in these areas following any disturbance
- Establish limitations on dredging and anchoring within the footprint of the Upgraded Cap by requesting, in accordance with 33 CFR 165.5, that the U.S. Coast Guard District Commander establish a regulated navigation area.

5.1.3.2 Compliance with ARARs

Implementation of Alternative 3N would involve the placement of fill material (the additional armor rock) into the San Jacinto River to create the Upgraded Cap. The placement of fill would trigger compliance with CWA Section 404(b)(1) and potentially other ARARs related to surface water quality standards. However, Alternative 3N is expected to generally meet the substantive requirements of the ARARs in Table 3-1 through implementation of the BMPs and the agency coordination actions outlined in Section 3.4. Construction of the Upgraded Cap would require the placement of approximately 3,400 CY of additional cap armor rock material. Based on the results of modeling (Appendix A), the long-term change to the maximum water surface elevation following placement of the additional armor rock is negligible.

5.1.3.3 Long-Term Effectiveness

The long-term effectiveness of the existing temporary armored cap in this alternative is enhanced by adding armor rock to the cap and flattening the slopes of the cap. Flattening the slopes to create the Upgraded Cap, as shown in Figures 4-1 and 4-2, would enhance the structural integrity and long-term reliability of the cap. The armor rock that will be used to create the Upgraded Cap will meet or exceed sediment cap design guidance and the recommendations made by USACE in its review of the cap design and construction in 2013, and a protective perimeter barrier would further increase the long-term effectiveness of the Upgraded Cap by protecting the cap from vessel traffic. An assessment of the Upgraded Cap (Alternative 3N) has determined that the cap would remain protective when subjected to the erosive forces under a 500-year flood event. However, the Upgraded Cap would not be able to reliably contain the waste material during a potential extreme storm as identified by the USACE in the 2016 Alternatives Evaluation report. The National Climate Assessment predicts an increasing number of extreme storms due to climate change. The USACE also acknowledged considerable uncertainty with regard to failure mechanisms related to propwash and potential changes in the channel of the San Jacinto River.

This alternative also may be effective over the long-term because of declines in sediment surface concentrations due to natural recovery (Appendix A) throughout USEPA's Preliminary Site Perimeter. Ongoing deposition may result in declines in surface sediment concentrations, however, deposition rates are low in most areas, particularly shallow areas. Further, should the river geometry change as a result of extreme erosion that was documented during the 1994 flood, then the predicted deposition may not occur. Monitoring would confirm the continued deposition of new sediment isolating the affected sediment outside of the footprint of the temporary armored cap. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

The dioxin within the waste pits was generally isolated from potential receptors by the temporary cap, but the temporary cap has required many repairs and extensive maintenance. Examples include, in December 2015, an area of missing rock that was found by the EPA Dive Team. This area was not identified by the regular inspections that had been done since the temporary cap construction was completed. Dioxin at 43,000 ng/kg was under water exposing the environment and potential receptors to the dioxin. Repairs to this area were completed in 2016. Other instances of thin or absent rock cover were identified in 2012, 2013, and in 2016. No flood since the cap was constructed in 2011 has exceeded a 100-year return period design flood.

Monitoring and maintenance will be required for as long as the dioxin/furan represents an unacceptable risk should exposure occur. Dioxins and furans are persistent contaminates that will not readily break down. While there is much uncertainty regarding how long the waste materials will represent an unacceptable risk should exposure occur, however, the EPA estimates that, for dioxins that are not exposed to sunlight, the dioxin half-life ranges from 25 to 100 years.

5.1.3.4 Reduction of Toxicity, Mobility or Volume

There is no additional reduction of TMV due to treatment associated with this remedial alternative beyond that achieved during the temporary cap construction. However, some of the impacted sediments at the Site, found in the Western Cell, were treated and mobility reduced via S/S during the construction.

5.1.3.5 Short-Term Effectiveness

Short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative are limited to minimal turbidity associated with placement of armor rock, potential accidents during construction of the Upgraded Cap, air emissions from construction equipment, and truck traffic in the community. The evaluation of air emissions and truck traffic was conducted to provide a comparative basis from which to understand the relative impact of construction for each remedial action. It is acknowledged that there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site, and the presence of I-10.

Because of the limited duration of construction for this alternative (2 months), these risks are considered to be low. As compared to Alternatives 4N, 5N, 5aN, and 6N, this alternative is also estimated to require the fewest truck trips (260) during construction. The short duration of construction is correlated with relatively low greenhouse gas, PM, and ozone-generating emissions from the construction equipment. Water quality impacts from turbidity associated with placing the new armor rock are also low for this alternative because the armor rock fines that would create the turbidity would be from the rock acquired for the project and therefore not be chemically impacted. Further, risks of impacts due to storm events during construction are considered negligible because implementation does not require removing the existing temporary armored cap to complete the work, and there are no rigid barriers that could restrict flow during potential flood events.

Finally, because construction work, and in particular over-water work, presents a higher risk of accidental injury or death to workers, the limited duration of this alternative results in a relatively low safety risk. The remedy, like Alternatives 1N and 2N, would achieve full protection within the Site upon completion of construction. As additional sediment continues to be deposited within the USEPA's Preliminary Site Perimeter, $TEQ_{DF,M}$ concentrations in surface sediments would continue to decline to background levels (Appendix A) and the buried sediment near the sand separation area with $TEQ_{DF,M}$ concentrations exceeding the sediment PRG would be further isolated from potential receptors.

5.1.3.6 Implementability

There are limited implementability concerns associated with this remedial alternative. Construction of the Upgraded Cap will require the placement of additional cap material on underwater slopes. The feasibility of this construction technique was successfully demonstrated during the temporary cap construction, and experienced local contractors are available to complete this work. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data, which are routine procedures for qualified environmental consultants and laboratories. Establishing ICs is fairly routine, so no administrative implementability issues are anticipated to be associated with this remedial alternative.

Technical implementability issues include obtaining access to the project work area, limited availability of off-site locations for staging, material management, and barge access, and the low clearance under the I-10 Bridge, which limits the size of marine-based equipment that can access the project work area from the water. During the TCRA, a single off-site location was identified that could accommodate the armor rock stockpiling and barge loading, and that was available for lease during the temporary cap construction. The rock was stockpiled for barge loading over an approximate 1-acre footprint at the off-site staging area located upstream from the Site and along the San Jacinto River. This same location might not necessarily be available during the remedial construction phase.

5.1.3.7 Cost

The estimated present worth cost associated with this remedial alternative is $4.1 million (Appendix C). The capital costs for this remedial alternative are primarily associated with the construction of the Upgraded Cap, including development and operation of the off-site staging area. However, because the exact location and configuration of the off-site staging area are beyond the scope of this FS these elements may not be fully reflected in the FS estimated durations or costs.

The costs of preparing sampling plans, deed restrictions and notices, and a soil management plan are the same as those for Alternative 2N. The long-term costs are for monitoring and maintenance of the Upgraded Cap, collecting and analyzing environmental samples, evaluating the data, and preparing reports to document MNR. The cost estimate for this alternative also includes Upgraded Cap monitoring and maintenance and USEPA 5-year reviews as described in Appendix C, and also assumes available access to the Site by water from a location along the river and by land through the TxDOT ROW. The number of monitoring events is subject to approval by USEPA and may be changed.

5.1.3a Alternative 3aN - Enhanced Cap, Protective Pilings, ICs, Ground Water Monitoring, and MNR

5.1.3a.1 Overall Protection of Human Health and the Environment

This alternative will only remain protective if the cap is properly maintained for the length of time (hundreds of years) that the impounded waste retains its toxicity, and its integrity is not compromised by extreme weather events, barge strikes and/or changes in the river channel which could result in a future release. This remedial alternative would achieve the RAOs through a combination of active remedial construction, monitoring and cap maintenance, MNR addressing additional sediment deposition and implementation of ICs. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data.

The active component will include construction of further enhancements to the temporary armored cap, even beyond the approved temporary armored cap constructed in 2011 and modified in January 2014, and the improvements included for Alternative 3N. For costing purposes, the additional cap enhancements added for this alternative include pre-stressed concrete or concrete filled steel pipe pilings placed 30 feet apart around the perimeter of the cap to protect from barge strikes. The spacing is designed to catch a typical barge, which is 35 feet wide. An additional armor stone cap with a thickness of at least 24 inches would be placed over the armor cap for Alternative 3N. The armor stone would have a median diameter of 15 inches. This additional armor stone would cover 13.4 acres of the 17.1 acre armored cap. Also, a course gravel filter layer would be placed on 1.5 acres of the Northwest Area where there is currently no geotextile under the armor cap. The actual scope and design of the cap enhancements, and additional area needed to construct the required slopes, would be determined in the Remedial Design. This additional weight of rock on top of the waste pits may cause cap settling and/or pushing the waste material out the sides of the cap; the Remedial Design will consider the significance of and design issues related to this. MNR would be used to achieve the PRG for sediment in the Sand Separation Area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the sediment PRG and would be further isolated by deposition of additional clean sediment as described in Appendix A. MNR would also be used to achieve the Texas Surface Water Quality Standard in the San Jacinto River. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place. The actual scope and timeline of monitoring would be determined in coordination with USEPA during remedial design.

ICs would be used to:

- Alert property owners of the presence of subsurface materials exceeding PRGs.
- Describe the need for protective equipment and training if excavation of subsurface materials exceeding PRGs is required in the footprint of the Upgraded Cap.
- Describe requirements for the management of any excavated soil or sediment exceeding PRGs.
- Describe the need to restore the cap or clean cover soil in these areas following any disturbance.
- Establish limitations on dredging and anchoring within the footprint of the Upgraded Cap by requesting, in accordance with 33 CFR165.5, that the U.S. Coast Guard District Commander establish a regulated navigation area.

5.1.3a.2 Compliance with ARARs

Implementation of Alternative 3aN would involve the placement of fill material (the additional armor rock) into the San Jacinto River to create the Upgraded Cap. The placement of fill would trigger compliance with CWA Section 404(b)(1) and potentially other ARARs related to surface water quality standards. However, Alternative 3aN is expected to generally meet the substantive requirements of the ARARs in Table 3-1 through implementation of the BMPs and the agency coordination actions outlined in Section 3.4. Construction of the Enhanced Cap would require the placement of approximately 51,900 CY of additional cap armor rock material compared to Alternative 3N. Based on the results of modeling (Appendix A), the long-term change to the maximum water surface elevation following placement of the additional armor rock under this alternative is negligible.

5.1.3a.3 Long-Term Effectiveness

The long-term effectiveness of the existing temporary armored cap in this alternative is enhanced by adding larger armor rock to the cap. The armor rock that will be used to create the Enhanced Cap (Alternative 3aN) will meet or exceed cap design guidance and the recommendations made by USACE in its review of the cap design and construction, and a protective perimeter barrier would further increase the long-term effectiveness of the Upgraded Cap by protecting the cap from vessel traffic. However, the Enhanced Cap may not be able to reliably contain the waste material during an extreme storm as identified by the USACE. The USACE modeled the effect of an extreme storm for the cap described in Alternative 3N, showing an estimated 80% erosion of the cap, and while the USACE speculated that use of larger rock as in Alternative 3aN would reduce scour during such an extreme storm, it was not modeled. Ongoing deposition may result in declines in surface sediment concentrations, however, deposition rates are low in most areas, particularly shallow areas. Further, should the river geometry change as a result of extreme erosion that was documented during the 1994 flood, then the predicted deposition may not occur. Monitoring would confirm the continued deposition of new sediment isolating the affected sediment outside of the footprint of the temporary armored cap. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

The dioxin within the waste pits was generally isolated from potential receptors by the temporary cap, but the temporary cap has required many repairs and extensive maintenance. Examples include, in December 2015, an area of missing rock that was found by the EPA Dive Team. This area was not identified by the regular inspections that had been done since the temporary cap construction was completed. Dioxin at 43,000 ng/kg was under water exposing the environment and potential receptors to the dioxin. Repairs to this area were completed in 2016. Other instances of thin or absent rock cover were identified in 2012, 2013, and in 2016. No flood since the cap was constructed in 2011 has exceeded a 100-year return period design flood. As for the other capping alternatives, the USACE acknowledged considerable uncertainty regarding potential future failure mechanisms including changes in the river bed of the San Jacinto River.

Monitoring and maintenance be required for as long as the dioxin/furan represents an unacceptable risk should exposure occur. Dioxins and furans are persistent contaminants that will not readily break down. While there is much uncertainty regarding how long the waste materials will represent an unacceptable risk should exposure occur, however, the EPA estimates that, for dioxins that are not exposed to sunlight, the dioxin half-life ranges from 25 to 100 years.

5.1.3a.4 Reduction of Toxicity, Mobility or Volume

There is no additional reduction of TMV due to treatment associated with this remedial alternative beyond that achieved during the temporary cap construction. However, some of the impacted sediments at the Site, found in the Western Cell, were treated and mobility reduced via S/S during the construction.

5.1.3a.5 Short-Term Effectiveness

Short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative are limited to minimal turbidity associated with placement of armor rock, potential accidents during construction of the Enhanced Cap, air emissions from construction equipment, and truck traffic in the community. The evaluation of air emissions and truck traffic was conducted to provide a comparative basis from which to understand the relative impact of construction for each remedial action. It is acknowledged that there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site, and the presence of I-10.

Water quality impacts from turbidity associated with placing the new armor rock are also low for this alternative because the armor rock fines that would create the turbidity would be from the rock acquired for the project and therefore not be chemically impacted. Further, risks of impacts due to storm events during construction are considered negligible because implementation does not require removing the existing temporary armored cap to complete the work, and there are no rigid barriers that could restrict flow during potential flood events.

The remedy, like Alternatives 1N 2N, and 3N would achieve full protection within the Site upon completion of construction. As additional sediment continues to be deposited within the USEPA's Preliminary Site Perimeter, $TEQ_{DF,M}$ concentrations in surface sediments would continue to decline to background levels (Appendix A) and the buried sediment near the sand separation area with $TEQ_{DF,M}$ concentrations exceeding the sediment PRG should be further isolated from potential receptors.

5.1.3a.6 Implementability

There are limited implementability concerns associated with this remedial alternative. Construction of the Enhanced Cap will require the placement of additional cap material on underwater slopes. The feasibility of this construction technique was successfully demonstrated during the temporary cap construction, and experienced local contractors are available to complete this work. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data, which are routine procedures for qualified environmental consultants and laboratories. Establishing ICs is fairly routine, so no administrative implementability issues are anticipated to be associated with this remedial alternative.

Technical implementability issues include obtaining access to the project work area, limited availability of off-site locations for staging, material management, and barge access, and the low clearance under the I-10 Bridge, which limits the size of marine-based equipment that can access the project work area from the water. During the TCRA, a single off-site location was identified that could accommodate the armor rock stockpiling and barge loading, and that was available for lease during the temporary cap construction. The rock was stockpiled for barge loading over an approximate 1-acre footprint at the off-site staging area located upstream from the Site and along the San Jacinto River. This same location might not necessarily be available during the remedial construction phase.

5.1.3a.7 Cost

The estimated present worth cost associated with this remedial alternative is $24.8 million (Appendix C). The capital costs for this remedial alternative are primarily associated with the construction of the Enhanced Cap, including development and operation of the off-site staging area. However, because the exact location and configuration of the off-site staging area are beyond the scope of this FS these elements may not be fully reflected in the FS estimated durations or costs.

The costs of preparing sampling plans, deed restrictions and notices, and a soil management plan are the same as those for Alternative 3N. The long-term costs are for monitoring and maintenance of the Enhanced Cap, collecting and analyzing environmental samples, evaluating the data, and preparing reports to document MNR. The cost estimate for this alternative also includes Upgraded Cap monitoring and maintenance and USEPA 5-year reviews as described in Appendix C, and also assumes available access to the Site by water from a location along the river and by land through the TxDOT ROW. The number and scope of monitoring events will be determined during the Remedial Design.

5.1.4 Alternative 4N – Partial Solidification/Stabilization, Upgraded Cap, Institutional Controls, Ground Water Monitoring and Monitored Natural Recovery

5.1.4.1 Overall Protection of Human Health and the Environment

This alternative will only remain protective if the cap is properly maintained for the length of time (hundreds of years) that the impounded waste retains its toxicity, and its integrity is not compromised by extreme weather events, barge strikes and/or changes in the river channel which could result in a future release. This remedial alternative would achieve the RAOs through a combination of treatment, enhanced engineering controls, ICs and MNR. S/S would be used to immobilize soil/sediment in the Site with the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter was used to define the most highly contaminated material. S/S may add another level of protection to the temporary armored cap. A Upgraded Cap as described under Alternative 3N would be constructed following the S/S process. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

Affected sediment near the sand separation area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the PRG, may be further isolated by deposition of additional sediment as described in Appendix A.

Ongoing deposition may result in declines in surface sediment concentrations, however, deposition rates are low in most areas, particularly shallow areas. Further, should the river geometry change as a result of extreme erosion similar to that which was documented during the 1994 flood, then the predicted deposition may not occur. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. Monitoring of sediment conditions in this area would be performed to confirm that deposition of clean sediment was continuing to maintain $TEQ_{DF,M}$

concentrations in surface sediments to below the PRG for hypothetical recreational visitors. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

The MNR plan would include methods for assessing whether deposition or erosion were occurring at monitoring stations between monitoring events. The actual scope and timeline of monitoring would be determined in coordination with USEPA during remedial design.

ICs would be used to:

- Alert property owners of the presence of subsurface materials exceeding PRGs
- Describe the need for protective equipment and training if excavation of subsurface materials exceeding PRGs is required in the Upgraded Cap
- Describe requirements for the management of any excavated soil or sediment exceeding PRGs
- Describe the need to restore the cap or clean cover soil in these areas following any disturbance
- Establish limitations on dredging and anchoring within the footprint of the Upgraded Cap as described for Alternatives 2N and 3N.

This remedy, like Alternatives 1N through 3N, would achieve protection of human health and the environment in the Site upon implementation. As with the previous alternatives, additional clean sediment may continue to be deposited within the area of the USEPA's Preliminary Site Perimeter through ongoing natural recovery processes. $TEQ_{DF,M}$ concentrations in the surface sediments may decline, and the buried sediment near the sand separation area with $TEQ_{DF,M}$ concentrations exceeding the PRG may be further isolated from potential receptors. While ongoing deposition may result in declines in surface sediment concentrations, however, deposition rates are low in most areas, particularly shallow areas. Further, should the river geometry change as a result of extreme erosion similar to that which was documented during the 1994 flood, then the predicted deposition may not occur.

5.1.4.2 Compliance with ARARs

Implementation of Alternative 4N would trigger additional compliance requirements beyond those discussed in Section 5.1.3 due to the removal and replacement of the existing temporary armored cap, as well as the implementation of the S/S treatment. The removal and replacement of cap material would trigger compliance with CWA Section 404(b)(1) and other ARARs related to surface water quality standards. The S/S may result in a 20 percent increase in the volume of the sediment in the area of treatment because of bulking due to the addition of the stabilization amendment. Application of the S/S to approximately 52,000 CY of sediment is estimated to result in 60,000 to 65,000 CY of amended sediment. This increase in volume could trigger a need to review potential flood storage impacts with Federal Emergency Management Agency (FEMA) and Harris County. Based on preliminary hydrodynamic modeling, the long- term change to the maximum water surface elevation following stabilization under this alternative is estimated to be 0.01 feet, which is an indication that the effect of S/S is negligible and cannot be quantified within the predictive capability of the flood model. Should Alternative 4N be identified as the remedy, additional evaluations would be conducted to determine the potential habitat impacts related to the construction of the Permanent Cap, dredging, and backfill.

It is anticipated that Alternative 4N, through implementation of the BMPs and the agency coordination actions outlined in Section 3.4, would generally meet the substantive requirements of the remainder of the ARARs in Table 3-1.

5.1.4.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative is primarily derived from the construction of the Upgraded Cap and treating approximately 52,000 CY of sediment by S/S, combined with the natural recovery processes described previously. Flattening the slopes, where appropriate, as shown in Figures 4-3 and 4-4, would further increase the stability and long-term reliability of the containment as described in Section 5.1.3, and the protective perimeter barrier would provide additional long-term effectiveness. The stabilization of sediment with the highest $TEQ_{DF,M}$ concentrations exceeding 13,000 ng/kg would enhance the shear strength of the stabilized sediments. This alternative is also effective over the long-term because of declines in sediment surface concentrations due to natural recovery (Appendix A) throughout USEPA's Preliminary Site Perimeter. Ongoing deposition may result in declines in surface sediment concentrations, however, deposition rates are low in most areas, particularly shallow areas. Further, should the river geometry change as a result of extreme erosion similar to that which was documented during the 1994 flood, then the predicted deposition may not occur. As described in Section 5.1.2, ICs would protect the integrity of the Upgraded Cap. Monitoring would confirm the continued deposition of clean sediment isolating the affected sediment outside of the footprint of the Upgraded Cap. Because the waste material will remain in place in the San Jacinto River for this alternative, and Principal Threat waste above 300 ng/kg and up to 43,000 ng/kg would remain untreated, the potential exists that a release of waste material could occur as a result of a future extreme storm or hurricane, or the impact of a barge strike that may breach the cap during the hundreds of years that the dioxin/furan will remain hazardous. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

The dioxin within the waste pits was generally isolated from potential receptors by the temporary cap, but the temporary cap has required many repairs and extensive maintenance. Examples include, in December 2015, an area of missing rock that was found by the EPA Dive Team. This area was not identified by the regular inspections that had been done since the temporary cap construction was completed. Dioxin at 43,000 ng/kg was under water exposing the environment and potential receptors to the dioxin. Repairs to this area were completed in 2016. Other instances of thin or absent rock cover were identified in 2012, 2013, and in 2016. No flood since the cap was constructed in 2011 has exceeded a 100-year return period design flood.

Over the long-term, ongoing deposition may also act to reduce concentrations in sediments impacted by sediment residuals and releases within the USEPA's Preliminary Site Perimeter, however, as noted, deposition rates are low in most areas, particularly shallow areas.

5.1.4.4 Reduction of Toxicity, Mobility or Volume

This remedial alternative includes the use of S/S treatment to reduce the potential mobility of waste material and sediment exceeding 13,000 ng/kg. Approximately 52,000 CY of waste material in the waste pits would be treated in situ. Remedies that incorporate treatment address a key goal set by USEPA for cleanup projects, as documented in 40 CFR 300.430 (e)(9)(D), "The degree to which alternatives employ recycling or treatment that reduces toxicity, mobility or volume shall be assessed, including how treatment is used to address the principal threats posed by the site" and 40 CFR 300.430 (f)(1)(E), "Each remedial action shall utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable."

5.1.4.5 Short-Term Effectiveness

Potential resuspension and releases, as discussed in Section 4.1, present short-term risks for this alternative because mixing the stabilization reagent requires removing areas of the cap and disturbing the waste material, and engineered barrier controls are subject to leakage. The modeling presented in Appendix A demonstrates short-term water column impacts.

Treatment of the soil/sediment within the waste pits would require first removing the existing temporary armored cap armor rock, geotextile and geomembrane in the affected area. This would increase the potential risk of a release during construction of the most impacted in situ soil/sediment at the Site. To evaluate the risk of removing the temporary armored cap, a 3-year storm event was considered, which has an average predicted water surface elevation of 3.5 feet NAVD88 and would inundate portions of the work area, including the sheet pile enclosure shown in Figure 4-3. Such an event could result in resuspension and upstream/downstream transport of the waste material from the inundated portion of the construction footprint where the cap is removed. The removal of cap materials also increases the risk of releasing sediment adhering to those cap materials. These two mechanisms result in an increase in the short-term risk of recontamination beyond the limits of the work area.

Shallow mixing augers may be used to implement S/S with minimal exposure of workers to the impacted soil/sediment; however, isolating the soil/sediment with a sheet pile barrier has been included as a component of this alternative to manage the risk of exposure mentioned above, and to facilitate effective solidification in relatively dry conditions. In situ solidification of wet soil/sediments below surface water has not been widely demonstrated at full scale, and the presence of free water has been shown to inhibit the chemical reactions necessary to achieve effective S/S (e.g., Manitowoc River, Renholds 1998; Kita and Kubo 1983).

In addition, the use of sheet piles increases the risk of recontamination and resuspension of soil/sediments during sheet pile installation and removal (Ecology 1995), and potential cross-contamination associated with driving sheet piling through impacted materials into non-impacted material. However, the area and mass of contamination impacted by the sheet piles leading to potential recontamination and resuspension of contaminated sediment during installation and removal are a small fraction of the reduction in potential releases achieved by their use over that of other BMPs such as silt curtains. Further, cross-contamination associated with driving sheet piling through impacted materials into non-impacted material does not pose additional risk because there would not be any exposure to the underlying materials, besides being of limited mass.

In addition to these environmental risks, construction for this alternative is estimated to require 1,600 truck trips. This alternative would have higher greenhouse gas, PM, and ozone impacts associated with construction emissions from equipment as compared to the previous alternatives. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. From a worker safety perspective, there is also a moderate risk of accidental injury to workers during construction.

5.1.4.6 Implementability

The implementation of this remedial alternative, particularly the treatment of soil/sediment after removal of the temporary armored cap, would be more challenging than implementation of Alternative 3N or 3aN. Stabilization of soil/sediment in the floodplain and subtidal areas will require precautions, such as the use of a sheet pile barrier wall to minimize potential releases of materials once the temporary armored cap is removed. Even with those precautions, because of the disturbance of sediments caused by removing the temporary armored cap, and the additional handling of previously undisturbed sediments during the S/S process, the release of some of these impacted materials into the river or onto the surface of the undisturbed parts of the temporary armored cap may be unavoidable, particularly if a storm or high water levels were to occur during construction. The results from chemical fate model simulations presented in Appendix A indicate that short-term increases in surface water concentrations could occur during the construction.

In addition, stabilization in areas that are normally below surface water increases the difficulty in successful implementation of this alternative. Construction of the Upgraded Cap following S/S would be implementable with challenges as generally noted under Alternative 3N for armor rock placement. Monitoring would involve collecting and analyzing sediment samples and evaluating the data, which are routine procedures for qualified environmental consultants and laboratories. Establishing ICs is routine, so there are no significant administrative implementability issues associated with this remedial alternative. As with Alternative 3N and 3aN, technical implementability issues include obtaining access to the project work area, limited availability of off-site locations for staging, material management, and barge access, and the low clearance under the I-10 bridge, which limits the size of marine-based equipment that can access the project work area from the water. As described under Alternative 3N, a 1-acre footprint was required for the off-site staging area to manage the rock stockpile. Because this alternative also requires treatment reagents, additional space could be necessary for the off-site staging area. This location used for the off-site staging area during the temporary cap construction might not necessarily be large enough to accommodate the work, or might not be available during the remedial construction phase.

5.1.4.7 Cost

The estimated present worth cost associated with this remedial alternative is $14.8 million (Appendix C). The capital costs for this remedial alternative are primarily associated with the S/S process and construction of the Upgraded Cap, including development and operation of the off-site staging area. However, because the exact location and configuration of the off-site staging area are beyond the scope of this FS these elements may not be fully reflected in the FS estimated durations or costs.

The costs of preparing sampling plans, deed restrictions and notices, and a soil management plan are the same as those for remedial Alternative 2N. The long-term costs are for monitoring the condition of the Upgraded Cap, collecting and analyzing environmental samples, evaluating the data, preparing reports to document MNR, and monitoring and maintenance of the Upgraded Cap. The estimated cost of this alternative includes USEPA 5-year reviews and also assumes available access to the Site by water from a location along the river and by land through the TxDOT ROW. The assumed number of monitoring events is discussed in Appendix C; the actual number of monitoring events is subject to approval by USEPA.

5.1.5 Alternative 5N – Partial Removal, Upgraded Cap, Institutional Controls, Ground Water Monitoring and Monitored Natural Recovery

5.1.5.1 Overall Protection of Human Health and the Environment

This alternative will only remain protective if the cap is properly maintained for the length of time (hundreds of years) that the impounded waste retains its toxicity, and its integrity is not compromised by extreme weather events, barge strikes and/or changes in the river channel which could result in a future release. This remedial alternative achieves the RAOs through a combination of soil/sediment removal, enhanced engineering controls, MNR and ICs. Following removal of portions of the existing temporary armored cap, soil and sediment with $TEQ_{DF,M}$ concentrations greater than the USEPA-identified limit of 13,000 ng/kg $TEQ_{DF,M}$ would be removed, dewatered, and transported off-site for disposal. The sediment removal area would be backfilled and a Upgraded Cap as described in Alternative 3N would be constructed following removal of the soil/sediment. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

Affected sediment near the sand separation area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the sediment PRG, may be further isolated by deposition of additional sediment as described in Appendix A. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. Monitoring of sediment conditions in this area would be performed to confirm that deposition of new sediment was continuing to maintain $TEQ_{DF,M}$ concentrations in surface sediments below the sediment PRG for protection of hypothetical recreational visitors. The MNR plan would include methods for assessing whether deposition or erosion was occurring. Appendix C describes cost assumptions used in this FS Report for MNR monitoring. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place. The actual scope and timeline of monitoring would be determined in coordination with USEPA during remedial design.

ICs would be used to:

- Alert property owners of the presence of remaining subsurface material exceeding PRGs
- Describe the need for protective equipment and training to limit exposure to contaminants if future additional excavation is required in the footprint of the Upgraded Cap
- Describe requirements for the management of any excavated soil or sediment
- Describe the need to restore the cap or clean cover soil in these areas following any disturbance
- Establish limitations on dredging and anchoring within the footprint of the Upgraded Cap as described in Alternatives 2N to 4N.

5.1.5.2 Compliance with ARARs

Implementation of Alternative 5N would include the removal of portions of the existing temporary armored cap, removal of underlying soil/sediment, and transportation of sediment to an upland disposal facility. The removal of the temporary armored cap and placement of rock for Upgraded Cap construction would trigger compliance with CWA Section 404(b)(1) and along with the dredging action would trigger other ARARs related to surface water quality standards. Should Alternative 5N be identified as the remedy, additional evaluations would be conducted to determine the potential habitat impacts related to the construction of the Upgraded Cap, dredging, and backfill.

The removal of sediment would require the construction of an off-site material handling facility near the work area to offload barges, manage waste, stockpile and dewater sediment, and load these materials onto trucks or rail cars for off-site disposal. The construction and operation of the material handling facility may require substantial compliance with relevant permit requirements.

Removal of impacted soil from the remedial action areas to an off-site disposal facility would require compliance with ARARs related to dust emissions, storm water controls, and disposal. Appropriate storm water and air-quality controls would be used to protect air and water quality. Equipment leaving the work site would be decontaminated as needed to prevent tracking impacted soil on public roads, and each load of soil would be tracked to confirm that the material was received by the designated disposal facility.

Construction of the Upgraded Cap would require the placement of approximately 3,400 CY of additional cap armor rock material. Hydrodynamic modeling was performed to confirm that the placement of the additional armor rock would not significantly affect flood-storage capacity in the San Jacinto River (Appendix A). Based on the results of this modeling, the long-term change to the maximum water surface elevation following placement of the additional armor rock under this alternative is estimated to be -0.01 to -0.02 feet, which is an indication that the effect of rock placement is negligible and immeasurable within the predictive capability of the flood model.

Alternative 5N would be expected, through implementation of the BMPs and the agency coordination actions outlined in Section 3.4, to generally meet the substantive requirements of the ARARs in Table 3-1.

5.1.5.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative is primarily derived from the construction of the Upgraded Cap and removing a substantial percentage of the highest concentration material (approximately 52,000 CY) from the Site, combined with natural recovery as described previously. Because the waste material under 13,000 ng/kg will remain in place in the San Jacinto River for this alternative, the potential exists that a release of waste material could occur as a result of a future extreme storm or hurricane, or the impact of a barge strike that may breach the cap during the hundreds of years that the dioxin/furan will remain hazardous.

The dioxin within the waste pits was generally isolated from potential receptors by the temporary cap, but the temporary cap has required many repairs and extensive maintenance. Examples include, in December 2015, an area of missing rock that was found by the EPA Dive Team. This area was not identified by the regular inspections that had been done since the temporary cap construction was completed. Dioxin at 43,000 ng/kg was under water exposing the environment and potential receptors to the dioxin. Repairs to this area were completed in 2016. Other instances of thin or absent rock cover were identified in 2012, 2013, and in 2016.

No flood since the cap was constructed in 2011 has exceeded a 100-year return period design flood.

Ongoing deposition from natural recovery processes may also act to reduce concentrations impacted by sediment residuals and releases within the USEPA's Preliminary Site Perimeter over the long-term, however, deposition rates are low in most areas, particularly shallow areas.

The removal of waste material with $TEQ_{DF,M}$ concentrations exceeding 13,000 ng/kg eliminates a potential future source of high concentration sediments from the waste pits. Flattening the slopes, where appropriate, as shown in Figures 4-3 and 4-4, and the other work to be performed in constructing the Upgraded Cap, would further increase the stability and long-term reliability of the containment as described in Section 5.1.3. This alternative is also effective over the long-term because of declines in sediment surface concentrations due to natural recovery throughout USEPA's Preliminary Site Perimeter. As described in Section 5.1.2, ICs would protect the integrity of the Upgraded Cap and the layer of clean surface soil. Monitoring would confirm the continued deposition of clean sediment isolating the affected sediment outside of the footprint of the Upgraded Cap. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

5.1.5.4 Reduction of Toxicity, Mobility or Volume

This remedial alternative would reduce the volume of material exceeding the waste material PRGs within the USEPA's Preliminary Site Perimeter. Approximately 52,000 CY of paper mill waste material in the waste pits would be removed for disposal. Sediment dewatering by amendment prior to transporting for disposal may reduce the potential mobility of contaminants during transportation and at the disposal facility.

5.1.5.5 Short-Term Effectiveness

Potential resuspension and releases, as discussed in Section 4.1.1, present short-term risks for this alternative because of the dredging, and engineered barrier controls are subject to leakage. However, the actual levels would be reduced by the use of BMPs during construction, including de-watering and excavation in the dry.

Removal of sediment under this alternative would require first removing the existing temporary armored cap armor rock, geotextile and geomembrane in the affected area. This would increase the potential risk of a release during removal of soil/sediment with concentrations exceeding 13,000 $TEQ_{DF,M}$. To evaluate the risk of removing the temporary armored cap, a 3-year storm was considered, which has an average predicted water surface elevation of 3.5 feet NAVD88 and would inundate portions of the work area, including the sheet pile enclosure shown in Figure 4-3. Such an event could result in resuspension and upstream/downstream transport of sediments from the inundated portion of the construction footprint where the cap is removed. For this reason, it may be necessary to conduct the work by removing only small portions of the cap at a time, and provide cover for any residuals before starting the next area.

In addition to a storm event as described above, releases would also be expected during dredging with potential sediments impacted by releases of dioxins and furans potentially settling onto areas within the USEPA's Preliminary Site Perimeter, and potentially causing temporary increases in surface water and tissue concentrations for various COCs. However, the actual levels would be reduced by the use of BMPs during construction, including de-watering and excavation in the dry. Even with those precautions, it would be difficult to avoid releasing any of these materials exceeding their PRGs into the river or onto the surface of the undisturbed parts of the Upgraded Cap. That risk would be increased if a storm or high water levels were to occur during construction, as described previously. It will be necessary to prepare a contingency plan as part of the Remedial Design in order to develop best practices to prevent, contain or manage any such release.

Additional environmental risks include the possibility of spills during transportation to the disposal facility and possible releases from the off-site landfill itself. In addition to these environmental risks, as compared to the previous four alternatives, construction for this alternative is estimated to require 9,300 truck trips. This alternative would have higher greenhouse gas and PM. impacts and ozone generating emissions associated with construction emissions from equipment operating within the project work area, as well as from equipment required for transportation and disposal of excavated sediments. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. From a worker safety perspective, there is a low to moderate risk of accidental injury to workers during construction. The remedy would achieve protection in the Site upon completion of construction. As additional clean sediment continues to be deposited throughout the USEPA's Preliminary Site Perimeter, $TEQ_{DF,M}$ concentrations in surface sediments may continue to decline and the buried sediment near the sand separation area with $TEQ_{DF,M}$ concentrations exceeding the sediment PRG would be further isolated from potential receptors.

5.1.5.6 Implementability

There are several implementability concerns associated with this remedial alternative. As discussed above, removal of sediment in the floodplain would require the use of engineering controls to minimize any releases of impacted sediment during construction and some releases to the surrounding environment could occur as described in Section 4.1.

Further, on-site space is very limited to accommodate contractor access, staging, stockpiling materials, and managing excavated sediment for transportation to an off-site disposal site. An off-site facility would need to be identified and secured to manage dredged materials (including dewatering, transloading, and shipping) and to stockpile and load imported armor rock. Given the nature of the material being managed at the off-site facility, locating a suitable property and willing landowner could be a challenge. During the temporary cap construction, a single off-site location was identified that could accommodate the armor rock stockpiling and barge loading, and that was available for lease during the construction. The rock was stockpiled for barge loading over an approximate 1-acre footprint at the off-site staging area located upstream from the site and along the San Jacinto River. This same location might not necessarily be compatible with managing dredged waste material, which can require a relatively large footprint for processing, and/or might not be available during the remedial construction phase. For example, the Port Gamble Interim Action dredging, which required excavation of 16,500 CY of material, required a dredge material stockpile footprint of approximately 3 acres in size (Hart Crowser 2007).

Replacement of the cap following sediment removal and backfilling would be implementable as noted for Alternative 3N. Monitoring would involve collecting and analyzing sediment samples and evaluating the data, which are routine procedures for qualified environmental consultants and laboratories. Establishing ICs is routinely done, so there are not anticipated to be administrative implementability issues associated with this remedial alternative either.

5.1.5.7 Cost

The estimated present worth cost associated with this remedial alternative is $29.8 million (Appendix C). The capital costs for this remedial alternative are primarily associated with the sediment removal and disposal and construction of the Upgraded Cap, including development and operation of the off-site staging area. However, because the exact location and configuration of the off-site staging area are beyond the scope of this FS these elements may not be fully reflected in the FS estimated durations or costs.

The costs of preparing sampling plans, deed restrictions and notices, and a soil management plan are the same as those for Alternative 2N. The long-term costs are for monitoring the condition of the Upgraded Cap, collecting and analyzing environmental samples, evaluating the data, preparing reports to document the MNR, maintenance of the Upgraded Cap, and USEPA 5-year reviews. Assumptions regarding monitoring and maintenance are described in Appendix C. The actual monitoring requirements and number of monitoring events will be subject to approval by USEPA and would be determined during remedial design. The estimated cost of this alternative assumes available access to the Site by water from a location along the river and by land through the TxDOT ROW.

5.1.6 Alternative 5aN – Partial Removal of Materials Exceeding the PRG, Upgraded Cap, Institutional Controls, Ground Water Monitoring and Monitored Natural Recovery

5.1.6.1 Overall Protection of Human Health and the Environment

This alternative will only remain protective if the capn is properly maintained for the length of time (hundreds of years) that the impounded waste retains its toxicity, and its integrity is not compromised by extreme weather events, barge strikes and/or changes in the river channel which could result in a future release. This remedial alternative would achieve the RAOs through a combination of waste material removal, capping, ICs and MNR. Waste material in the TCRA Site where the water depth is 10 feet or less and with $TEQ_{DF,M}$ concentrations exceeding the hypothetical recreational visitor PRG (200 ng/kg), plus waste material that exceed 13,000 ng/kg $TEQ_{DF,M}$ in any water depth, would be removed, dewatered, and transported to a permitted landfill for disposal. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River.

This alternative would require partial removal of the armored cap. Soil/sediment removal would be performed behind an engineered barrier, including a berm in shallow water areas of the project work site, and a sheet pile in deeper water areas of the project work site. Following removal of the soil/sediment, a two layer residuals cover would be placed.

An Upgraded Cap as described under Alternative 3N would be constructed in the area of the Site where the waste material PRG is exceeded but the water is deeper than 10-feet.

Affected sediment near the sand separation area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the sediment PRG, may be further isolated by deposition of additional sediment as described in Appendix A. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. Monitoring of sediment conditions in this area would be performed to confirm that deposition of new sediment was continuing to maintain

$TEQ_{DF,M}$ concentrations in surface sediments below the PRG for protection of hypothetical recreational visitors and fishers. The MNR plan would include methods for assessing whether deposition and erosion were occurring. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place. MNR monitoring assumptions are described in more detail in Appendix C. The actual scope and timeline of monitoring would be determined in coordination with USEPA during remedial design.

ICs would be used to:

- Alert property owners of the presence of remaining subsurface material exceeding PRGs
- Describe requirements for the management of any excavated soil or sediment
- Describe the need to restore the Upgraded Cap or clean cover soil in these areas following any disturbance
- Establish limitations on dredging and anchoring within the footprint of the Upgraded Cap as described in Alternatives 2N to 5N.

5.1.6.2 Compliance with ARARs

Alternative 5aN would generally trigger the same compliance requirements as Alternative 5N. If Alternative 5aN is identified as the preferred alternative, additional evaluations would need to be conducted to determine the potential habitat impacts related to impacts of dredging and placement of clean residual layer management materials to document compliance with CWA Section 404(b)(1) and other natural resource based ARARs.

Removal of impacted soil from the remedial action areas to an off-site disposal facility would require compliance with ARARs related to dust emissions, storm water controls, and disposal. Appropriate storm water and air-quality controls would be used to protect air and water quality. Equipment leaving the work site would be decontaminated as needed to prevent tracking impacted soil on public roads, and each load of soil would be tracked to confirm that the material was received by the designated disposal facility.

Removal of sediments and placement of a residuals cover would result in a net lowering of the mudline in the work area. Hydrodynamic modeling was performed to evaluate the effect of this change on flood-storage capacity in the San Jacinto River (Appendix A). Based on the results of this modeling, the long-term change to the maximum water surface elevation following dredging and residuals management placement is estimated to be -0.04 to -0.05 feet, which may not be measurable using the predictive capability of the flood model.

BMPs will be incorporated into the Remedial Design as necessary to support water quality and attainable use standards for this section of the San Jacinto River as described in Section 3.3.1 above. On-site water discharges will comply with the substantive technical requirements of the Clean Water Act, but do not require a permit. A water treatment system will be designed as necessary during the Remedial Design to meet the discharge requirements.

5.1.6.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative is primarily derived from the removal of soil and sediment and the enhancement of the existing temporary armored cap. Approximately 137,600 CY of soil and sediment would be removed from beneath the existing temporary armored cap. The anticipated limits of the excavation are shown in Figures 4-5 and 4-6. The dredging activity would result in a reduction in the volume of soil/sediment with concentrations above 200 mg/kg $TEQ_{DF,M}$; however, a residual layer of impacted material with $TEQ_{DF,M}$ above 200 mg/kg may remain at the bottom of the excavated surfaces due to dredging-related releases as described in Section 4.1. The concentration of those residual materials would likely require at least two layers of clean sediment residuals cover across the dredge footprint. Because the waste material will remain in place in the San Jacinto River for this alternative, the potential exists that a release of waste material could occur as a result of a future extreme storm or hurricane, or the impact of a barge strike that may breach the cap during the hundreds of years that the dioxin/furan will remain hazardous. Over the long-term, ongoing deposition may also act to reduce concentrations associated with dredge residuals and releases within the USEPA's Preliminary Site Perimeter, however, deposition rates are low in most areas, particularly shallow areas. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

5.1.6.4 Reduction of Toxicity, Mobility or Volume

This remedial alternative would remove most of the waste materials exceeding the waste material PRGs from within the USEPA's Preliminary Site Perimeter. Approximately 137,600 CY of waste material would be removed from within the USEPA's Preliminary Site Perimeter for disposal. Sediment dewatering by amendment prior to transporting the waste material to a landfill for disposal would reduce the potential mobility of constituents during transportation and at the disposal facility. Water generated from sediment dewatering would need to be treated on-site for discharge, or collected and transported off-site for disposal.

5.1.6.5 Short-Term Effectiveness

Potential resuspension and releases, as discussed in Section 4.1.1, present short-term risks for this alternative. The engineered barrier controls are subject to leakage and may occur during construction even with the use of BMPs. The water column impacts associated with Alternative 5aN is estimated to increase the annual average water column concentration of TCDD, however, the actual levels would be reduced by the use of BMPs during construction, including de-watering and excavation in the dry.

Removal of waste material from the waste pits would require first removing the existing temporary armored cap in the affected area. This would increase the potential risk of a release during construction of sediments containing the highest concentrations of dioxins and furans detected within USEPA's Preliminary Site Perimeter if a storm or flood event were to compromise the perimeter barrier, when sediments that are currently capped would be exposed. To evaluate the risk of removing the temporary armored cap, a 3-year storm was considered, which has an average predicted water surface elevation of 3.5 feet NAVD88 and would inundate portions of the work area, including overtopping the perimeter berm and the sheet pile enclosure. Such an event could result in resuspension and upstream/downstream transport of the waste material from the inundated portion of the construction footprint where the cap is removed. For this reason, the USACE recommended removing only small areas of the cap at time to minimize potential releases.

In addition, short-term water quality impacts would occur due to dredging operation releases (Appendix A). Surface water 2,3,7,8-TCDD concentrations within the USEPA's Preliminary Site Perimeter would be predicted to increase, however, the actual levels would be reduced by the use of BMPs during construction. These releases would also be expected to increase tissue concentrations in the early years following remedy implementation and also result in slight increases in surface sediment concentration in surrounding areas.

In addition to these environmental risks, construction for this alternative is estimated to require 12,855 truck trips. Relative to the other alternatives, this alternative would have high greenhouse gas, PM, and ozone impacts associated with construction emissions from equipment operating in the work areas, as well as from equipment required for off-site transportation and disposal of excavated sediments. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. From a worker safety perspective, there is a moderate to high risk of accidental injury to workers during construction. The remedy would be intended to achieve full protection upon completion of construction; however, there could be short-term releases of dioxins and furans to the surrounding environment during implementation that would be unavoidable and could affect the water column, increase sediment concentrations beyond the work area, and increase tissue concentrations of COCs.

5.1.6.6 Implementability

There are implementability concerns associated with this remedial alternative. On-site space is limited to accommodate access, staging and stockpiling materials and excavated sediment for transportation to an off-site disposal site. The considerations discussed under Alternative 5N for locating and securing an off-site material handling area are also applicable to this alternative. Given the scope and scale of this alternative, it is likely that a relatively large river-side property near the work area would need to be leased for the duration of the work to accommodate staging, material processing, stockpiling, and transloading of materials. The logistical concerns over locating and securing a suitable off-site material handling area would be more for this remedial alternative than for the partial removal (Alternative 5N) because of the longer duration of the project (19 months versus 13 months) and the greater extent of the removal area, which would leave less on-site upland space for managing materials, as well as the greater volume of material removed which could require a larger off-site location. There may be greater community impacts (traffic, noise, air emissions, etc.) during implementation. Finally, the volume of material removed could have an impact on the capacity of available landfills; thus the acceptance of this amount of material for disposal is uncertain. Establishing ICs is routinely done, so there are not any anticipated administrative implementability issues associated with this remedial alternative.

5.1.6.7 Cost

The estimated present worth cost associated with this remedial alternative is $69.6 million. The capital costs for this remedial alternative are primarily associated with the waste material removal and disposal and construction of the Upgraded Cap, including development and operation of the off-site staging area. However, because the exact location and configuration of the off-site staging area are beyond the scope of this FS these elements may not be fully reflected in the FS estimated durations or costs.

The long-term costs are for monitoring the condition of the Upgraded Cap, collecting and analyzing environmental samples, evaluating the data, preparing reports to document the MNR, maintenance of the Upgraded Cap, and USEPA 5-year reviews. Cost assumptions regarding monitoring and maintenance are described in Appendix C. The actual monitoring requirements and number of monitoring events will be subject to approval by USEPA and would be determined during remedial design. Further details on the cost assumptions for this alternative are presented in Appendix C.

5.1.7 Alternative 6N – Full Removal of Waste Materials Exceeding the PRG, MNR, and Institutional Controls

5.1.7.1 Overall Protection of Human Health and the Environment

Alternative 6N best realizes the Threshold Criteria (protecting human health and the environment) because the waste material would be removed and therefore not subject to a potential future release. This remedial alternative would achieve the RAOs through a combination of waste material and /sediment removal and ICs (for the residuals following removal). Waste material in the temporary cap site exceeding the waste material PRG (200 ng/kg) would be removed, dewatered, and transported to a permitted landfill for disposal. As for Alternatives 5N and 5aN, complete removal of materials exceeding the PRG may not be possible for all areas because of dredging residuals, which will leave a layer material exceeding PRGs that will need to be managed by placing a two layer post-dredge clean cover. MNR would be used to achieve the PRG for sediment (30 ng/kg) in the sand separation area and the Texas Surface Water Quality Standard in the San Jacinto River. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data.

ICs would be used to:

- Alert property owners of the presence of remaining subsurface material exceeding PRGs.
- Describe requirements for the management of any excavated soil or sediment.
- Describe the need to restore the residuals cover soil in areas exceeding the PRGs following any disturbance.
- Establish limitations on dredging and anchoring within the footprint of the residuals cover.
- Alert property owners of the presence of remaining subsurface material exceeding PRGs, if necessary.

5.1.7.2 Compliance with ARARs

Implementation of Alternative 6N would generally trigger the same compliance requirements as Alternatives 5N and 5aN. Selection of Alternative 6N will require additional evaluations to be conducted to determine the potential habitat impacts related to impacts of waste material and sediment removal and placement of clean residual layer management materials to document compliance with CWA Section 404(b)(1) and other natural-resource based ARARs. Removal of waste materials and sediments and placement of a residuals cover would result in a net lowering of the mudline in the work area. The construction of any of the proposed Alternatives is not expected to cause any flooding in the vicinity of the Site, and therefore should not require the implementation of any flood control measures during the construction of any of the Alternatives under consideration by the EPA.

BMPs will be incorporated into the Remedial Design as necessary to support water quality and attainable use standards for this section of the San Jacinto River as described in Section 3.3.1 above. On-site water discharges will comply with the substantive technical requirements of the Clean Water Act, but do not require a permit. A water treatment system will be designed as necessary during the Remedial Design to meet the discharge requirements.

5.1.7.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative is derived from the removal of waste material and sediment exceeding their respective PRGs. Approximately 152,000 CY of waste material would be removed from the waste pits. The anticipated limits of the excavation are shown in Figures 4-5 and 4-6. The removal activity would reduce the volume of waste material with concentrations above 200 mg/kg; however, a residual layer of contaminated materials may remain at the bottom of the excavated surfaces as explained relative to Alternative 5aN. The concentration of those residual materials would be similar to the removed materials and would likely require two clean sediment residuals cover layers across the dredge footprint for greater protectiveness. Sediment in the vicinity of the sand separation area is currently stable and net sedimentation in this area is expected to provide continued isolation at this buried location; however, propeller wash from tug boat operations could disturb these sediments. Monitoring would confirm the continued deposition of clean sediment isolating the affected sediment outside of the footprint of the Permanent Cap.

Alternative 6N would not result in the potential for a future release due to an extreme storm or hurricane, nor the impacts of a barge strike or erosion from propwash or changes in the river bed channel as is the case for all of the other alternatives because the waste material has been removed. Over the long-term, ongoing deposition should also act to reduce dioxin TEQ $_{DF,M}$ concentrations in sediment associated with dredge residuals and releases within the USEPA's Preliminary Site Perimeter.

5.1.7.4 Reduction of Toxicity, Mobility or Volume

This remedial alternative would use sediment dewatering by amendment to reduce the mobility of COCs during transportation and at the disposal facility. Approximately 152,000 CY of waste material and sediment with TEQ $_{DF,M}$ concentrations exceeding their PRGs would be removed from within the USEPA's Preliminary Site Perimeter for disposal. Water generated from sediment dewatering would need to be treated on-site for discharge, or collected and transported off-site for disposal.

5.1.7.5 Short-Term Effectiveness

Potential resuspension and releases, as discussed in Section 4.1.1, present short-term risks for this alternative. However, these short term risks would be mitigated by the use of BMPs and engineering controls to reduce resuspension. Containment structures to reduce resuspension would consist of berms and sheet pile walls or caissons to an elevation of about +10 NAVD88 (protection from 25-year or 50-year flood stage). If performing excavation of the waste materials in the dry, the top of the berms would preferably be no lower than +5 NAVD88 (protection from 5-year or 10-year flood stage). The USACE estimated in the 2016 Alternatives Evaluation report that there could be releases of approximately 0.2% of the total waste material if all excavations in the northern waste pits can be performed behind sheet pile walls with most of the excavation in the dry and the Northwest Cell can be protected by sheet pile walls; and approximately 0.34% of the total waste materials could be released if the removal of the Northwest Cell is performed behind silt curtains.

Removal of waste material from the Site would require first removing the existing temporary armored cap in the affected area. This would increase the potential risk of a release during removal of sediment with the highest TEQ $_{DF,M}$ concentrations within the USEPA's Preliminary Site Perimeter, particularly if a storm or flood event occurred, when the sediment that is currently capped would be exposed. To evaluate the risk of removing the temporary armored cap, a 3-year storm was considered, which has an average predicted water surface elevation of 3.5 feet NAVD88 and would inundate portions of the work area. This risk can be reduced through the removal of only small areas of the cap at any one time.

In addition to these environmental risks, construction for this alternative is estimated to require 17,500 truck trips. Relative to the other alternatives, this alternative would have higher greenhouse gas, PM, and ozone impacts associated with construction emissions from equipment operating in the work areas, as well as from equipment required for off-site transportation and disposal of excavated sediments. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. From a worker safety perspective, there is a moderate to high risk of accidental injury to workers during construction. The remedy would be intended to achieve full protection upon completion of construction; however, there may be releases of dioxins and furans to the surrounding environment during implementation that would be unavoidable and would affect the water column, increase sediment concentrations beyond the work area, and increase tissue concentrations of COCs in the short-term.

5.1.7.6 Implementability

There are several implementability concerns associated with this remedial alternative. As discussed above, removal of waste materials in the floodplain would require the use of engineering controls to minimize the release of contaminated sediment during construction; nevertheless some loss is expected based on documented case histories and published guidance even with the use of those controls. It would be extremely difficult to avoid releasing impacted materials into the river, particularly if a storm or high water levels occur during construction. During the Remedial Design, it will be necessary to identify BMPs to minimize the potential release of impacted materials into the river, and to develop a contingency plan to minimize, if possible, any releases that do occur.

Further, on-site space is limited to accommodate access, staging and stockpiling materials and excavated sediment for transportation to an off-site disposal site. The considerations discussed under Alternatives 5N and 5aN for locating and securing an off-site material handling area are also applicable to this alternative. However, the logistical concern over locating and securing an off-site facility would be more significant for this remedial alternative than for Alternative 5N because of the longer duration of the project and the greater volume of material removed than that required for Alternatives 5N and 5aN, and which would have greater community impacts (traffic, noise, air emissions, etc.) during implementation. Given the scope and scale of this alternative, it is likely that a larger river-side property near the work area would need to be leased for the duration of the work to accommodate staging, material processing, stockpiling, and transloading of materials. The need for such an area adds additional complexity to this alternative. Finally, the volume of material removed could have an impact on the capacity of available landfills; thus the acceptance of this amount of material for disposal is less certain. Establishing ICs is routine, so there are no anticipated administrative implementability issues associated with this part of the remedial alternative.

5.1.7.7 Cost

The estimated present worth cost associated with this remedial alternative is $87 million. The capital costs for this remedial alternative are primarily associated with the waste material removal and disposal, including development and operation of the off-site staging area. However, because the exact location and configuration of the off-site staging area are beyond the scope of this FS these elements may not be fully reflected in the FS estimated durations or costs.

The long-term costs are for collecting and analyzing environmental samples, evaluating the data, and preparing reports to document USEPA 5-year reviews. The costs of preparing sampling plans, deed restrictions and notices, and a soil management plan are the same as those for remedial Alternative 2N. Cost assumptions regarding monitoring and maintenance for this alternative are described in Appendix C. The actual monitoring requirements and number of monitoring events will be subject to approval by USEPA and would be determined during remedial design. Further details on the cost assumptions for this alternative are presented in Appendix C.

5.2 Area South of I-10

5.2.1 Alternative 1S – No Further Action

5.2.1.1 Overall Protection of Human Health and the Environment

This remedial alternative would not be protective of human health and the environment. Although the subsurface soil is isolated from potential receptors by several feet of soil with $TEQ_{DF,M}$ concentrations below the soil PRG for the hypothetical future construction worker, this exposure scenario considers excavation and potential exposure to subsurface soil to a depth of 10-feet below grade. In the absence of controls, soil that is currently isolated from receptors by depth could potentially be excavated and placed on the surface.

5.2.1.2 Compliance with ARARs

Alternative 1S would not result in construction impacts or other changes to baseline conditions that would trigger any action-, chemical-, or location-specific ARARs identified in Table 3-1.

5.2.1.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative was evaluated considering the potential for natural forces or human activity to expose the sediment or soil with $TEQ_{DF,M}$ concentrations that exceed the soil PRG. If no action is taken to alert future property owners or construction workers to the presence of subsurface soil with $TEQ_{DF,M}$ concentrations above the PRG, workers performing excavation in the specific areas shown in Figure 4-11 could be exposed to elevated $TEQ_{DF,M}$ concentrations.

5.2.1.4 Reduction of Toxicity, Mobility or Volume

There is no reduction of TMV due to treatment associated with this remedial alternative.

5.2.1.5 Short-Term Effectiveness

There are no short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative.

5.2.1.6 Implementability

There are no technical or administrative implementability issues associated with this remedial alternative.

5.2.1.7 Cost

The estimated present worth cost associated with this remedial alternative is $0 (Appendix C).

5.2.2 Alternative 2S – Institutional Controls and Ground Water Monitoring

5.2.2.1 Overall Protection of Human Health and the Environment

This remedial alternative would achieve the RAOs through the implementation of ICs. The following ICs would be implemented:

- Deed restrictions would be applied in the area south of I-10 where the depth-weighted average $TEQ_{DF,M}$ concentrations in upper 10-feet of subsurface soil exceed the soil PRG for the hypothetical future construction worker.

- Notices would be attached to deeds of affected properties to alert potential future purchasers of the presence of waste and soil with $TEQ_{DF,M}$ concentrations exceeding the soil PRG.

Notifying future property owners and construction workers would address the exposure pathway to impacted soil. Potential health risks to hypothetical future construction workers would be addressed by the implementation of this remedial alternative. The ICs would provide protection against anthropogenic disturbance of the clean surface soil and the underlying impacted soil. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

5.2.2.2 Compliance with ARARs

The implementation of ICs would not involve activities that would trigger ARARs. Therefore, no compliance issues are anticipated for this remedial alternative.

5.2.2.3 Long-Term Effectiveness

Soil in the area of investigation south of I-10 with the $TEQ_{DF,M}$ concentrations greater than the PRG is isolated from potential receptors by a layer of at least 2-feet of soil with $TEQ_{DF,M}$ concentrations well below the PRG for hypothetical construction workers. Long-term effectiveness is provided by the ICs, which would alert future owners to the presence and location of soil with elevated $TEQ_{DF,M}$ concentrations, identify the need for appropriate PPE, and identify restrictions on the placement of soil excavated from the affected areas. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

5.2.2.4 Reduction of Toxicity, Mobility or Volume

There is no reduction of TMV due to treatment associated with this remedial alternative.

5.2.2.5 Short-Term Effectiveness

There are no short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative. The remedy would achieve protection in the area south of I-10 immediately upon completion.

5.2.2.6 Implementability

There are no technical implementability issues associated with this remedial alternative. Establishing ICs is routine and the current property owners have generally been cooperative with activities required for the remedial investigation.

5.2.2.7 Cost

The estimated present worth cost associated with this remedial alternative is $1.02 million (Appendix C). The capital costs for this remedial alternative are associated with preparation of deed restrictions and notices and a soil management plan, and conducting USEPA 5-year reviews.

5.2.3 Alternative 3S – Enhanced Institutional Controls and Ground Water Monitoring

5.2.3.1 Overall Protection of Human Health and the Environment

This remedial alternative would achieve the RAOs through a combination of ICs and engineering controls. ICs would be the same as those described in Section 5.2.2. The engineering controls used to enhance the effectiveness of the ICs (subsurface marker layer and bollards) would alert to potential future construction workers of the presence of deeper soil with elevated $TEQ_{DF,M}$ concentrations. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

5.2.3.2 Compliance with ARARs

This remedial alternative would involve limited excavation and stockpiling of shallow soil to place the marker layer and bollards. Construction activities would comply with ARARs, including the control of dust and storm water.

5.2.3.3 Long-Term Effectiveness

This remedial alternative would control the potential risk to hypothetical future construction workers by providing warnings and information on how to control exposure to soil with $TEQ_{DF,M}$ concentrations exceeding the PRG. The marker layer and bollards would identify the limits of the impacted areas and alert potential future construction workers to the presence of impacted soil and the need to take the precautions associated with excavating the impacted soil. Ground water monitoring would be implemented to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

5.2.3.4 Reduction of Toxicity, Mobility or Volume

There is no reduction of TMV due to treatment associated with this remedial alternative.

5.2.3.5 Short-Term Effectiveness

There are minimal short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative. Impacted soil would not be disturbed by the shallow excavation or the bollard installation, and measures would be implemented to control dust, storm water runoff, and tracking of soil on equipment leaving the site. The remedy would achieve full protection in the area south of I-10 immediately upon implementation.

5.2.3.6 Implementability

There are no technical implementability issues associated with this remedial alternative. Placement of the marker layer and bollards are standard construction items, requiring no specialized equipment. Other than safety training required for workers at all cleanup sites, there are no specialized requirements for workers. Establishing ICs is routine, but landowners may raise objections to the presence of the bollards to be installed in implementing this alternative, which may create obstacles to the implementability of this alternative.

5.2.3.7 Cost

The estimated present worth cost associated with this remedial alternative is $1.4 million (Appendix C). The capital costs for this remedial alternative are associated with excavation and replacement of soil, placement of the marker layer, installation of bollards, and the preparation of deed restrictions, notices, and a soil management plan, and conducting USEPA 5-year reviews.

5.2.4 Alternative 4S – Removal and Off-site Disposal, Institutional Controls

5.2.4.1 Overall Protection of Human Health and the Environment

This remedial alternative achieves the RAOs through removal of impacted soil in the potential exposure depth interval and replacement with unimpacted imported fill. Institutional controls may be necessary to prevent exposure to contamination below the 10 foot cleanup interval. Institutional controls may be necessary to prevent exposure to contamination below the 10 foot cleanup interval, and to notify owners regarding subsoil dioxin and furan concentrations that are above the soil protective level (51 ng/kg) allowing for unlimited use and unrestricted access.

5.2.4.2 Compliance with ARARs

Removal of impacted soil from the remedial action areas delineated on Figure 4-11 to an off-site disposal facility would require compliance with ARARs related to dust emissions, storm water controls, and disposal. Appropriate storm water and air-quality controls would be used to protect air and water quality. Equipment leaving the work site would be decontaminated as needed to prevent tracking impacted soil on public roads, and each load of soil would be tracked to confirm that the material was received by the designated disposal facility.

5.2.4.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative is primarily derived from the removal and secure disposal of soil in the 0- to 10-foot depth interval with $TEQ_{DF,M}$ concentrations exceeding the PRG. Approximately 50,000 CY of soil would be removed from the three remedial action areas south of I-10. The anticipated limits of the excavations are shown in Figure 4-11. The excavated areas would be restored to existing grade and vegetative cover would be re-established. As all of the soil in the affected depth interval (0- to 10-feet below grade) would be replaced with unimpacted, imported fill, the residual risk would be negligible.

5.2.4.4 Reduction of Toxicity, Mobility or Volume

This remedial alternative would involve no reduction of TMV through treatment. The soil may be landfilled without treatment of the COCs. Some of the soil may require dewatering to eliminate free liquids for transportation and disposal. Drying by amendment with Portland cement would incidentally reduce the potential mobility of COCs adsorbed to the soil.

5.2.4.5 Short-Term Effectiveness

Excavation of impacted soil would temporarily increase the potential for exposure to COCs. Dust suppression would be implemented during excavation and backfilling operations to control potential inhalation hazards. Storm water controls would be implemented to minimize the potential for releasing impacted soil, although the potential exists for a release if an extreme storm or high-water event floods the Site while one of the excavations is open. The excavations should be backfilled as soon as practical to minimize the potential for such a release. Additional environmental risks include the possibility of spills during transportation to the disposal facility and possible releases from the off-site landfill itself. In addition to these environmental risks, as compared to the previous three remedial alternatives, the construction of this alternative would have higher greenhouse gas and PM impacts, and ozone generation emissions associated with construction emissions from equipment operating within the project work area, as well as from equipment required for transportation and disposal of excavated soil. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. This remedial alternative, like Alternatives 1S through 3S, would achieve full protection in the area south of I-10 immediately upon completion of construction.

5.2.4.6 Implementability

There are no significant implementability concerns associated with this remedial alternative. Excavated soil may be loaded directly into trucks for transportation to the disposal facility to eliminate the need for stockpiles of impacted soil. Dewatering (groundwater lowering) may be necessary to allow excavation to 10-feet below grade in sufficiently dry conditions, but excavation of soil to 10-feet is a standard construction operation that will not require specialized equipment or workers. Two landfills have been contacted that have indicated preliminarily that they would be able to accept the soil. The compliance status of the selected disposal facility would be confirmed, in conformance to the Off-site Rule, by communication with the USEPA Regional Off-Site Contact prior to beginning construction. The most significant implementability concern may be the temporary additional truck traffic on Market Street and access roads to I-10. Provisions may need to be made to time this traffic or to accommodate the increased volume.

5.2.4.7 Cost

The estimated present worth cost associated with this remedial alternative is $9.9 million (Appendix C). The capital costs for this remedial alternative are primarily associated with the excavation and disposal of soil and conducting USEPA 5-year reviews.

6 COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section compares the alternatives relative to each of the FS evaluation criteria listed under the NCP. Tables 5-1 and 5-2 summarize the criteria for each alternative and provide the basis for the comparative evaluation discussion in this section. Table 6-1 provides an evaluation summary for all of the criteria, assessed using the criteria "Low," "Medium" and "High", where "Low" represents the least favorable, and "High" represents the most favorable assessment of the alternative relative to the specific criterion.

6.1 Area North of I-10

6.1.1 Threshold Criteria

The containment alternatives (2N through 5aN) will only remain protective if they are properly maintained for the length of time (hundreds of years) that the impounded waste retains its toxicity, and their integrity is not compromised by extreme weather events, barge strikes and/or changes in the river channel which could result in a future release. Alternative 6N best realizes the Threshold Criteria (protecting human health and the environment and addressing ARARs) because the waste material would be removed and therefore not subject to a potential future release. As noted in the RAM, the surface-weighted average $TEQ_{DF,M}$ concentration in surface sediments (which are associated with a variety of dioxin sources in addition to paper mill waste that was placed in the impoundments) was reduced by more than 80 percent by the implementation of the temporary cap. However, the protectiveness of all capping alternatives is dependent on the continued integrity of the cap, which, given the dynamic river environment in which the pits are located, has a high degree of uncertainty.

6.1.2 Long-Term Effectiveness

Construction of the temporary armored cap reduced SWAC $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter by approximately 80 percent. While the final remedial action is being selected and constructed, natural recovery will continue to reduce SWAC $TEQ_{DF,M}$ because of the ongoing input of sediment with low $TEQ_{DF,M}$ concentrations from upstream sources. However, the long-term effectiveness of all capping alternatives is dependent on the continued integrity of the cap.

Sediment in the vicinity of the sand separation area is stable and net sedimentation in this area is expected to provide continued isolation at this buried location; however, propeller wash from tug boat operations, without ICs, could disturb these sediments as could changes to the river bed from future weather events.

Alternative 1N does not include ICs and MNR nor ground water monitoring; the site is not assessed over time, so the long-term effectiveness of this alternative ranks lower than all of the other alternatives. The existing temporary armored cap is not further enhanced in Alternatives 1N or 2N compared to Alternative 3N and 3aN, which could increase the need for future long-term monitoring and maintenance under Alternatives 1N and 2N.

The dioxin within the waste pits was generally isolated from potential receptors by the temporary cap, but the temporary cap has required many repairs and extensive maintenance. Examples include, in December 2015, an area of missing rock that was found by the EPA Dive Team. This area was not identified by the regular inspections that had been done since the temporary cap construction was completed. Dioxin at 43,000 ng/kg was under water exposing the environment and potential receptors to the dioxin. Repairs to this area were completed in 2016. Other instances of thin or absent rock cover were identified in 2012, 2013, and in 2016. No flood since the cap was constructed in 2011 has exceeded a 100-year return period design flood.

The USACE performed evaluations in the 2016 Alternatives Evaluation report to address the permanence of the existing repaired temporary cap with the proposed modifications outlined in the capping Alternative 3N. The expected long-term releases from capping are generally very small in the absence of cap erosion or a major disturbance by a barge strike. However, the USACE found that a potential severe storm could erode a sizable portion of the Alternative 3N cap, which consists of upgrades to the temporary cap that exists currently. The most severe event simulated was the hypothetical synoptic occurrence of Hurricane Ike (Category 2 hurricane) and the October 1994 flood, with a peak discharge of approximately 390,000 cubic feet per second occurring at the time of the peak storm surge height at the Site. This storm flow is about is about 8% higher than the river flow during the 1994 storm. Approximately 80 percent (12.5 acres) of the 15.7 acre Alternative 3N cap incurred severe erosion during the simulated flood. The maximum scour depth in any grid cell within the cap boundary during this potential extreme event was 2.4 feet resulting in erosion and release of the paper mill waste material containing dioxin

The existing repaired cap with the proposed modifications outlined in the capping Alternative 3N and 3aN may be permanent in the absence of extreme weather events, but will require many repairs and extensive maintenance. However, the uncertainty inherent in any quantitative analysis technique used to estimate the long-term (hundreds of years) reliability of the cap is very high. This includes the empirical analysis developed by Maynord (2000) to estimate the potential scour of the cap due to prop wash generated by ship traffic since a lot of the site data needed to properly perform this analysis were not available. The latter analysis probably has the smallest uncertainty associated with any of the evaluations performed to assess the long term reliability of the cap, and its estimated uncertainty is at least ± one order of magnitude. So, if the estimate of prop induced scour is 10 cm, then the range of uncertainty would be from 1 cm to 100 cm. This estimate of the uncertainty takes into account the lack of a complete data set for the Site and the uncertainty in Maynord's empirically based methodology itself. Further, changes in channel planform morphology due to bank erosion, shoreline breaches, etc. during a high flow event caused by a major flood or hurricane as occurred in other areas of the San Jacinto River during the 1994 storm is beyond the ability of existing sediment transport models to simulate.

The impact of continued subsidence on the integrity and reliability of the existing cap to prevent any release of contaminated material would be dependent on the long-term rate of subsidence. The latter is not well known and cannot be predicted with any reliability. In general, subsidence and the slow rise in sea level would both result in slightly deeper water depths over the Eastern Cell and Northwestern Area of the cap, but the USACE does not believe that these effects would be substantial enough to affect the tidal, river and wind induced circulation in the San Jacinto River estuary.

Regarding the potential impacts of barge strikes, strikes pose significant impacts only from loaded barges and only in proximity of the Northwestern Area. Strikes on the present 1V:2H or the proposed upgraded 1V:3H slope could cause sloughing from gouging and displacement of armor and slope instability from grounding due to the added loadings on the slope from the grounded weight of the barge, exposing a sizeable area of highly contaminated sediment. Low to moderate impacts can occur in the same area from the grounding of an empty barge on the mildly sloped area above the steep slope. This would expose a relatively small area having high levels of contamination in the area immediately north of the Western Cell and directly north and east of the northern end of the center berm.

The impacts of strikes during high flow flood conditions are much greater due to potential erosion of exposed sediment; however, flood conditions occur only about 1% of the time. Strike protection control measures, such as pilings, caissons or a wall, could be used in a 500 to 700 foot reach along the base of the slope in the deep water (15 feet) of the Northwest Area, which are components of Alternatives 3N (wall) and 3aN (wall and pilings). These control measures could prevent all but very low impact strikes.

Alternatives 4N, 5N, 5aN, and 6N, which involve either S/S or partial or full removal, all result in increased long-term protectiveness compared to Alternatives 1N, 2N, 3N, and 3aN because either the resistance to erosion or damage is increased (Alternative 4N), or the potential loss to erosion or damage is reduced due to the removal of part (Alternatives 5N and 5aN) or all (Alternative 6N) of the waste material. All of the alternatives that involve removal of part or all of the cap will result in releases during construction, however these releases would be mitigated by using BMPs including excavation in the dry where possible, berms, sheet piles, silt curtains, cap removal in sections, etc. The actual design and application of Best Management Practices for construction will be determined during the Remedial Design.

All of the alternatives involving either partial or full removal, including Alternatives 5N, 5aN, and 6N, would have re-suspension of sediment. Alternative 5N uses silt curtains to control the re-suspension of sediment. Silt curtains are the lease effective controls. Alternative 5aN uses more effective re-suspension controls including sheet piles and earthen berms. Alternative 6N adds removal in the dry in addition to sheet piles and earthen berms and results in the most effective control of re-suspension.

There will also be a requirement for a residuals management cover or backfill over the excavated areas for Alternatives 5N, 5aN, and 6N.

Alternative 6N has the greatest long-term effectiveness and protectiveness of all the alternatives because the waste material would be removed and not subject to the potentially severe conditions in the San Jacinto River, and because any construction related releases would result in sediment concentrations initially well below the PRG with further sediment concentration declines over the long term. The impact of dredge residuals will be reduced by the use of BMPs, including using a two layer residuals cover system.

6.1.3 Reduction of Toxicity, Mobility or Volume

Alternatives 1N and 2N do not include additional measures to reduce TMV. However, a portion of the waste materials in the Western Cell were previously solidified during the temporary cap construction as shown in Figures 4-1, 4-3, 4-5, 4-7, and 4-9. No other reduction of toxicity, mobility or volume will be achieved by treatment in any of the alternatives, with the exception Alternative 4N and the dewatering of excavated waste material that may occur in Alternatives 5N, 5aN and 6N. Thus, these alternatives are comparable in reduction of TMV. Alternative 3N and 3aN further reduce potential mobility within the waste pits by increasing the protection of the armored slopes, and thus rank more favorably than Alternatives 1N and 2N. Alternatives 4N and 5N take additional measures through S/S (Alternative 4N) or removal (Alternative 5N) of approximately 52,000 CY of sediments and soils, and are comparatively better than Alternative 3N for reduction of TMV. Potential mobility of the highest concentration materials addressed in Alternatives 4N and 5N would be increased during remedy implementation, somewhat offsetting any reduction in TMV. Alternative 5aN removes approximately 137,600 CY of sediment, and thus compares more favorably for reduction of TMV than Alternatives 4N and 5N, but subject again to possible issues related to mobility of materials during remedy implementation. Alternative 6N has the greatest volume of removal – 152,000 CY. This alternative is more effective in reducing the toxicity, mobility, and volume of waste compared to all of the other alternatives.

6.1.4 Short-Term Effectiveness

The short-term impacts of remediation activities are primarily related to resuspension of sediment, erosion of residuals, and the concurrent release of contaminants. Enhancement of the TCRA cap under Alternative 3N or 3aN would be expected to produce very little short-term impacts, while removal under Alternative 6N would be expected to increase short-term exposures to contaminants. Approximately 0.2% of the contaminant mass is predicted to be released under Alternative 6N using BMPs (Appendix A, Table 12-19) when sheet piles are used to isolate all waste pit areas during removal and to perform excavation in the dry where feasible; if use of sheet piles is not feasible in the Northwest Cell, this estimated amount increases to approximately 0.34%.

Depending on the selection of BMPs, flooding and high flow conditions during removal operations could significantly increase the erosion of waste material residuals. Releases from flood flows over the containment structure regardless of the removal alternative will be dependent on the height of the containment structure and the flood stage. A sheet pile wall built in and supported by an armored waste pit berm and along the southern shoreline to an elevation of about +10 ft would protect the waste pit excavation from releases from more common floods (e.g., the 25-yr or 50-yr flood stage, Appendix A). Excavation would be performed in the dry to the extent practicable. Removals may be performed in small sections at a time such that the armor stone and geotextile within the small section would be removed, and then the sediment removed and a thin layer of sacrificial fill placed before advancing to the next section and repeating the process. Under these removal operations, it would also be advisable to limit or restrict removal activities to a period when there is a lower probability of tropical storms and flooding conditions. The actual design of protective sheet piles and berms will be determined during the Remedial Design.

The USACE found that fish tissue contaminant concentrations are directly related to the releases to the water column, but are also related to the entirety of their food sources which are largely impacted by the water column concentrations and releases. Consequently, depending on the BMPs employed and the feeding range of the fish species, fish tissue contaminant concentrations may be dozens of times higher (for Alternative 6N) than existing tissue concentrations for several years before returning to near existing values (Appendix A). The release amount referenced in the USACE's Alternative Evaluation Report, 2 grams of dioxin, or 0.34% of the amount removed, is based on using silt curtains in the Northwestern Area. However, using robust BMPs, including sheet piles in the Northwestern Area, would reduce the release by 40% and therefore the estimated fish tissue contaminant concentrations decreases by 40% as well (Appendix A, Table 12-19).

The capping alternatives, such as 3N or 3aN, would not result in any significant short-term fish tissue contaminant increases, however, the capping alternatives would leave the waste material in place with the resulting long-term risk of a severe hurricane or storm scouring the waste pits and creating a much larger release.

Alternatives 1N and 2N do not entail any construction, and thus have no short-term impacts. Alternative 3N has the shortest duration of the remaining alternatives, does not result in water column, sediment, or tissue impacts (except for minor turbidity during armor rock placement), and has the lowest risk to worker safety, the lowest greenhouse gas and PM emissions, and the least traffic and ozone (smog) impact. Further, Alternative 3N does not disturb the temporary armored cap or require handling of sediments. Alternative 3aN has a longer construction time than 3N and therefore more short-term impacts, but would also have greater long-term permanence because of the armor upgrades. Compared to Alternatives 4N, 5N, 5aN, and 6N, which have longer durations, Alternative 3N and 3aN rank more favorably for short-term effectiveness.

Alternatives 4N, 5N, 5aN, and 6N each have risk of short-term impacts associated with residuals and releases during construction. Because of their longer duration these alternatives also have a higher likelihood that a high-water event during construction could overtop perimeter water quality control features, which would exacerbate short-term impacts because the armor cap needs to be removed to accomplish the work. However, raised berms and sheet pile walls, as well as removing a section of the waste material while other areas remain capped, will mitigate the impact of flooding during construction. The actual scope and design of BMPs will be determined during the Remedial Design.

Alternative 4N has a longer construction duration than Alternatives 5N and 6N and all entail removing portions of the temporary armored cap and managing a volume of sediments. Compared to Alternative 3N, there is higher risk to worker safety (8 to 9 times the number of injuries and fatalities) and higher environmental impacts (8 to 9 times the number of hours of operation and truck trips) due to releases that would be expected during construction. Alternative 4N is considered similar to Alternative 5N for emissions of ozone precursors, PM (smog-forming) and greenhouse gases; under Alternative 4N, construction is limited to work within the USEPA's Preliminary Site Perimeter and does not result in additional emissions during off-site shipment of sediments, but this is counterbalanced by the shorter duration of Alternative 5N.

Alternative 5aN has the longest construction duration. Alternatives 5aN and 6N are the least favorable for short-term effectiveness. The greater number of work hours has attendant higher worker safety risk (20 times the number of injuries and fatalities compared to Alternative 3N) and higher emissions of ozone precursors, PM (smog-forming) and greenhouse gases (20 times the number of equipment operating hours and truck trips compared to Alternative 3N), and the time required for Alternatives 5aN and 6N to achieve protection is also longer. The levels of post-removal sediment and water contaminant concentrations would be reduced by the use of BMPs during construction, including excavation in the dry, etc.

Construction of any of the proposed Alternatives is not expected to cause any flooding in the vicinity of the Site (Appendix A), and therefore should not require the implementation of any flood control measures during the construction of any of the Alternatives under consideration for the Site.

6.1.5 Implementability

Alternatives 1N and 2N do not have any implementability issues because they do not entail construction. Both are more favorable from an implementability standpoint compared to Alternatives 3N, 4N, 5N, 5aN, and 6N. Alternative 3N is a short-duration project that entails proven technology (i.e., the same activities were demonstrated during construction of the temporary armored cap) that can be deployed with readily-available materials and local, experienced contractors.

Implementability concerns, such as Site access, limited staging areas, restrictions on equipment size, and availability of off-site staging area properties are greater for Alternatives 4N, 5N, 5aN, and 6N compared to Alternatives 3N and 3aN because of the much larger scope and scale of these alternatives. Identifying and securing an off-site staging area is considered an even greater challenge for Alternatives 5N, 5aN, and 6N compared to Alternative 4N because removed sediment would need to be managed at the off-site staging area, which requires a larger footprint, and given the nature of the material removed, might make finding a willing landowner difficult. Proper management of cap material and excavated wastes, and on-site processing and management for removed sediments for off-site transportation to neighboring roadways, will be critical for effective implementation of Alternatives 5N, 5aN, and 6N. Finding a suitable off-site facility for Alternatives 5N, 5aN, and 6N is considered a more significant implementability challenge than Alternative 4N because the former alternatives will manage removed sediments at the facility. Compared to Alternative 5N, this issue is magnified for Alternatives 5aN and 6N because of the greater volume of material that must be handled at the off-site facility. Based on these factors, Alternatives 3N and 3aN are less favorable than Alternatives 1N and 2N, but more favorable than the remaining alternatives.

Alternative 4N requires the removal of the temporary armored cap, and requires S/S to be completed for an area of sediments that is typically submerged and would need to be dewatered, which is considered a technical challenge. Engineering controls for Alternative 4N may not be adequate to prevent the release of sediments exceeding PRGs to the surrounding environment; this would be especially true during potential high flow events that could occur during construction. Alternative 4N is considered to be less favorable for implementability compared to Alternative 3N.

Alternatives 5N, 5aN, and 6N also require removal of the temporary armored cap and management of waste material for off-site disposal. Similar to Alternative 4N, engineering controls may not be adequate to prevent the release of sediments exceeding PRGs to the surrounding environment. For Alternatives 4N through 6N there is a 30 to 40 percent chance that a high water event could occur during construction resulting in overtopping of the engineering controls. Thus, all of these alternatives are considered equally less favorable as Alternative 4N for implementability compared to Alternatives 1N, 2N, 3N, and 3aN.

6.1.6 Cost

Appendix C provides the detailed estimates that were developed for this FS Report. Costs range from lowest to highest in order from Alternative 1N to Alternative 6N: Alternative 1N is estimated to cost $0.4 million; Alternative 2N is estimated to cost $2.0 million; Alternatives 3N and 4N differ by a factor of 3.6, with estimated costs of $4.1 and $14.8 million, respectively; Alternative 3aN has estimated costs of $24.8 million; Alternative 5N is estimated to cost $29.8 million; Alternative 5aN is estimated to cost $69.6 million; and Alternative 6N is estimated to cost $87 million. Estimated costs include development and operation of the off-site staging area. However, because the exact location and configuration of the off-site staging area are beyond the scope of this FS these elements may not be fully reflected in the FS estimated durations or costs.

6.1.7 Summary of Comparative Benefits and Risks

The waste material is highly toxic and may be highly mobile in a severe storm and therefore is considered a Principal Threat Waste. The Environmental Protection Agency considers material at the Site with more than 300 ng/kg dioxin to be a Principal Threat Waste. This concentration was calculated by multiplying the sediment PRG of 30 ng/kg by a factor of 10.

The location of materials, either partially submerged within the San Jacinto River (northern impoundments) or on a small peninsula on the San Jacinto River (southern impoundment), is in a river environment that is subject to dramatic change, creating concerns about the permanence of an armored cap. The area has a high threat of repeated storm surges and flooding from hurricanes and tropical storms, which, if the material was left in place, could result in a release of hazardous substances. The history of repeated temporary armor cap maintenance to replace missing or eroded armor stone, with flooding that has been less severe than the design 100-year flood, also creates concerns about the long-term permanence of an armored cap.

Alternatives 1N, 2N, 3N, and 3aN have similar impacts to sediments and water column concentrations. Alternative 4N would increase the shear strength of soils and sediments through treatment, which would further increase their stability beyond that provided by the temporary armored cap. Alternatives 5N, 5aN, and 6N would remove impacted sediments from the Site and thus provide higher long-term protectiveness. Alternative 3N relies on the Upgraded Cap, but retains the capped material at the Site that would result in the potential for a future release due to an extreme storm or hurricane or the impacts of a barge strike; while more protective than Alternative 3N, under Alternative 3aN the paper mill waste material remains in the dynamic river environment of the San Jacinto River, with a high degree of uncertainty as to the long-term integrity of the cap. Alternatives 1N and 2N do not enhance the existing temporary armored cap, and so provide lower long-term protectiveness than all of the other alternatives. Alternative 1N does not include ground water monitoring and would not be able to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place. All of the other alternatives, except Alternative 6N, which removes the waste above the PRG, do include ground water monitoring to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

Additionally there is risk of harm to the environment during implementation of the remedies associated with Alternatives 4N, 5N, 5aN, and 6N, although these risks would be mitigated by the use of BMPs and engineering controls as discussed under Short-Term Effectiveness. Risks from short-term environmental impacts during and following construction (water column, sediment, and localized tissue impacts) and worker safety (estimated injury and fatality rates) are significantly (7 to 20 times) higher for Alternatives 4N, 5N, 5aN, and 6N than for Alternatives 1N, 2N, or 3N.

Alternatives 4N, 5N, 5aN, and 6N are less sustainable alternatives, as assessed, considering potential ozone precursor, PM and greenhouse gas emissions from the construction activity, and will result in more community impact from traffic including on-going daily distractions and the potential for accidents and off-site spills (6 to nearly 70 times the number of truck trips). However, there will be only an incremental increase of traffic in comparison with the other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the nearby presence of I-10. These alternatives are expected to require a relatively large off-site facility for management of materials and related activities (armor rock and removed sediment stockpiling, sediment dewatering, transloading, and off-site shipping), which could be difficult to obtain.

6.2 Area South of I-10

Other than Alternative 1S, the remedial alternatives for the area south of I-10 considered in this FS Report meet both of the threshold criteria: protectiveness and compliance with ARARs. The potentially affected receptor (hypothetical future construction worker) would be protected from exposure to soil with elevated $TEQ_{DF,M}$ concentrations by warnings and restrictions (Alternatives 2S and 3S) or removal of impacted soil (Alternative 4S). Alternative 4S is the only alternative that provides for complete removal of the Principal Threat Waste from the southern impoundment.

Alternative 1S does not include ground water monitoring and would not be able to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place. All of the other alternatives, except Alternative 4S, which removes the waste above the soil PRG, do include ground water monitoring to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

The pockets of subsurface soil with $TEQ_{DF, M}$ concentrations exceeding the hypothetical future construction worker risk-based PRG in the area south of I-10 are isolated from the surface by several feet of soil with dioxin levels less than the soil screening level allowing for unlimited use and unrestricted access (51 ng/kg). $TEQ_{DF, M}$ concentrations for specific sample intervals are shown in Figure 2-5. Potential exposure to soil exceeding the PRG in this area is limited to circumstances involving excavation into the affected depth zone or potential contact with excavated soil if it were to be left at the surface. The hypothetical future construction worker PRG is based on exposure to soil from 0- to 10-feet below the surface.

With reasonable care, any of the remedial alternatives could be implemented in compliance with ARARs. Soil that is removed (Alternative 4S) would be transported in compliance with Department of Transportation standards and permanently managed in a permitted landfill cleared by the USEPA's regional off-site rule contact. BMPs would be implemented to control dust, storm water, and potential releases of impacted soil.

6.2.1 Long-Term Effectiveness

As noted in the previous section, soil with $TEQ_{DF, M}$ concentrations exceeding the soil risk-based PRG is isolated from the surface by clean overburden. The only route of potential exposure is through excavation into the impacted depth interval. Through the use of appropriate PPE and proper management of excavated soil, the potential risks posed by the impacted soil can be reliably and effectively managed. The physical markers (Alternative 3S) would draw attention to the ICs and enhance their effectiveness. Alternative 4S would achieve long-term effectiveness by permanently removing the impacted soil from the 0- to 10-foot depth interval from the Site and securely disposing of the soil in a permitted landfill. While the ICs, particularly with the addition of physical markers (Alternative 3S), would provide reliable long-term protection, they rely on the integrity of future owners, construction workers, and employees to comply with the restrictions. Therefore, complete removal of the impacted soil in the depth interval of potential excavation (Alternative 4S) may provide a somewhat higher level of long-term effectiveness because it is not subject to inappropriate future use of the area.

Alternative 1S does not include ground water monitoring and would not be able to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place. All of the other alternatives, except Alternative 4S, which removes the soil above the PRG, do include ground water monitoring to ensure that there are no long-term unacceptable impacts to ground water resulting from the waste left in place.

6.2.2 Reduction of Toxicity, Mobility and Volume

Alternatives 2S and 3S do not include any treatment of impacted soil. Alternative 4S would include some treatment of excavated soil, as needed to eliminate free liquids for transportation and disposal. The treatment may involve amendment of the soil with Portland cement, which would reduce the potential mobility of COCs. Water removed from the excavation would be treated, if necessary, to reduce toxicity prior to discharge.

6.2.3 Short-Term Effectiveness

Alternative 2S does not entail any construction, and thus has no short-term impacts. Excavations (Alternative 3S and 4S) would require BMPs to control dust and storm water. Short-term impacts associated with Alternative 3S would be minimal given the shallow depth of excavation, limited volume of material that would be moved, and absence of significant concentrations of COCs in the shallow soil. Alternative 4S would require exposing soil with $TEQ_{DF,M}$ concentrations exceeding the PRG, which introduces the potential for exposure to COCs through direct contact with the soil, inhalation or ingestion of impacted dust, and contact with impacted soil suspended in runoff. However, measures would be implemented to mitigate these issues, including a health and safety plan, runoff controls, dust control measures, etc. The volume of soil and the duration of the project would also be greater than for Alternative 3S, and Alternative 4S would require off-site transportation of the soil to a disposal facility, increasing the potential for exposure to COCs, emissions of greenhouse gasses, nitrogen oxides (NOx), and PM, and potential tracking of COCs off-site. However, measures would be implemented to reduce the amount of any materials lost during transportation. The Remedial Design will determine the actual type and scope of the control measures to be used to address these issues.

6.2.4 Implementability

There are no significant implementability concerns associated with Alternatives 2S and 3S. None of the alternatives requires specialized equipment, techniques, or personnel. Coordination with property owners would be required to establish ICs and for access to the project work site. Alternative 4S would involve more physical activity for implementation, including off-site transportation of impacted soil, but the operations are routine for remedial actions. The additional implementability concerns are the increased truck traffic on Market Street and the potential for flooding while impacted soil is exposed during implementation of Alternative 4S. Provisions may need to be made to handle the additional volume of traffic. The duration of the excavation should not exceed 7 months and implementation could be timed for periods when high water is least likely.

6.2.5 Cost

Appendix C provides the detailed estimates that were developed for this FS. Costs range from lowest to highest in order from Alternative 1S to Alternative 4S. Alternative 1S (No Action) is estimated to cost $143,000, Alternative 2S (ICs) is estimated to cost $1.02 million, Alternative 3S (Enhanced ICs) is estimated to cost $1.4 million, and Alternative 4S is estimated to cost $9.9 million.

6.2.6 Summary of Comparative Benefits and Risks

Alternative 4S would result in the permanent removal of impacted soil from the 0- to 10-foot interval. Risk management achieved by ICs is somewhat less for the area south of I-10, even with the addition of the physical markers that are part of Alternative 3S. Alternatives 2S and 3S would not require exposing impacted soil or transporting material off-site and would be simpler to implement. Alternative 4S is the only alternative that provides for complete removal of the Principal Threat Waste from the southern impoundment. The cost of Alternative 4S, $9.9 million, is 7 times the cost of Alternative 3S and almost 10 times the cost of Alternative 2S. However, Alternatives 2S and 3S do not address the Principal Threat Waste, which Alternative 4S does by removal and disposal. Also, Alternative 4S offers increased long-term effectiveness by removing the impacted soil, although at an increased cost.

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TABLES

Table 3-1
Applicable or Relevant and Appropriate Requirements Summary

Potential ARARs[1]	Citation	Summary	Comment
Federal			
Clean Water Act (CWA): Criteria and standards for imposing technology-based treatment requirements under §§ 309(b) and 402 of the Act	33 U.S.C. §§ 1319 and 1342 (implementing regulations at 40 CFR Part 125 Subpart A)	Both on-site and off-site discharges from CERCLA sites to surface waters are required to meet the substantive CWA (National Pollutant Discharge Elimination System) NPDES requirements (USEPA 1988).	On-site discharges must comply with the substantive technical requirements of the CWA but do not require a permit (USEPA 1988). Off-site discharges would be regulated under the conditions of a NPDES permit (USEPA 1988). Standards of control for direct discharges must meet technology-based requirements. Best conventional pollution control technology (BCT) is applicable to conventional pollutants. Best available technology economically achievable (BAT) applies to toxic and non-conventional pollutants. For CERCLA sites, BCT/BAT requirements are determined on a case-by-case basis using best professional judgment. This is likely to be a potential requirement only if treated water or excess dredge water is discharged during implementation.
CWA Sections 303 and 304: Federal Water Quality Criteria	33 U.S.C. §§1313 and 1314 (Most recent 304(a) list as updated to issuance of ROD)	Under §303 (33 U.S.C. §1313), individual states have established water quality standards to protect existing and attainable uses (USEPA 1988). CWA §301(b)(1)(C) requires that pollutants contained in direct discharges be controlled beyond BCT/BAT equivalents (USEPA 1988). CERCLA §121(d)(2)(B)(i) establishes conditions under which water quality criteria, which were developed by USEPA as guidance for states to establish location-specific water quality standards, are to be considered relevant and appropriate. Two kinds of water quality criteria have been developed under CWA §304 (33 U.S.C. §1314): one for protection of human health, and another for protection of aquatic life. These requirements include establishment of total maximum daily loads (TMDL).	The FS considers the ability of remedial alternatives to satisfy established water quality criteria. Best management practices (BMPs) would be established for remedial actions and applied during construction. Water quality would also be monitored during construction and additional BMPs may be implemented if necessary to protect water quality. Where water quality state standards contain numerical criteria for toxic pollutants, appropriate numerical discharge limitations may be derived for the discharge and considered (USEPA 1988). Where state standards are narrative, either the whole-effluent or chemical-specific approach may generally be used as a standard of care (USEPA 1988).
CWA Section 307(b): Pretreatment standards	33 U.S.C. §1317(b)	CERCLA §121(e) states that no Federal, state, or local permit for direct discharges is required for the portion of any removal or remedial action conducted entirely on-site (the aerial extent of contamination and all suitable areas in close proximity to the contamination necessary for implementation of the response action) (USEPA 1988).	If off-site discharges from a CERCLA response activity were to enter receiving waters directly or indirectly, through treatment at a Publicly Owned Treatment Works (POTWs), they must comply with applicable Federal, State, and Local substantive requirements and formal administrative permitting requirements (USEPA 1988). This requirement may be triggered by disposal methods for waste. Based on the current set of proposed alternatives, none of the alternatives involve discharge to a POTW, and therefore, this regulation is not likely to be applicable.
CWA Section 401: Water Quality Certification	33 U.S.C. §1341	Requires applicants for Federal permits for projects that involve a discharge into navigable waters of the U.S. to obtain certification from state or regional regulatory agencies that the proposed discharge will comply with CWA Sections 301, 302, 303, 306, and 307.	Proposed activities that are on-site would not require a Federal permit. Therefore, certification is not legally required for on-site actions. Certification would be required for off-site actions. For on-site or off-site actions, certification should occur as part of the state identification of substantive state ARARs (USEPA 1988). Compliance with water quality criteria is discussed under CWA Sections 303 and 304.

[1] ARARs are applicable or relevant and appropriate requirements of Federal or state environmental laws and state facility siting laws. CERCLA section 121(d) requires that remedial actions generally comply with ARARs. The USEPA has stated a policy of attaining ARARs to the greatest extent practicable on remedial or removal actions (USEPA 1988). USEPA also stated that certain nonpromulgated Federal and state advisories or guidelines would be considered in selecting remedial or removal actions; these guidelines are referred to as TBCs, or "to be considered."

Table 3-1
Applicable or Relevant and Appropriate Requirements Summary

Potential ARARs[1]	Citation	Summary	Comment
CWA Section 404 and 404(b)(1): Dredge and Fill	33 U.S.C. §1344 (b)(1) (implementing regulations at 33 CFR 320 and 330; 40 CFR 230)	Discharges of dredged and fill material into waters of the U.S. must comply with the CWA §404 (33 U.S.C. 1344) guidelines and demonstrate the public interest is served (USEPA 1988).	The San Jacinto site is a water of the U.S. (USEPA 2007). Dredge and fill permits are applicable to dredging, in-water disposal, capping, construction of berms or levees, stream channelization, excavation and/or dewatering within waters of the U.S. (USEPA 1988). Permits are not required, however, for on-site CERCLA actions. Under the 404(b)(1) guidelines, efforts should be made to avoid, minimize, and mitigate adverse effects on the waters of the U.S. and, where possible, select a practicable (engineering feasible) alternative with the least adverse effects. The substantive requirements of Section 404 will be considered in the development and evaluation of remedial alternatives to minimize adverse impacts to waters of the U.S.
Safe Drinking Water Act	42 U.S.C. §300f (implementing regulations at 40 CFR Part 141, et seq.)	The Safe Drinking Water Act is applicable to public drinking water sources at the point of consumption ("at the tap"). Maximum contaminant levels (MCLs) have been established for certain constituents to protect human health and to preserve the aesthetic quality of public water supplies.	Safe Drinking Water Act standards are applicable to public drinking water sources. The San Jacinto River is not a public water supply and does not recharge an aquifer used to supply drinking water. Therefore, the Safe Drinking Water Act is not applicable. The MCL for 2,3,7,8-tetrachlorodibenzodioxin may be considered for protecting water quality.
Federal Drinking Water Regulations (Primary and Secondary Drinking Water Standards)[2]	40 CFR 141 and Part 143	USEPA has established two sets of drinking water standards: one for protection of human health (primary) and one to protect aesthetic values of drinking water (secondary) (USEPA 1988). MCLs are applicable to public drinking water sources at the point of consumption.	Safe Drinking Water Act standards are applicable to public drinking water sources. The San Jacinto River is not a public water supply and does not recharge an aquifer used to supply drinking water. Therefore, the Safe Drinking Water Act is not applicable. The MCL for 2,3,7,8-tetrachlorodibenzodioxin may be considered for protecting water quality.
Resource Conservation And Recovery Act (RCRA): Hazardous Waste Management	42 U.S.C. §§6921 et seq. (implementing regulations at 40 CFR Parts 260 – 268)	RCRA is intended to protect human health and the environment from the hazards posed by waste management (both hazardous and nonhazardous). RCRA also contains provisions to encourage waste reduction. RCRA Subtitle C and its implementing regulations contain the Federal requirements for the management of hazardous wastes.	This requirement would apply to certain activities if the affected sediments contain RCRA listed hazardous waste or exhibit a hazardous waste characteristic. RCRA requirements are applicable only if waste is managed (treated, stored, or disposed of) after effective date of RCRA requirement under consideration or if CERCLA activity constitutes treatment, storage, or disposal as defined by RCRA. The sludge and sediment at the site are not listed hazardous waste, do not contain listed hazardous waste, and do not meet any of the characteristics of hazardous waste. Therefore, the RCRA rules for hazardous waste are neither applicable nor relevant and appropriate.
Toxic Substances Control Act (TSCA)	15 USC §2601 et. seq. (implementing regulations at 40 CFR 761.61 (c)	40 CFR 761.61 provides TSCA cleanup and disposal options for PCB remediation waste, which includes PCB-contaminated soil, sediment, sewage or industrial sludge, and building material. 761.61(c) is the risk-based option for PCB remediation waste.	A proposed site cleanup plan was developed, under the TSCA risk-based option, developing a remedial plan to reach risk-based cleanup levels that are protective of human health and the environment.
RCRA: General Requirements for Solid Waste Management	42 U.S.C. §§6941 et seq. (implementing regulations at 40 CFR 258)	Requirements for construction for municipal solid waste landfills that receive RCRA Subtitle D wastes, including industrial solid waste. Requirements for run-on/run-off control systems, groundwater monitoring systems, surface water requirements, etc.	This requirement would be relevant if a landfill was constructed for the disposal of non-hazardous solid waste. There are no specific Federal requirements for non-hazardous waste management; state regulations provide specific applicable requirements for siting, design, permitting, and operation of landfills.
Clean Air Act (CAA)	42 U.S.C. §§7401 et seq.	Would apply if dredging and/or excavation activities generate air emissions sufficient to require a permit, greater than 10 tons of any pollutant per year under the CAA operational permit (USEPA 2009).	None of the remedial alternatives is expected to trigger an operational permit.

[2] Underground injection is not anticipated as a part of the potential remedial action. Furthermore, the site is not located in a sole-source aquifer (USEPA 2008). It is also assumed that no wellhead protection area is located near the study area.

Table 3-1
Applicable or Relevant and Appropriate Requirements Summary

Potential ARARs[1]	Citation	Summary	Comment
Rivers And Harbors Act of 1899: Obstruction of navigable waters (generally, wharves; piers, etc.); excavation and filling-in	33 U.S.C. §401	Controls the alteration of navigable waters (i.e., waters subject to ebb and flow of the tide shoreward to the mean high water mark). Activities controlled include construction of structures such as piers, berms, and installation of pilings as well as excavation and fill. Section 10 may be applicable for any action that may obstruct or alter a navigable waterway.	No permit is required for on-site activities. However, substantive requirements might limit in-water construction activities.
Endangered Species Act	16 U.S.C. §§ 1531 et seq.	Federal agencies must ensure that actions they authorize, fund, or carry out are not likely to adversely modify or destroy critical habitat of endangered or threatened species. Actions authorized, funded, or carried out by Federal agencies may not jeopardize the continued existence of endangered or threatened species as well as adversely modify or destroy their critical habitats.	Based on a 2010 evaluation, as well as a desktop review of site photos and USFWS and NMFS species and habitat maps, no Federally listed threatened or endangered (T&E) species or their critical habitat are present on the site or utilize areas in the vicinity of the site. Therefore, this requirement is not relevant to the evaluation of remedial alternatives. NMFS includes endangered sea turtles in Trust resources impacted by contaminated surface water and sediments that may have been transported from the site. USEPA will consult with the resource agencies to gain concurrence on the determination that the proposed remedial alternative will have no effect on listed species.
Fish and Wildlife Coordination Act	16 U.S.C. §§661 et seq., 16 U.S.C. §742a, 16 U.S.C. § 2901	Requires adequate provision for protection of fish and wildlife resources. This title has been expanded to include requests for consultation with USFWS for water resources development projects (Mueller 1980). Any modifications to rivers and channels require consultation with the USFWS, Department of Interior, and state wildlife resources agency[3]. Project-related losses (including discharge of pollutants to water bodies) may require mitigation or compensation.	Applicable to any action that controls or modifies a body of water.
Bald and Golden Eagle Protection Act	16 U.S.C. §668a-d	Makes it unlawful to take, import, export, possess, buy, sell, purchase, or barter any bald or golden eagle, nest, or egg. "Take" is defined as pursuing, hunting, shooting, poisoning, wounding, killing, capturing, trapping and collecting, molesting, or disturbing.	This requirement is potentially relevant to CERCLA activities. No readily available information suggests bald or golden eagles frequent the project area; however, a qualified biologist would perform a site visit prior to a potential remedial action to confirm that bald and golden eagles do not frequent the project area.
Migratory Bird Treaty Act	16 U.S.C. §§703-712 (implementing regulations at 50 CFR §10.12)	Makes it unlawful to take, import, export, possess, buy, sell, purchase, or barter any migratory bird. "Take" is defined as pursuing, hunting, shooting, poisoning, wounding, killing, capturing, and trapping and collecting.	This requirement is potentially relevant to CERCLA activities. No readily available information suggests migratory birds frequent the project area, and aerial photography of the site suggests no suitable nesting or stopover habitat is present; however, a qualified biologist would perform a site visit prior to a potential remedial action to confirm that migratory birds do not frequent the project area.
Coastal Zone Management Act	16 USC §§1451 et seq. (implementing regulations at 15 CFR 930)	Federal activities must be consistent with, to the maximum extent practicable, State coastal zone management programs. Federal agencies must supply the State with a consistency determination (USEPA 1989).	The San Jacinto River lies within the Coastal Zone Boundary according to the Texas Coastal Management Plan (TCMP) prepared by the General Land Office (GLO). The FS considers whether the remedial alternatives would affect (adversely or not) the coastal zone, and the lead agency is required to determine whether the activity will be consistent with the State's CZMP (USEPA 1989). More information regarding the state requirements is provided under Texas Coastal Coordination Council (TCCC) Policies for Development in Critical Areas.
FEMA (Federal Emergency Management Agency), Department of Homeland Security (Operating Regulations)	42 U.S.C. 4001 et seq. (implementing regulations at 44 CFR Chapter 1)	Prohibits alterations to river or floodplains that may increase potential for flooding.	This requirement is relevant to CERCLA activities in floodplains and in the river because the project area is within a designated flood zone. The FS includes a brief review of the potential impacts of remedial alternatives on the floodplain, and there will be a full evaluation of the selected alternative as part of the remedial design process.
National Flood Insurance Program (NFIP) Regulations	42 U.S.C. subchapter III, §§4101 et seq.	Provides federal flood insurance to local authorities and requires that the local authorities not allow fill in the river that would cause an increase in water levels associated with floods.	The FS includes a brief review of the potential impacts of remedial alternatives on the floodplain, and there will be a full evaluation of the selected alternative as part of the remedial design process.

[3] Texas Parks and Wildlife Department.

Table 3-1
Applicable or Relevant and Appropriate Requirements Summary

Potential ARARs[1]	Citation	Summary	Comment
Title 40: Protection of the Environment - Statement of Procedures on Floodplain Management and Wetlands Protection	40 CFR Part 6 App. A; Executive Orders (EO) 11988 and 11990	Requires Federal agencies to conduct their activities to avoid, if possible, adverse impacts associated with the destruction or modification of wetlands and occupation or modification of floodplains. Executive Orders 11988 and 11990 require Federal projects to avoid adverse effects and minimize potential harm to wetlands and within flood plains. The EO 11990 requires Federal agencies to avoid to the extent possible the long and short-term adverse impacts associated with the destruction or modification of wetlands and to avoid direct or indirect support of new construction in wetlands wherever there is a practicable alternative (USEPA 1994).	This requirement is potentially relevant to disposal or treatment activities in the upland as well as any in-water facilities that might displace floodwaters. The waste pits are located within the floodway and Zone AE, or the 1% probability floodplain. The FS includes a brief review of the potential impacts of remedial alternatives on the floodplain, and there will be a full evaluation of the selected alternative as part of the remedial design process. Effects on the base flood, typically the 100-year or 1% probability flood, should be minimized to the maximum extent practicable (Code of Federal Regulations 1985 as amended). The agency also adopted a requirement that the substantive requirements of the Protection of Wetlands Executive Order must be met (USEPA 1994). Unavoidable impacts to wetlands must be mitigated (USEPA 1994)[4].
National Historic Preservation Act	16 U.S.C. §§ 470 et seq. (implementing regulations at 36 CFR 800)	Section 106 of this statute requires Federal agencies to consider effects of their undertakings on historic properties. Historic properties may include any district, site, building, structure, or object included in or eligible for the National Register of Historic Places (NRHP), including artifacts, records, and material remains related to such a property.	According to the San Jacinto River Waste Pits Remedial Investigation/Feasibility Study (RI/FS) cultural resources assessment, "no NRHP-eligible properties are documented in the area of concern. Because of the extensive disturbance to the site and minimal ground disturbance that will likely occur for the project, it is not likely that NRHP-eligible historic properties will be affected by RI/FS or eventual site remediation activities" (Anchor QEA 2009).
Noise Control Act	42 U.S.C. §§ 4901 et seq. (implementing regulations at 40 CFR Subchapter G §201 et seq.	Noise Control Act remains in effect but unfunded (USEPA 2010).	Noise is regulated at the state level. See Texas Penal Code under state ARARs.
Hazardous Materials Transportation Act	49 U.S.C. §§1801 et seq. (implementing regulations at 49 CFR. Subchapter C)	Establishes standards for packaging, documenting, and transporting hazardous materials.	This requirement would apply to remedial alternatives that involve transporting hazardous materials off-site for treatment or disposal.

[4] Each agency is expected to minimize the destruction, loss, or degradation of wetlands, and to preserve and enhance the natural and beneficial values of wetlands when implementing actions such as CERCLA sites (President of the United States 1977). If §404 of the Clean Water Act is considered an ARAR, then the 404(b)(1) guidelines established in a Memorandum of Understanding (MOU) between USEPA and Department of Army should be followed (USEPA 1994). When habitat is severely degraded, a mitigation ratio of 1:1 may be acceptable (USEPA 1994). However, any mitigation would be at the discretion of the agency and the USEPA may elect to orient mitigation towards "minimizing further adverse environmental impacts rather than attempting to recreate the wetlands original value on site or off site" (USEPA 1988).

Table 3-1
Applicable or Relevant and Appropriate Requirements Summary

Potential ARARs	Citation	Summary	Comment
State			
30 Texas Administrative Code (TAC) Part 1: Industrial Solid Waste and Municipal Hazardous Waste General Terms	30 TAC §§335.1 – 335.15	General Terms: Substantive requirements for the transportation of industrial solid and hazardous wastes; requirements for the location, design, construction, operation, and closure of solid waste management facilities.	Guidelines to promote the proper collection, handling, storage, processing, and disposal of industrial solid waste or municipal hazardous waste in a manner consistent with the purposes of Texas Health and Safety Code, Chapter 361. Solid nonhazardous waste provisions are applicable if material is transported to an upland disposal facility.
30 TAC Part 1: Industrial Solid Waste and Municipal Hazardous Waste: Notification	30 TAC Chapter 335 Subchapter P	Requires placement of warning signs in contaminated and hazardous areas if a determination is made by the executive director of the Texas Water Commission a potential hazard to public health and safety exists which will be eliminated or reduced by placing a warning sign on the contaminated property.	Warning signs and fencing were placed around the site as part of the Time Critical Removal Action. The FS includes additional institutional controls for all alternatives, including additional warning signs and fencing.
30 TAC Part 1: Industrial Solid Waste and Municipal Hazardous Waste: Generators	30 TAC Chapter 335, Subchapter C	Standards for hazardous waste generators either disposing of waste on-site or shipping off-site with the exception of conditionally exempt small quantity generators. The definition of hazardous involves state and Federal standards.	The sludge and sediment at the site are not listed hazardous waste, do not contain listed hazardous waste, and do not meet any of the characteristics of hazardous waste. Therefore, the rules for hazardous waste are neither applicable nor relevant and appropriate.
Texas Surface Water Quality Standards	30 TAC §307.4-7, 10	These state regulations provide: • General narrative criteria • Anti-degradation Policy • Numerical criteria for pollutants • Numerical and narrative criteria for water-quality related uses (e.g., human use) • Site specific criteria for San Jacinto basin	Surface water quality standards are potentially relevant to the determination of risks, but should not override any site-specific toxicity values or risks determined through the risk assessment process. It is also relevant to the identification of potential sources and the short-term and long-term effectiveness of removal alternatives. However, the surface water quality criterion for TEQ, expressed as a concentration in edible fish tissue in 30 TAC §307.6 (c) 11, is generally not being met throughout the Houston Ship Channel, San Jacinto Bay and Galveston Bay areas. In more than 90 percent of edible fish tissue samples and in more than 85 percent of edible crab tissue collected by Respondents, TCEQ and TDSHS outside of USEPA's Preliminary Site Perimeter from 2002 through 2011, TEQ concentrations exceeded this tissue-based standard. Therefore, applicability to evaluation of effectiveness is limited due to ambient conditions in the region.
Texas Water Quality: Pollutant Discharge Elimination System (TPDES)	30 TAC §279.10	These state regulations require stormwater discharge permits for either industrial discharge or construction-related discharge. The State of Texas was authorized by USEPA to administer the NPDES program in Texas on September 14, 1998 (Texas Commission on Environmental Quality 2009).	The proposed remedial alternatives evaluated in the FS do not include off-site remedial action beyond disposal of sediments in upland disposal facilities that would be previously permitted, and therefore no discharge permit for off-site remedial actions would be required.
Texas Water Quality: Water Quality Certification	30 TAC §279.10	These state regulations establish procedures and criteria for applying for, processing, and reviewing state certifications under CWA, §401. It is the purpose of this chapter, consistent with the Texas Water Code and the Federal CWA, to maintain the chemical, physical, and biological integrity of the state's waters.	The development and evaluation of remedial alternatives will include consideration of potential water-quality impacts, relevant to the Water Quality Certification in Texas. Although permits are not required for on-site CERCLA actions, water quality certification is relevant as part of identification of substantive state ARARs (USEPA 1988).
Texas Risk Reduction Program	30 TAC §350	Activated upon release of Chemicals of Concern (COC). The Risk Reduction Program uses a tiered approach incorporating risk assessment techniques to help focus investigations, to determine appropriate protective concentration levels for human health, and when necessary, for ecological receptors. Includes protective concentration levels.	Risk assessment was performed as part of the remedial investigation. Sediment and soil contaminated with COCs is isolated from potential receptors by existing soil and sediment or the TCRA cap such that there are no unacceptable risks to human health or the environment. The remedial alternatives would increase the permanence of the existing barriers to exposure, thereby enhancing the risk reduction.
Natural Resources Code, Antiquities Code of Texas	Texas Parks and Wildlife Commission Regulations 191.092-171	Requires that the Texas Historical Commission staff review any action that has the potential to disturb historic and archeological sites on public land. Actions that need review include any construction program that takes place on land owned or controlled by a state agency or a state political subdivision, such as a city or a county. Without local control, this requirement does not apply.	Assessment of historical resources during the TCRA produced no known eligible properties and determined that disturbance of any archaeological or historic resources is unlikely within the TCRA Site. Depending on the magnitude and specific boundaries of ground disturbance determined during the FS for the overall site, this ARAR will need to be re-evaluated relative to CERCLA activities outside of the TCRA boundaries. (Anchor QEA 2009).

Table 3-1
Applicable or Relevant and Appropriate Requirements Summary

Potential ARARs	Citation	Summary	Comment
Practice and Procedure, Administrative Code of Texas	13 TAC Part 2, Chapter 26	Regulations implementing the Antiquities Code of Texas. Describes criteria for evaluating archaeological sites and permit requirements for archaeological excavation.	This requirement is only applicable if an archaeological site is found; based on evaluations conducted as part of the RI/FS and TCRA processes, it is unlikely that archaeological resources would be found on the Site
State of Texas Threatened and Endangered (T&E) Species Regulations	31 TAC 65.171 - 65.176	No person may take, possess, propagate, transport, export, sell or offer for sale, or ship any species of fish or wildlife listed as threatened or endangered.	The presence or absence of state T&E species was evaluated in 2010, and concluded that no state T&E species were likely to occur on the Site or in the vicinity.
TCCC Policies for Development in Critical Areas	31 TAC §501.23	Dredging in critical areas is prohibited if activities have adverse effects or degradation on shellfish and/or jeopardize the continued existence of endangered species or results in an adverse effect on a coastal natural resource area (CNRA)[5]; prohibit the location of facilities in coastal natural resource areas unless adverse effects are prevented and /or no practicable alternative. Actions should not be conducted during spawning or nesting seasons or during seasonal migration periods. Specifies compensatory mitigation.	The FS evaluates the potential effects of remedial alternatives on Coastal Natural Resource Area (CNRAs), which includes coastal wetlands (Railroad Commission of Texas n.d.).
Texas Coastal Management Plan (CMP) Consistency	31 TAC, §506.12	Specifies Federal actions within the CMP boundary that may adversely affect CNRAs; specifically selection of remedial actions.	The San Jacinto River lies within the Coastal Zone Boundary (GLO TCMP). The FS will evaluate whether remedial alternatives may affect (adversely or not) the coastal zone and will provide a technical basis for the lead agency to determine whether the activity will be consistent with the State's CMP (USEPA 1989).
Texas State Code – obstructions to navigation	Natural Resources Code § 51.302 Prohibition and Penalty	Prohibits construction or maintenance of any structure or facility on land owned by the State without an easement, lease, permit, or other instrument from the State.	The FS evaluates whether the remedial alternatives include construction on state-owned land, and implementation of any alternative occurring on state lands presumes the obtainment of an easement, lease, permit, or other instrument from the State.
Noise Regulations	Texas Penal Code Chapter 42, Section 42.01	The Texas Penal Code regulates any noise that exceeds 85 decibels after the noise is identified as a public nuisance.	Noise abatement may be required if actions are identified as a public nuisance. Due to the isolation of the site, its location adjacent to a freeway with high volumes of traffic during normal working hours, and the industrial nature of the nearest properties, noise from construction activity associated with a potential remedial action is unlikely to constitute a public nuisance. Noise associated with truck traffic to and from the site should be considered for alternatives that involve transportation of materials off-site.

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[5] A CNRA is a coastal wetland, oyster reef, hard substrate reef, submerged aquatic vegetation, tidal sand, or mud flat.

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Table 4-1a

Selected Sediment Capping Projects

Sediment Project	Chemicals of Concern	Site Conditions	Cap Area	Date Constructed	References
St. Paul Waterway (Simpson Tacoma Kraft Superfund Site) Tacoma, Washington	Phenols, PAHs, dioxins, furans	Shallow, near shore sediments, down to -20 feet MLLW.	17 acres	1988	USACE 1998
West Waterway CAD Site Seattle, Washington	PCBs, metals	Subtidal river, active industrial waterway.	1.3 acres	1984	HDR 2013
Olympic View Resource Area Tacoma, Washington	Dioxin	Intertidal and subtidal areas. Water depth up to -15 feet MLLW.	0.4 acres	2003	Hart Crowser 2003
McCormick and Baxter Old Mormon Slough Stockton, California	Dioxins, PAHs	Dead-end waterway; 10 feet deep; maintenance-dredged for barge access; tidally influenced.	8.8 acres	2005	SMWG 2008
McCormick and Baxter Portland Plant Portland, Oregon	PAHs	0.5 mile reach of the Willamette River.	15 acres	2004	SMWG 2008
General Motors Superfund Site St. Lawrence River Massena, New York	PCBs	11-acre near shore site. Depth of river at cap no deeper than 4 feet.	1.7 acre	1995	USACE 1998
Housatonic River, Upper 1/2 Mile General Electric Site Pittsfield, Massachusetts	PCBs	Water depth typically 3-4 feet. Can range from 2-10 feet.	2-3 acres	2002	SMWG 2008
Lower Fox River OU2 – 5 Appleton to Green Bay, Wisconsin	PCBs	39 mile long river; shallow water up to 20 to 24 feet deep in navigation channel.	450 acres	ongoing	SMWG 2008
Koppers Superfund Site Charleston, South Carolina	PAHs, pentachoro-phenol, trace dioxin, lead, arsenic	Ashley River; intertidal system; 1,500 feet reach; cap mostly in intertidal zone; Under 6 feet of water at high tide.	3 acres	2001	SMWG 2008

Notes:

1. This table presents a summary of selected sediment remediation sites where capping was selected as a component of the remedy, and where site conditions (water levels, flow conditions, and/or COCs) are similar to the SJRWP Site.
2. This list is meant to be representative and is not exhaustive. In a 2005 summary prepared by USACE, capping was shown to have been selected as a remedy for sediment remediation at more than 80 sites in the United States.

Table 4-1b
Selected Sediment Dredging Projects

Sediment Project	Chemicals of Concern	Dredging Method	Volume Dredged (cy)	Date Constructed	References
Black Lagoon/Detroit River Trenton, MI	PCBs, PAHs, heavy metals (including mercury, lead and zinc), oil and grease	Mechanical	115,000	2004	USEPA 2009d
Duwamish Diagonal Seattle, WA	PCBs, mercury, and phthalates.	Mechanical	66,000	2003	SMWG 2008
Hudson River Phase 1 Glenns Falls, NY	PCBs	Hydraulic and Mechanical	293,000	2009	Anchor QEA and Arcadis 2010
Kinnickinnic River Milwaukee, WI	PCBs and PAHs	Mechanical	167,000	2009	USEPA 2009e
Lower Fox River - Phase 1 De Pere, WI	PCBs	Hydraulic	132,000	2007	Shaw et. al. 2008
Lower Saginaw River Saginaw, MI	PCBs	Mechanical	345,000	2001	SMWG 2008
Saginaw River - Wickes Park Midland, MI	Dioxins/Furans	Hydraulic	625	2007	USEPA 2008
St. Lawrence River (Reynolds) Massena, NY	PCBs, PAHs, PCDFs	Hydraulic and Mechanical	86,000	2001	Malcolm Pirnie and TAMS Consultants 2004
Tittabawassee River - Reach D Midland, MI	Dioxins/furans, PAHs, metals, chlorinated organic compounds	Hydraulic and Mechanical	19,200	2007	Dow 2009

Table 4-2
Release Case Studies

Project	Environmental Dredging Activity	BMPs	Source of Release Estimate	Contaminant Mass Released	Primary Reference
1995 Grasse River NTCRA Pilot Study	3,000 cy of sediment and debris removed using hydraulic dredge for sediments	Dredging operation BMPs and silt curtains	Caged fish monitoring	Adjacent fish tissue concentrations increased 50x; 0.9 km downstream fish tissue concentrations increased 5x	"Non-Time Critical Removal Action (NTCRA) Pilot Dredging in the Grasse River" presentation to the NAS Panel on Risk-management Strategy for PCB-Contaminated Sediments. November 8, 1999.
1999-2000 Fox River SMU 56/57 Dredging Pilot Study	82,000 cy removed using hydraulic cutterhead dredge	Dredging operation BMPs and silt curtains	Water quality monitoring data collected 100 to 200 feet downstream of the dredge, outside of silt curtains	Average **2.2%** of dredged PCB mass released into water column, with roughly 30% as dissolved phase PCBs	Steuer, J.J., 2000. A mass-balance approach for assessing PCB movement during remediation of a PCB-contaminated deposit on the Fox River, Wisconsin. USGS Water-Resources Investigations Report 00-4245.
2004 Duwamish/ Diagonal Early Action	70,000 cy removed using clamshell mechanical dredge	Dredging operation BMPs	Fate/transport and food web modeling to simulate measured fish tissue PCB increases during and after dredging	Fish tissue increases simulated assuming an average **3%** (range: 1 to 6%) of dredged PCB mass released and available for bioaccumulation	Stern, J. H., 2007. Temporal effects of dredge-related releases on fish tissue concentrations: Implications to achieving net risk reduction. SETAC North America 28th Annual Meeting, Nov. 2007, Milwaukee, WI.
2005 Grasse River Remedial Options Pilot Study	25,000 cy removed using hydraulic cutterhead dredge	Dredging operation BMPs and silt curtains	Water quality monitoring data collected more than 2,000 feet downstream of the dredge, outside of silt curtains	Average **3%** of dredged PCB mass released into water column, with more than 50% as dissolved phase PCBs	Connolly J.P., J.D. Quadrini , and L.J. McShea, 2007. Overview of the 2005 Grasse River Remedial Options Pilot Study. In: Proceedings, Remediation of Contaminated Sediments—2007. Savannah, GA. Columbus (OH): Battelle.
2005 Lower Passaic River Dredging Pilot Study	4,000 cy removed using clamshell mechanical dredge	Dredging operation BMPs and rinse tank	Water quality monitoring data collected 400 feet downstream of the dredge over the 5 day dredging event	Average **3 to 4%** (range: 1 to 6%) of dredged dioxin mass released into water column	Lower Passaic River Restoration Project Team, 2009. Revision and Updates to the Environmental Dredging Pilot Study. Project Delivery Team Meeting. March 2009.
2009 Hudson River Phase I Dredging	280,000 cy removed using clamshell mechanical dredge	Dredging operation BMPs and silt curtains	Water quality monitoring data collected more than 10,000 feet downstream of the dredge, outside of silt curtains	Average **3 to 4%** of dredged PCB mass released into water column, with 70 to 90% as dissolved phase PCBs	Anchor QEA and Arcadis, 2010. Phase 1 Evaluation Report: Hudson River PCBs Superfund Site. Report prepared for General Electric, Albany, New York. March 2010.

Table 4-3

Summary of Quantities and Durations - Area North of I-10

	Alternative 1N Armored Cap and Ongoing OMM (No Further Action)	Alternative 2N Armored Cap	Alternative 3N Permanent Cap	Alternative 3aN Enhanced Permanent Cap	Alternative 4N Partial Solidification/ Stabilization	Alternative 5N Partial Removal	Alternative 5aN Partial Removal	Alternative 6N Full Removal of waste Materials
Site Preparation								
TCRA Armor Rock Removal (cy)	N/A	N/A	0	0	8,500	8,500	27,400	29,900
Duration (days)	N/A	N/A	0	0	14	14	46	50
Sheetpile Install (lf)	N/A	N/A	0	0	800	0	3,100	0
Duration (days)	N/A	N/A	0	0	40	0	60	90
Perimeter Berm Install (lf)	N/A	N/A	0	0	0	0	820	0
Duration (days)	N/A	N/A	0	0	0	0	16	0
Sheetpile Removal (lf)	N/A	N/A	0	0	800	0	3,100	0
Duration (days)	N/A	N/A	0	0	40	0	60	90
Perimeter Berm Removal (lf)	N/A	N/A	0	0	0	0	820	0
Duration (days)	N/A	N/A	0	0	0	0	16	0
Construction of a Permanent Cap								
Armor Rock Placement (cy)	N/A	N/A	3,400	51,900	3,400	3,400	1,400	0
Rubble Mound Protection (cy)	N/A	N/A	1,600	1,600	1,600	1,600	1,600	0
Treatment								
Sediment Solidification (cy)	N/A	N/A	0	0	52,000	0	0	0
Duration (days)	N/A	N/A	0	0	173	0	0	0
Removal								
Dredging (cy)	N/A	N/A	0	0	0	52,000	137,600	152,000
Residuals Cover/Backfill (cy)	N/A	N/A	0	0	0	52,000	13,700	19,800
Duration (days)	N/A	N/A	0	0	0	169	199	290
Armored Cap Restoration								
Armor Rock Replacement (cy)	N/A	N/A	0	0	8,000	8,000	0	0
Duration (days)	N/A	N/A	0	0	53	53	0	0
TOTAL DURATION (months)	**N/A**	**N/A**	**2**	**15**	**17**	**13**	**19**	**19**

Notes:
1.All quantities include a 20 percent contingency
2.Quantities shown in cubic yards (cy) or linear feet (lf)
3.Durations assume a 22 day month, rounded up
4.Production rates assumed as follows:
a.Armor Rock Removal - 600 cy/day
b.Sheetpile Install/Remove - 20 lf/day
c.Armor Rock Placement - 150 cy/day
d.Perimeter Berm Install/Remove - 50 lf/day
e.Solidification - 300 cy/day; f. Dredging - 800 cy/day; g. Residuals Cover/Backfill - 500 cy/day

Table 4-4
Summary of Quantities and Durations - Area South of I-10

	Alternative 1S No Further Action	Alternative 2S Institutional Controls (ICs)	Alternative 3S Enhanced ICs	Alternative 4S Removal and Off-site Disposal
Site Preparation				
Stockpile/Loading Area Preparation	N/A	N/A		
Duration (days)	N/A	N/A	3	3
Construction				
Structure Removal (sf)	N/A	N/A	0	800
Duration (days)	N/A	N/A	0	5
Pad Removal (sf)	N/A	N/A	0	9,710
Duration (days)	N/A	N/A	0	4
Land-based Excavation (cy)	N/A	N/A	8,000	50,000
Duration (days)	N/A	N/A	5	50
House debris (ton)				20
Concrete Pad (ton)				364
Portland Cement (soil amendment, ton)				3,333
Marker Layer Placement (sy)	N/A	N/A	12,000	0
Duration (days)	N/A	N/A	2	0
Backfill (cy)	N/A	N/A	10,400	50,000
Duration (days)	N/A	N/A	10	50
Vegetative Cover (acre)	N/A	N/A	2	2
Duration (days)	N/A	N/A	1	1
Build Replacement Structure (sf)	N/A	N/A	0	800
Duration (days)	N/A	N/A	0	20
Replace Pad (sf)	N/A	N/A	0	9,710
Duration (days)	N/A	N/A	0	7
TOTAL DURATION (months)	**N/A**	**N/A**	**1**	**7**

Notes:

1. Durations assume a 22 day month, rounded up.
2. Production rates assumed as follows:
   a. Shallow Excavation/On-site Stockpiling - 1,500 cy/day
   b. Excavation/Soil Amendment - 1,000 cy/day
   c. Backfill - 1,000 cy/day
   d. Structure Removal - 150 sf/day
   e. Pad Removal - 2,500 sf/day
   f. Marker Layer Placement - 10,000 sy/day
   g. Vegetative Cover - 5 acre/day
   h. Replace Structure - 40 sf/day
   i. Replace Pad - 1,500 sf/day

Table 6-1a
Summary of Detailed Evaluation- Area North of I-10

Remedial Alternative	Evaluation Criterion						
	Overall Protection	Compliance with ARARs	Long-Term Effectiveness	Reduction of TMV Through Treatment	Short-Term Effectiveness	Implementability	Cost Effectiveness
1N Armored Cap and No Further Action	Meet	Meet	Low-Med	Low	High	High	High
2N Armored Cap, ICs and MNR	Meet	Meet	Low - Med	Low	High	High	High
3N Permanent Cap, ICs and MNR	Meet	Meet	Medium	Low	High	High	Med-High
3aN Enhanced Cap, ICs and MNR	Meet	Meet	Med-High	Low	High	High	Medium
4N Partial Solidification/ Stabilization, Permanent Cap, ICs and MNR	Meet	Meet	Med-High	High	Medium	Med-Low	Medium
5N Partial Removal, Permanent Cap, ICs and MNR	Meet	Meet	Med-High	Medium	Medium	Medium	Low-Med
5aN Partial Removal of Materials Exceeding the PCL, Permanent Cap, ICs and MNR	Meet	Meet	Med- High	Medium	Medium	Medium	Medium
6N Full Removal of Materials Exceeding the PRG, MNR, & ICs	Meet	Meet	High	Medium	Medium	Medium	Medium

Notes:

Overall Protection and Compliance with ARARs are Threshold Criteria. For all other criteria, remedial alternatives are evaluated to determine the degree to which the criterion is addressed.

ARAR - Applicable or relevant and appropriate requirements of environmental laws.

IC - Institutional controls

Med - Medium

MNR - Monitored natural recovery

TMV - Toxicity, mobility or volume

Table 6-1b
Summary of Detailed Evaluation
Area South of I-10

Remedial Alternative		Evaluation Criterion						
		Overall Protection	Compliance with ARARs	Long-Term Effectiveness	Reduction of TMV Through Treatment	Short-Term Effectiveness	Implementability	Cost Effectiveness
1S	No Further Action	No	Meet	Low	Low	High	High	High
2S	ICs	Meet	Meet	Medium	Low	High	High	High
3S	Enhanced ICs	Meet	Meet	Med-High	Low	High	High	Med-High
4S	Removal and Off-site Disposal	Meet	Meet	High	Medium	Med - High	Med-High	Medium

Notes:

Overall Protection and Compliance with ARARs are Threshold Criteria, for which the evaluation is that the remedial alternative does or does not meet the criterion. For all other criteria, remedial alternatives are evaluated to determine the degree to which the criterion is addressed.

ARAR - Applicable or relevant and appropriate requirements of environmental laws.

IC - Institutional controls

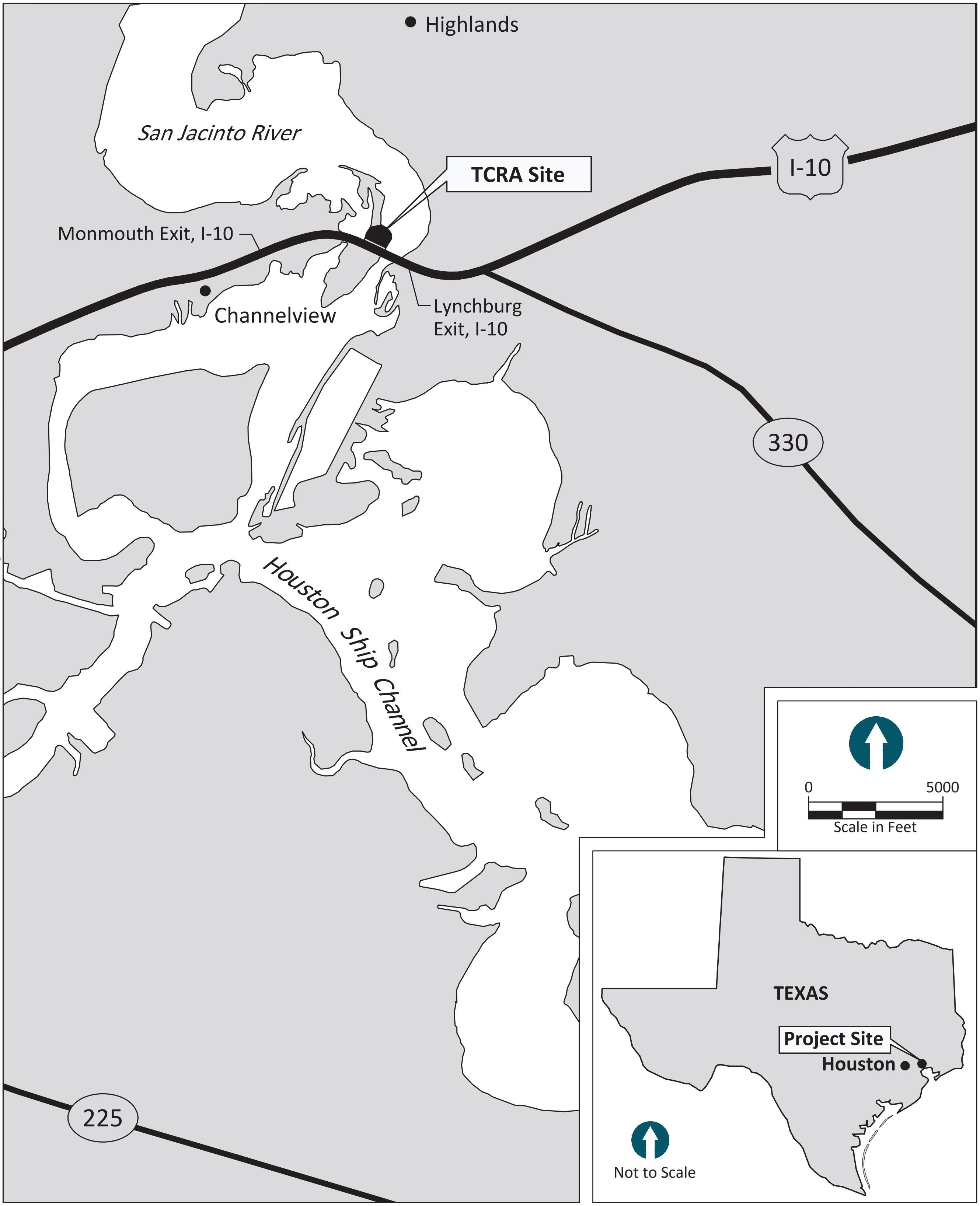
Med - Medium

MNR - Monitored natural recovery

PCL - Protective concentration level

TMV - Toxicity, mobility or volume

FIGURES



K:\Jobs\090557-San Jacinto\090557-01 - San Jacinto\09055701-RP-049.dwg FIG 1-1 FS

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Figure 1-1
Vicinity Map
Feasibility Study
San Jacinto River Waste Pits Superfund Site

ANCHOR QEA
integral consulting inc.

077508

LEGEND

- Interstate 10
- Original (1966) Perimeter of the Impoundments North of I-10
- USEPA's Preliminary Site Perimeter
- Soil Investigation Area 4

NOTES:

1.Designation of the Sand Separation Area is intended to be a general reference to areas in which such activities are believed to have taken place based on a review of aerial photography from 1998 through 2002.
2. Aerial Imagery: Copyright Microsoft Bing Maps, 2010.
3. Hog Island location source: Google Earth, 2011.

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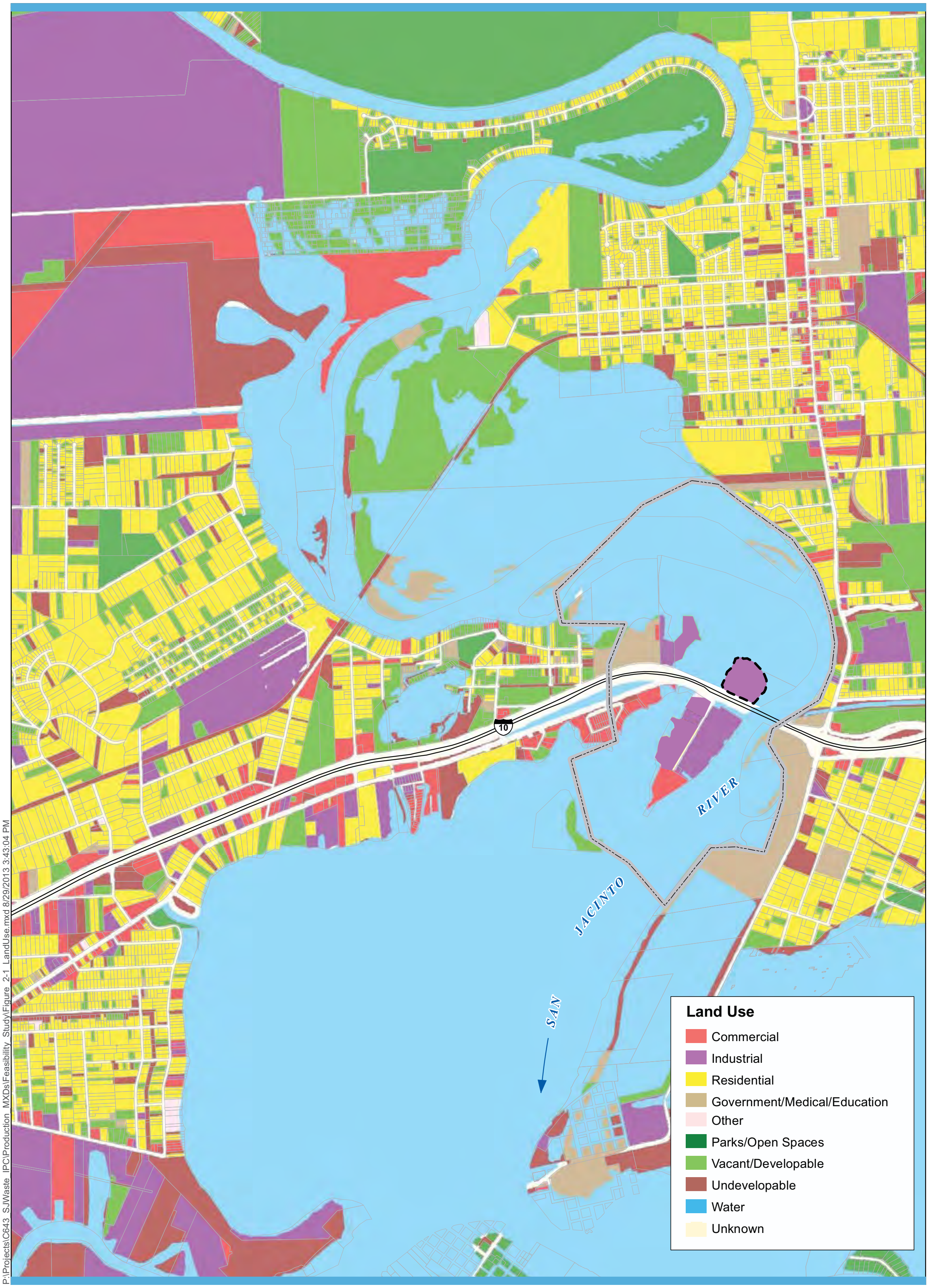
ANCHOR QEA

integral

0 1,500 3,000
Feet

Figure 1-2
USEPA's Preliminary Site Perimeter and Surrounding Area
Feasibility Study
San Jacinto River Waste Pits Superfund Site



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ANCHOR QEA integral consulting inc

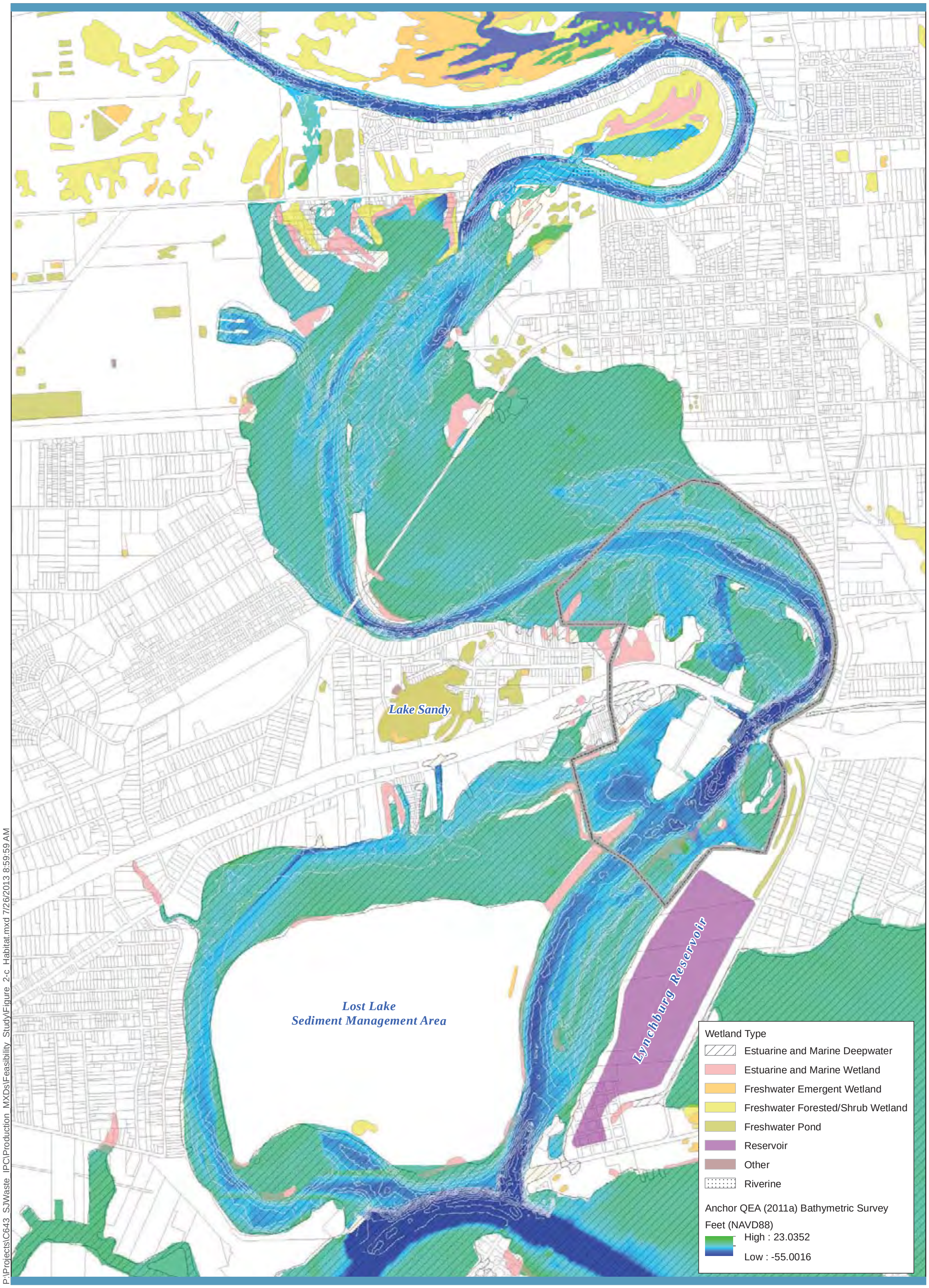
USEPA's Preliminary Site Perimeter
Limit of TCRA Cap
Tax Parcel Boundary

0 0.5
Scale in Miles

FEATURE SOURCES:
Land Use: Modified from Houston-Galveston Area Council*
Parcel Boundaries: Harris County Appraisal District

*Modifications to land use within USEPA's Preliminary Site Perimeter to show reasonably anticipated future land use where appropriate.

Figure 2-1
Land Use in the Vicinity of USEPA's Preliminary Site Perimeter
Feasibility Study
San Jacinto River Waste Pits Superfund Site



ANCHOR QEA integral consulting inc

USEPA's Preliminary Site Perimeter

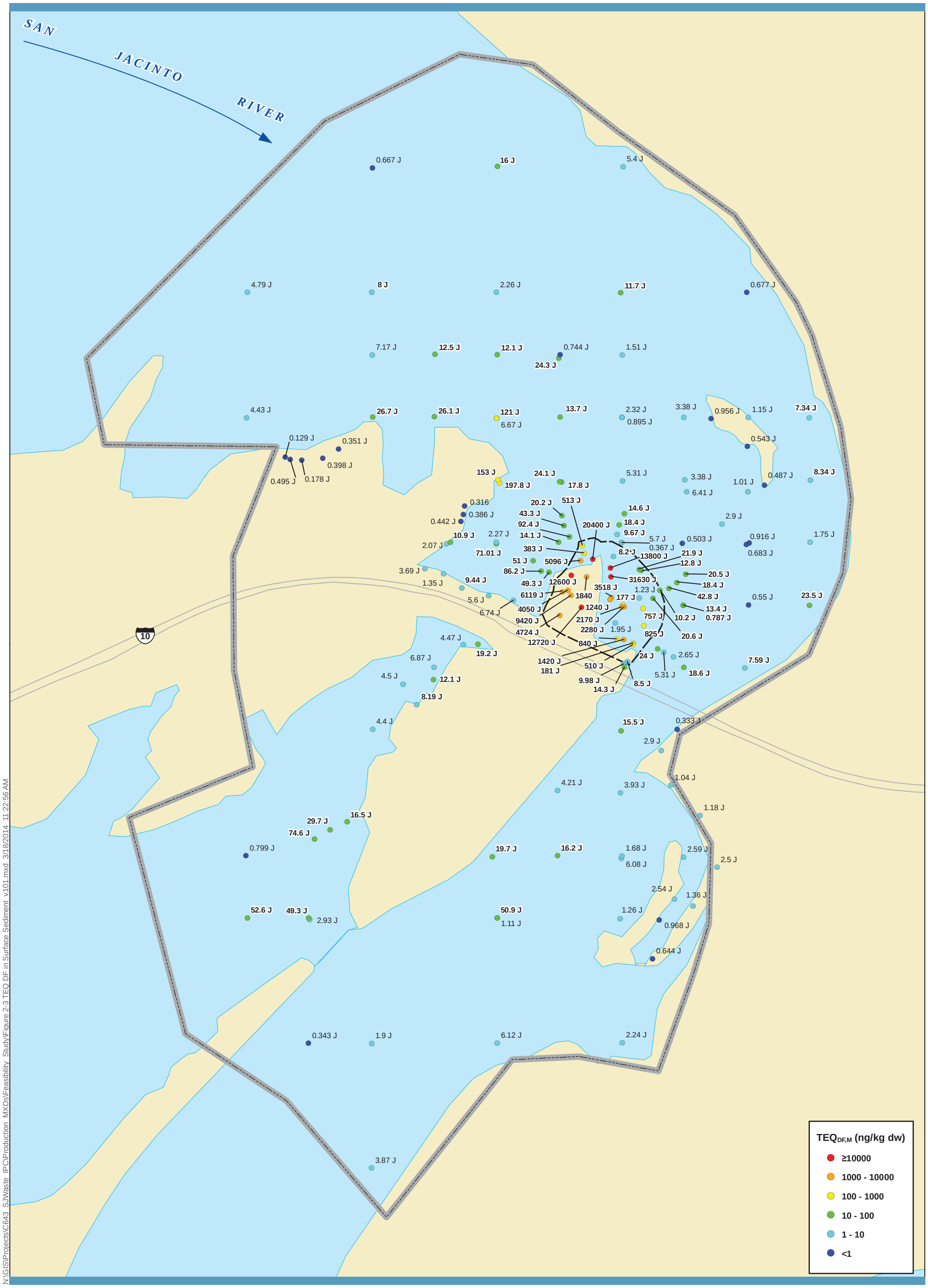
1-Meter 1995 Bathymetric Contour

Parcel Boundary

Figure 2-2
Habitats in the Vicinity of USEPA's Preliminary Site Perimeter
Feasibility Study
San Jacinto River Waste Pits Superfund Site

0 0.5
Miles

FEATURE SOURCES:
Bathymetry and Contours: Anchor QEA (2011a)
Wetlands: U.S. Fish and Wildlife Service.
Parcel Boundaries: Harris County Appraisal District.



N:\GIS\Projects\C643_SJWaste_IPC\Production_MXDs\Feasibility_Study\Figure 2-3 TEQ DF in Surface Sediment_v101.mxd 3/18/2014 11:22:56 AM

ANCHOR QEA
integral consulting inc.

USEPA's Preliminary Site Perimeter
Limit of Armored Cap
Surface Sediment Sample Location

0 800
Feet

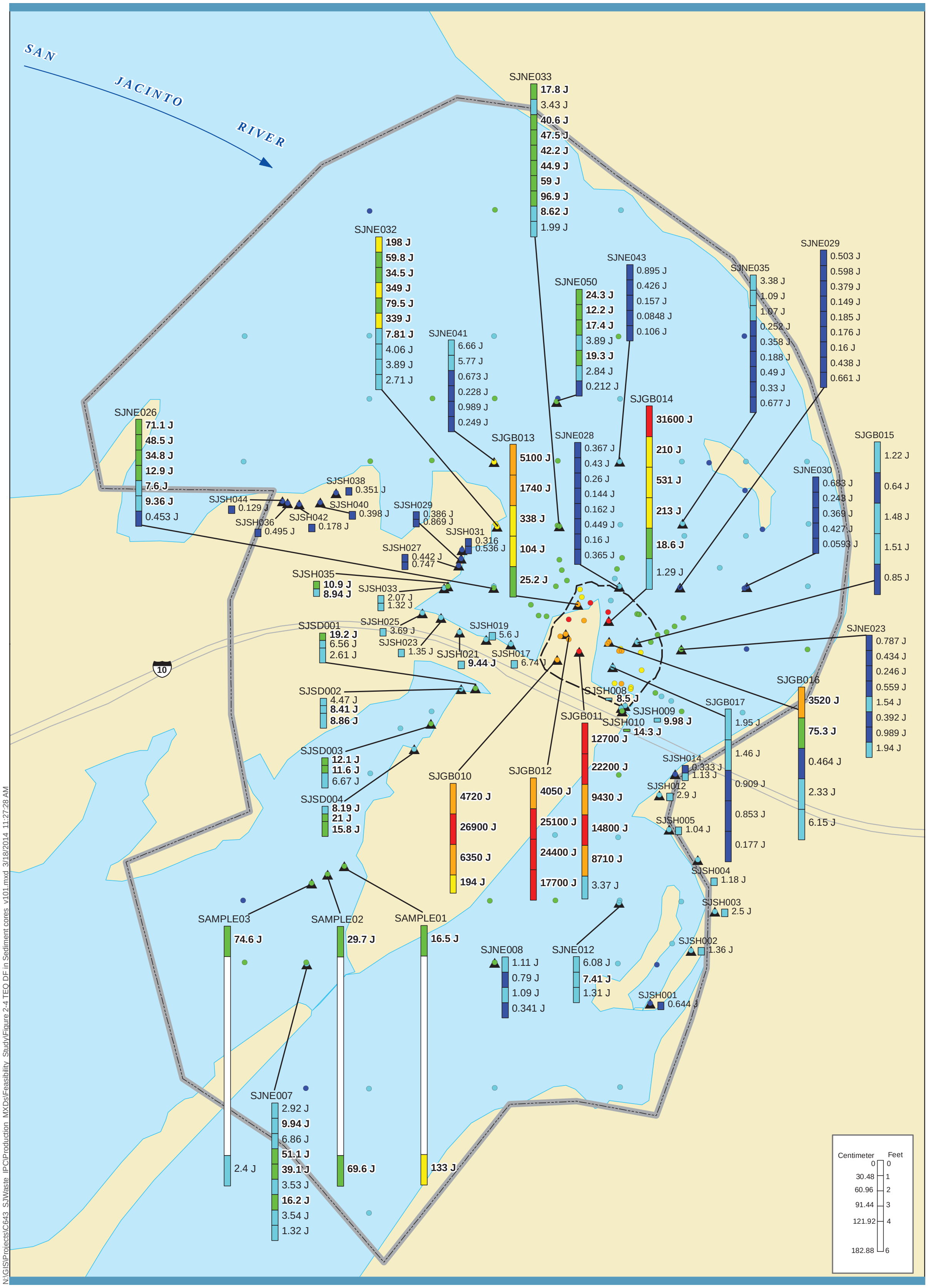
Notes:
TEQ$_{DF,M}$ = Toxicity equivalent for 2,3,7,8-TCDD calculated for dioxins and furans using mammalian TEFs from van den Berg et al. (2006) (nondetect = 1/2 detection limit)

J = Estimated. One or more congeners used to calculate the TEQ$_{DF,M}$ was not detected.

Concentrations in bold indicate values above reference envelope value (REV); REV = 7.2 ng/kg dw

Figure 2-3
TEQ$_{DF,M}$ Concentrations in Surface Sediment & Waste Material
Feasibility Study
San Jacinto River Waste Pits Superfund Site

077512



USEPA's Preliminary Site Perimeter

Limit of Armored Cap

▲ Core Location

○ Surface Sediment Sample Location

$TEQ_{DF,M}$ (ng/kg dw)

Cores

- ≥10000
- 1000 - 10000
- 100 - 1000
- 10 - 100
- 1 - 10
- <1
- No analysis

Notes:
$TEQ_{DF,M}$ = Toxicity equivalent for 2,3,7,8-TCDD calculated for dioxins and furans using mammalian TEFs from van den Berg et al. (2006) (nondetect = 1/2 detection limit)

J = Estimated. One or more congeners used to calculate the $TEQ_{DF,M}$ was not detected.

Concentrations in bold indicate values above reference envelope value (REV); REV= 7.2 ng/kg dw

ANCHOR QEA

integral consulting inc.

0 800

Scale in Feet

Figure 2-4

$TEQ_{DF,M}$ Concentrations in Cores

Feasibility Study

San Jacinto River Waste Pits Superfund Site

N:\GIS\Projects\C643_SJWaste_IPC\Production_MXDs\Feasibility_Study\Figure 2-4 TEQ DF in Sediment cores_v101.mxd 3/18/2014 11:27:28 AM

077513

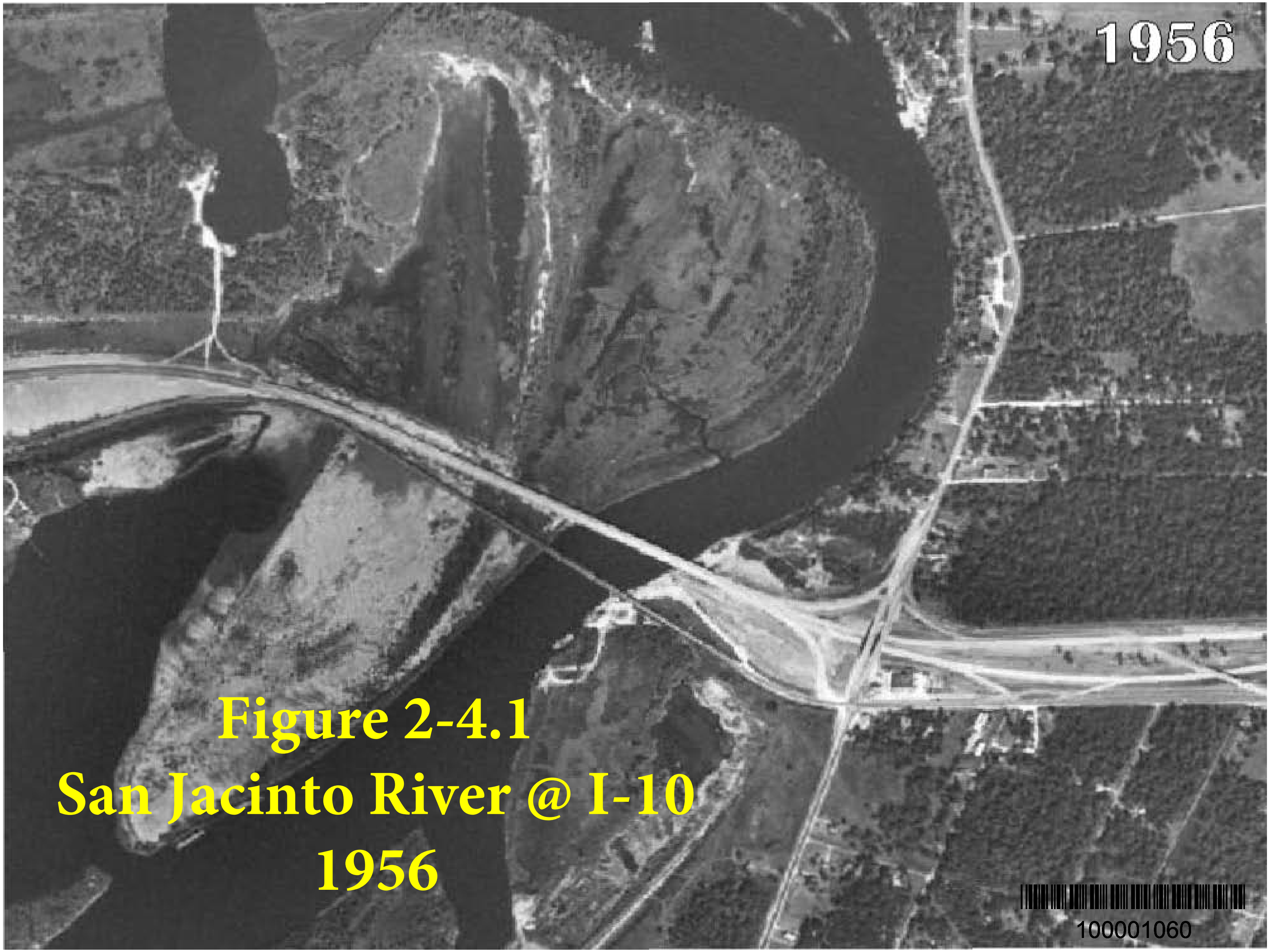


Figure 2-4.1
San Jacinto River @ I-10
1956

100001060

077514

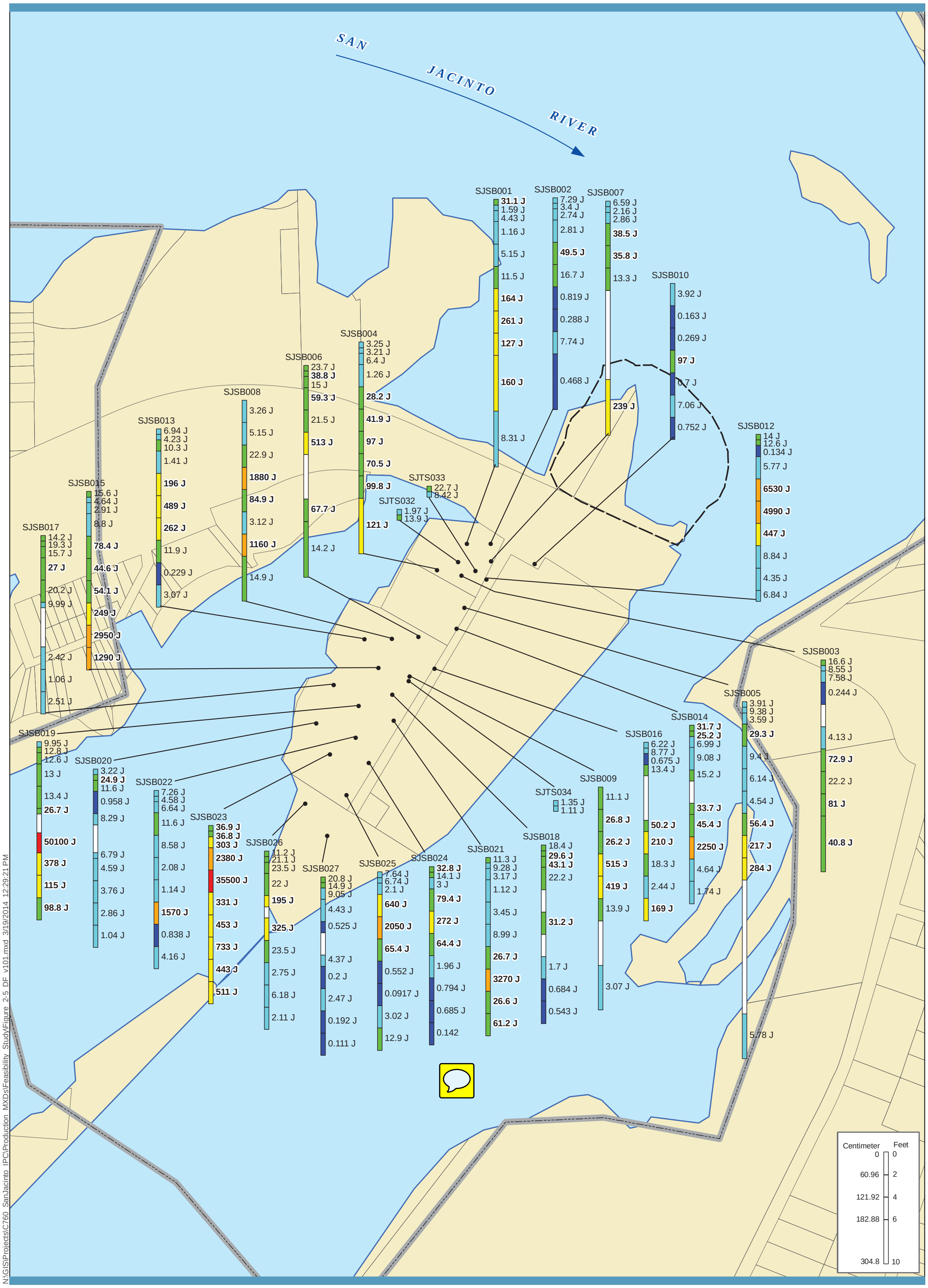
Figure 2-4.2
San Jacinto River @ I-10
1966

077515

Figure 2-4.3
San Jacinto River @ I-10
1973

077516

077517



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ANCHOR QEA
integral consulting inc.

0 800
Feet

USEPA's Preliminary Site Perimeter
Limit of Armored Cap
Soil Boring Location

Notes:
TEQ$_{DF,M}$ = Toxicity equivalent for dioxins and furans using mammalian TEFs from van den Berg et al. (2006) (nondetect =1/2 detection limit)

J = Estimated, One or more congeners used to calculate the TEQ$_{DF,M}$ was not detected

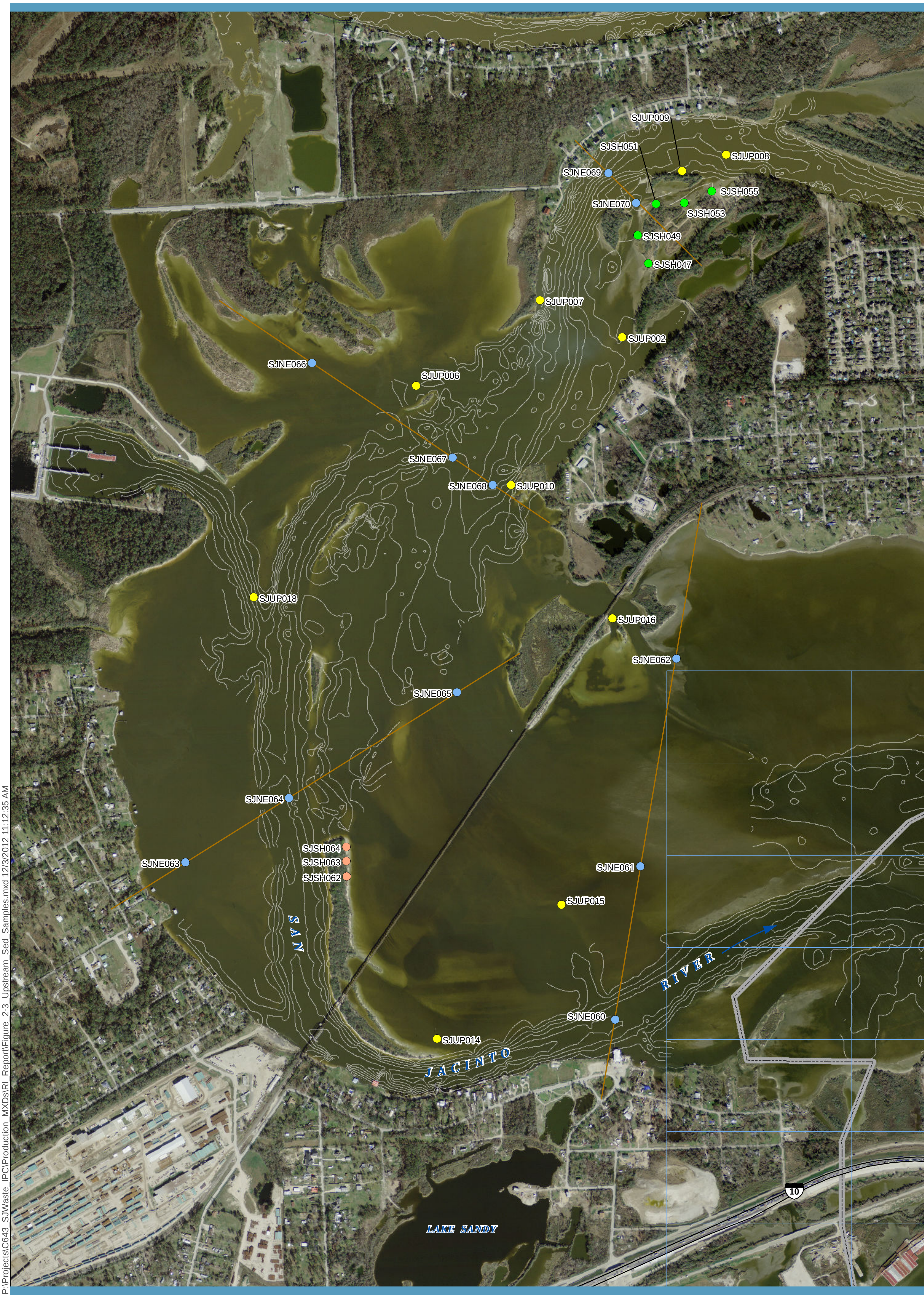
Concentrations in bold indicate values above reference envelope value (REV); REV= 24.3 ng/kg dw

FEATURE SOURCES:
Parcel Boundaries: Harris County Appraisal District
Hydrology: Harris County Flood Control District

TEQ$_{DF,M}$ (ng/kg dw)
Cores
- ≥10000
- 1000 - 10000
- 100 - 1000
- 10 - 100
- 1 - 10
- <1
- No analysis

Figure 2-5
TEQ$_{DF,M}$ Concentrations in Soil South of I-10
Feasibility Study
San Jacinto River Waste Pits Superfund Site

077518



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ANCHOR QEA
integral consulting inc.

0 800
Scale in Feet

077519

USEPA's Preliminary Site Perimeter
1-Meter 1995 Bathymetric Contour
Sampling Transect

BERA = Baseline Ecological Risk Assessment
BHHRA = Baseline Human Health Risk Assessment
COPC = Chemical of Potential Concern

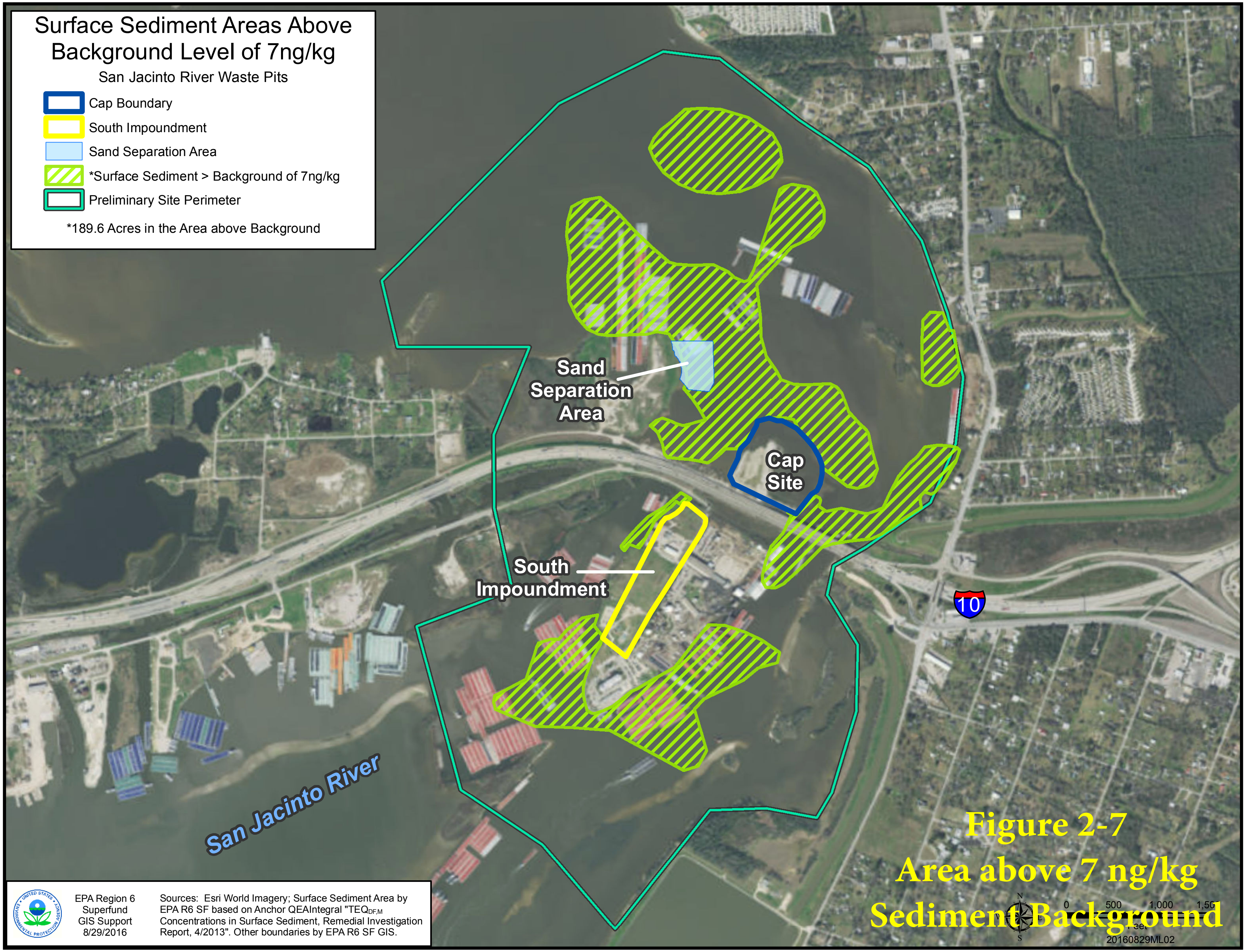
FEATURE SOURCES:
Aerial Imagery: 0.5-meter 2008/2009 DOQQs
- Texas Strategic Mapping Program (StratMap), TNRIS;
Contours: NOS Survey H10619 (1995)

Actual Sample Location

- Surface Sediment for BHHRA (Primary COPCs)[a]
- Surface Sediment (Dioxins and Furans only)
- Surface Sediment (Primary and Secondary COPCs)
- Surface Sediment for BERA (Primary COPCs)

[a]Subsurface samples were collected at SJSH047 and SJSH055 but were determined to be unnecessary (Integral 2011a), and were disposed.

Figure 2-6
Upstream Background Sediment Sampling Locations
Remedial Investigation Report
San Jacinto River Waste Pits Superfund Site


Surface Sediment Areas Above Background Level of 7ng/kg
San Jacinto River Waste Pits
Cap Boundary
South Impoundment
Sand Separation Area
*Surface Sediment > Background of 7ng/kg
Preliminary Site Perimeter
*189.6 Acres in the Area above Background
Sand Separation Area
Cap Site
South Impoundment
San Jacinto River
10
Figure 2-7
Area above 7 ng/kg
Sediment Background
0
500
1,000
20160829ML02
EPA Region 6
Superfund
GIS Support
8/29/2016
Sources: Esri World Imagery; Surface Sediment Area by EPA R6 SF based on Anchor QEAIntegral "TEQDF,M Concentrations in Surface Sediment, Remedial Investigation Report, 4/2013". Other boundaries by EPA R6 SF GIS.

077520

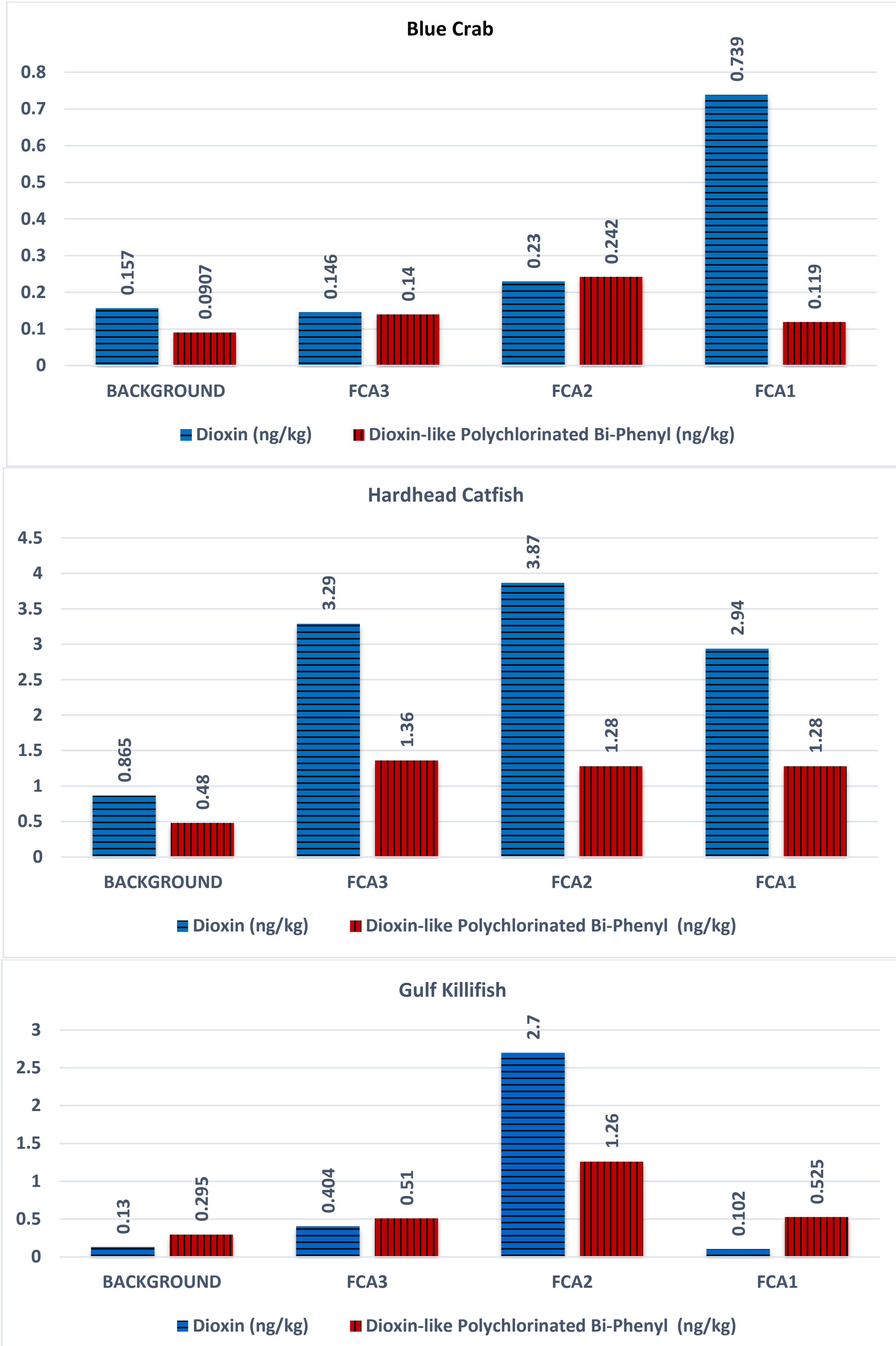
Figure 2-8
Area above 30 ng/kg Sediment PRG

077521

Figure 2-9
Exposure Units for Fish and Shellfish Tissue, Area North of I-10 and Aquatic Environment
San Jacinto River Waste Pits Site

Modified from: Integral Consulting Inc. and Anchor QEA, LLC. 2013. Baseline Human Health Risk Assessment, San Jacinto River Waste Pits Superfund Site. Prepared for: McGinnes Industrial Maintenance Corporation, International Paper Company, and U.S. Environmental Protection Agency, Region 6. May.

077522



FCA 1: Immediately Downstream
FCA 2: Adjacent to Northern Impoundments
FCA 3: Immediately Upstream

Figure 2-10
Summary of Average
Tissue Results

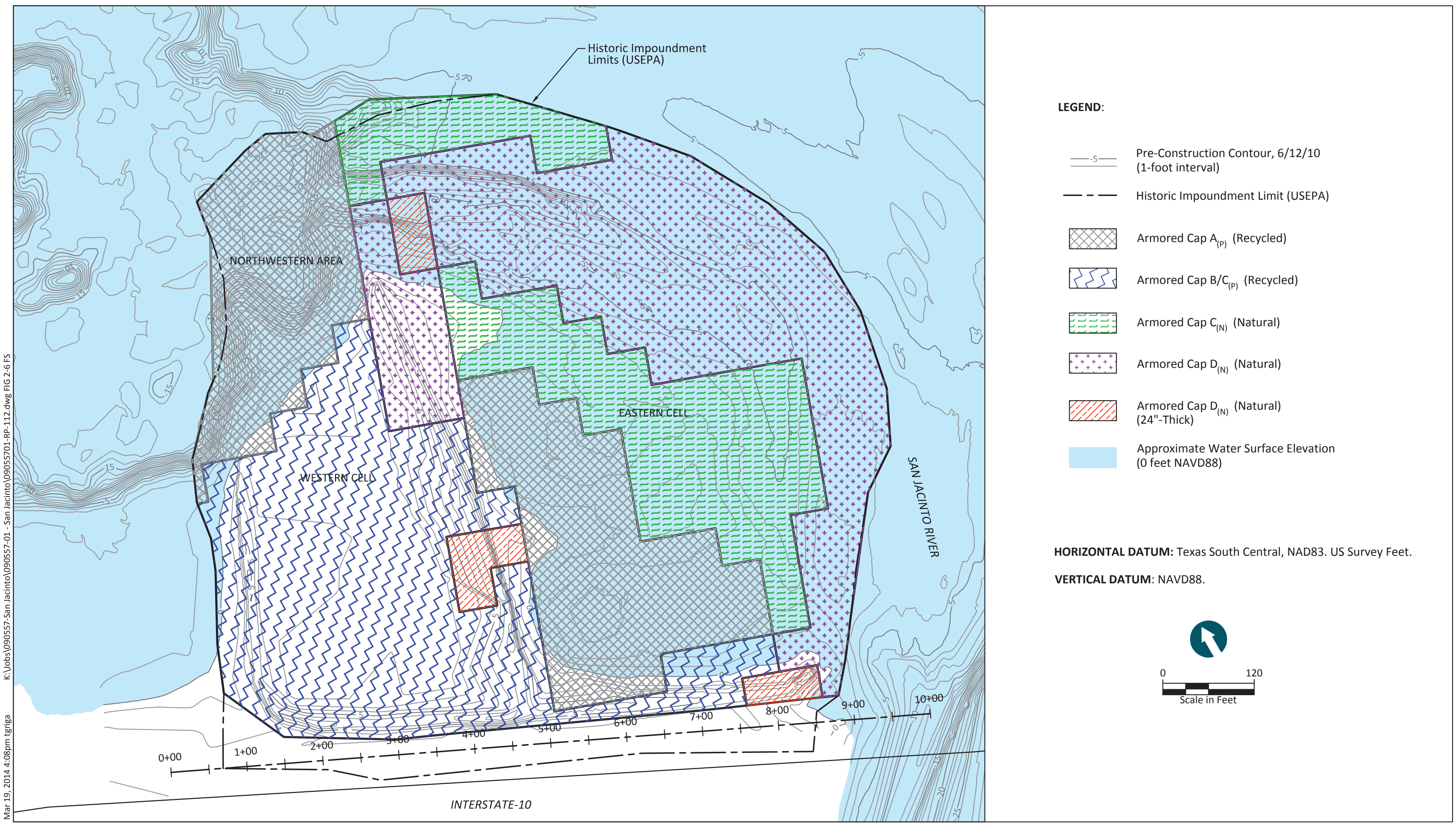


Figure 2-11
Temporary Cap As-Built Drawing
Feasibility Study
San Jacinto River Waste Pits Superfund Site

ANCHOR QEA

077524

San Jacinto River - Upstream Background Sediment Samples

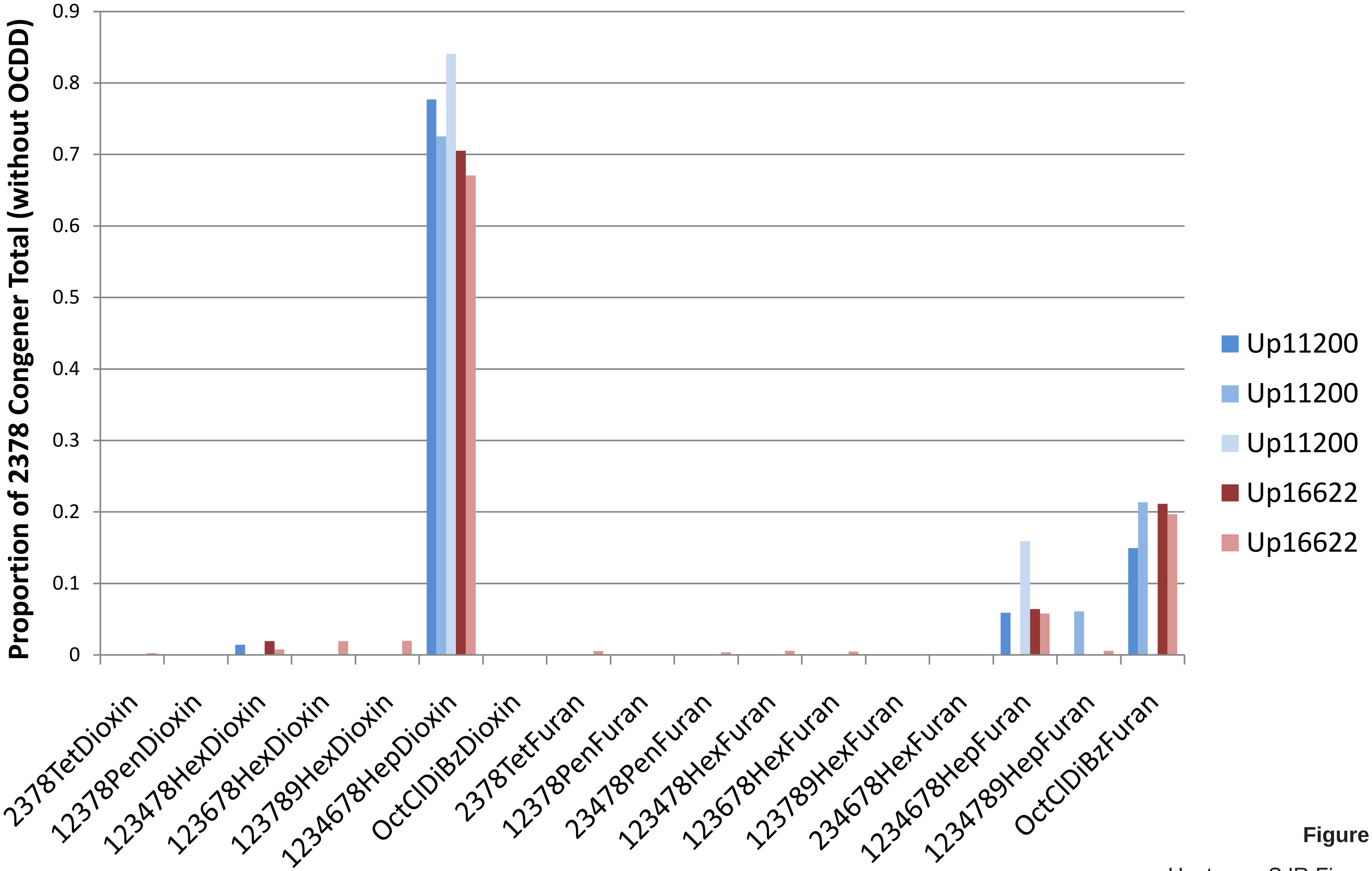


Figure 2-12

Upstream SJR Fingerprint
San Jacinto River Waste Pits
Superfund Site

077525

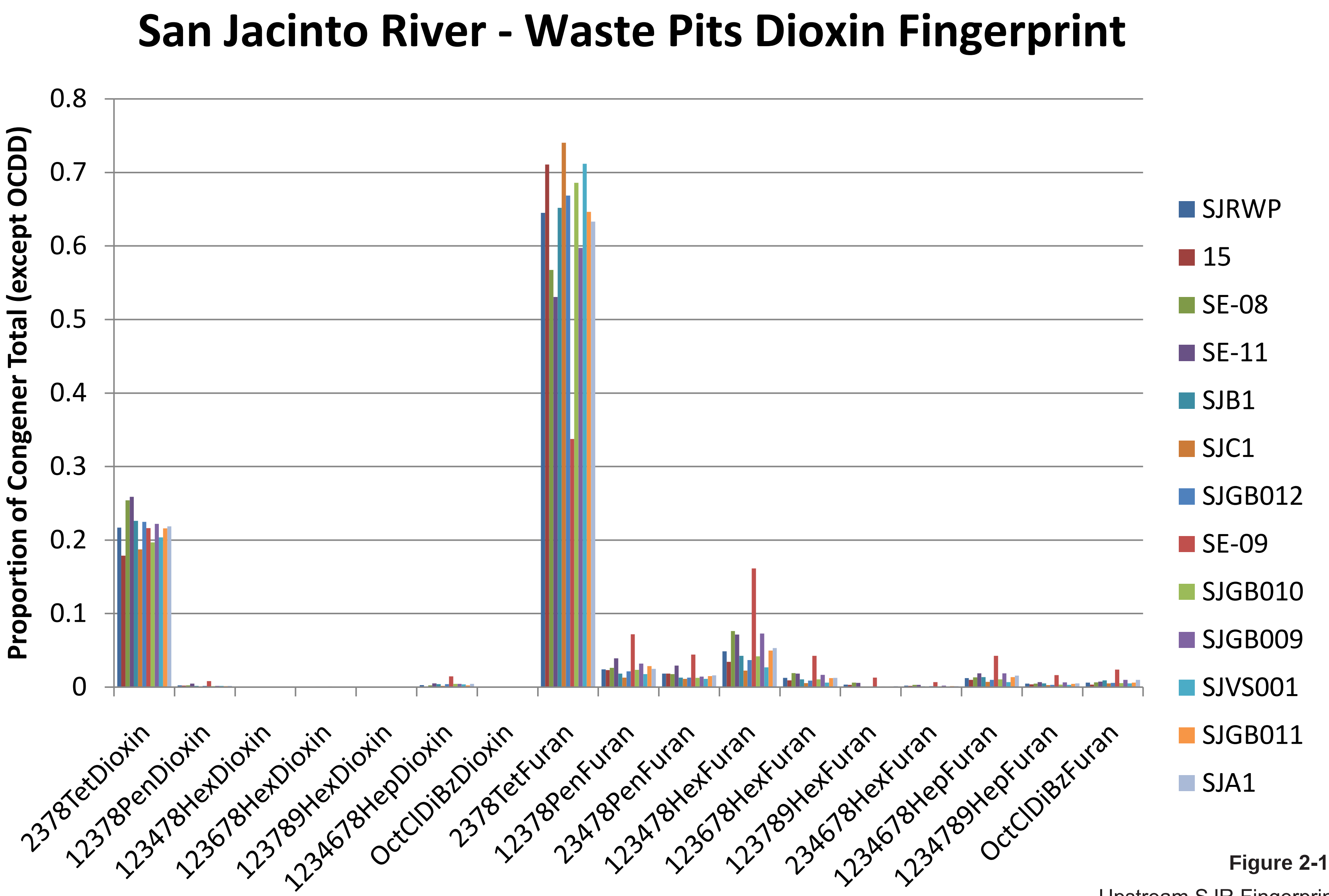


Figure 2-13

Upstream SJR Fingerprint
San Jacinto River Waste Pits
Superfund Site

077526

Figure 3-1
Exposure Units for Sediment, Area North of I-10 and Aquatic Environment Baseline
San Jacinto River Waste Pits Site

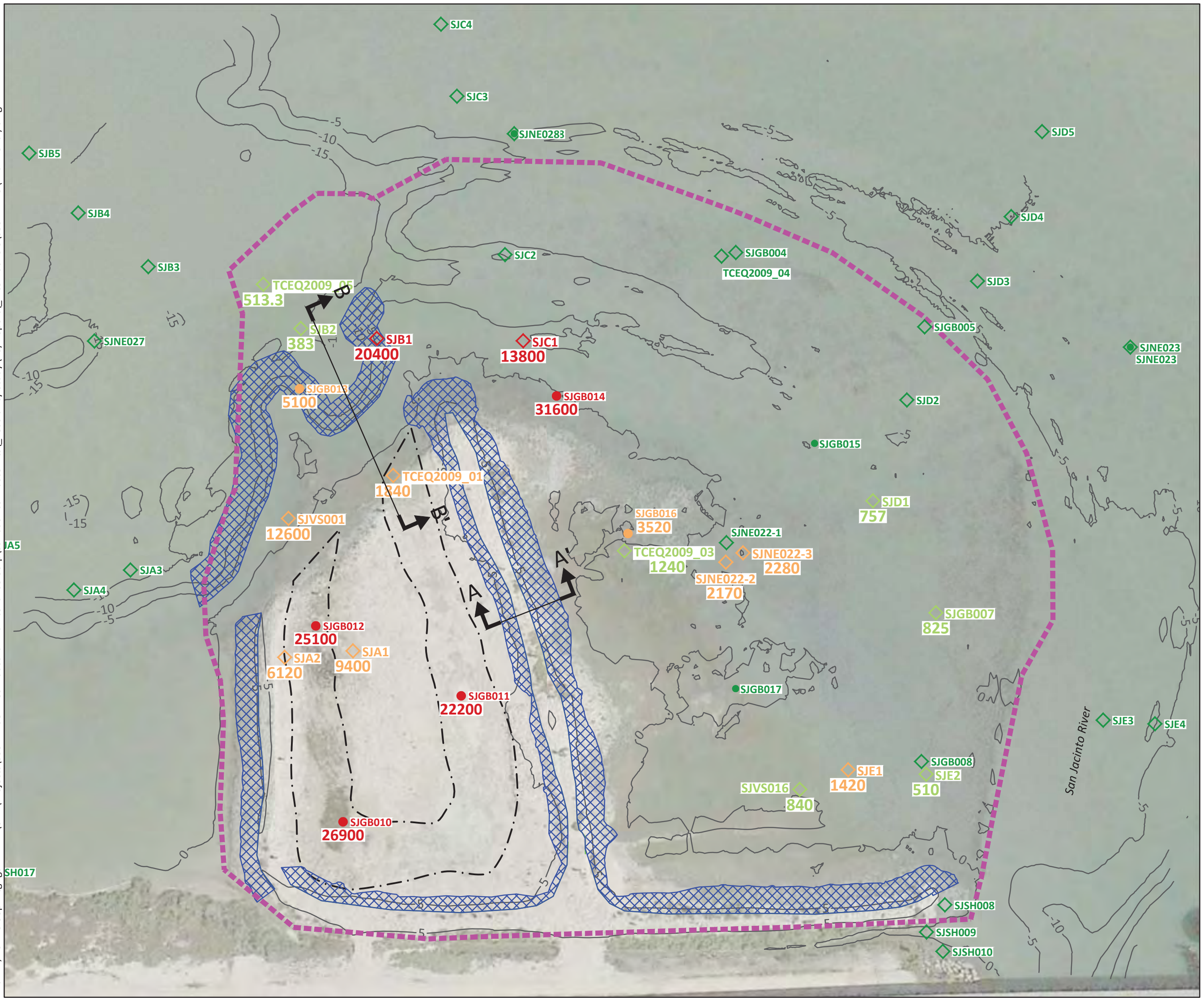
Modified from: Integral Consulting Inc. and Anchor QEA, LLC. 2013. Baseline Human Health Risk Assessment, San Jacinto River Waste Pits Superfund Site. Prepared for: McGinnes Industrial Maintenance Corporation, International Paper Company, and U.S. Environmental Protection Agency, Region 6. May.

Figure 3-2
Exposure Units for Fish and Shellfish Tissue Area

North of I-10 and Aquatic Environment
San Jacinto River Waste Pits Site

Modified from: Integral Consulting Inc. and Anchor QEA, LLC. 2013. Baseline Human Health Risk Assessment, San Jacinto River Waste Pits Superfund Site. Prepared for: McGinnes Industrial Maintenance Corporation, International Paper Company, and U.S. Environmental Protection Agency, Region 6. May.

077528



LEGEND:

Existing Contour (5 Foot Interval)

Armored Cap Limit

Area of Additional Rock Placement for Flattening Slopes to 5H:1V on berms and 3H:1V in the Northwest Area

TCRA Footprint of Stabilization

SJGB014●	Core location:	TEQ ≥ 13,000 ng/kg
SJGB013●	Core location:	1,300 ≤ TEQ < 13,000 ng/kg
SJGB016●	Core location:	220 ≤ TEQ < 1,300 ng/kg
SJGB017●	Core location:	TEQ < 220 ng/kg
SJB1 ◇	Grab location:	TEQ ≥ 13,000 ng/kg
SJA1 ◇	Grab location:	1,300 ≤ TEQ < 13,000 ng/kg
SJB2 ◇	Grab location:	220 ≤ TEQ < 1,300 ng/kg
SJC3 ◇	Grab location:	TEQ < 220 ng/kg
825	Concentration	TEQ_{DF} (ng/kg dw) (See Note 1)

A A' Cross Section Location (See Figure 4-2)

NOTE:
1. Concentration shown at each sample location represents the highest concentration calculated at any depth interval at that location.

AERIAL SOURCE: Google Earth Pro, dated October 2012.
SOURCE: Drawing prepared from surveys provided by Hydrographic Consultants dated October 2012 and January/February 2013.
HORIZONTAL DATUM: Texas State Plane South Central, NAD83, U.S. Feet.
VERTICAL DATUM: NAVD 88.

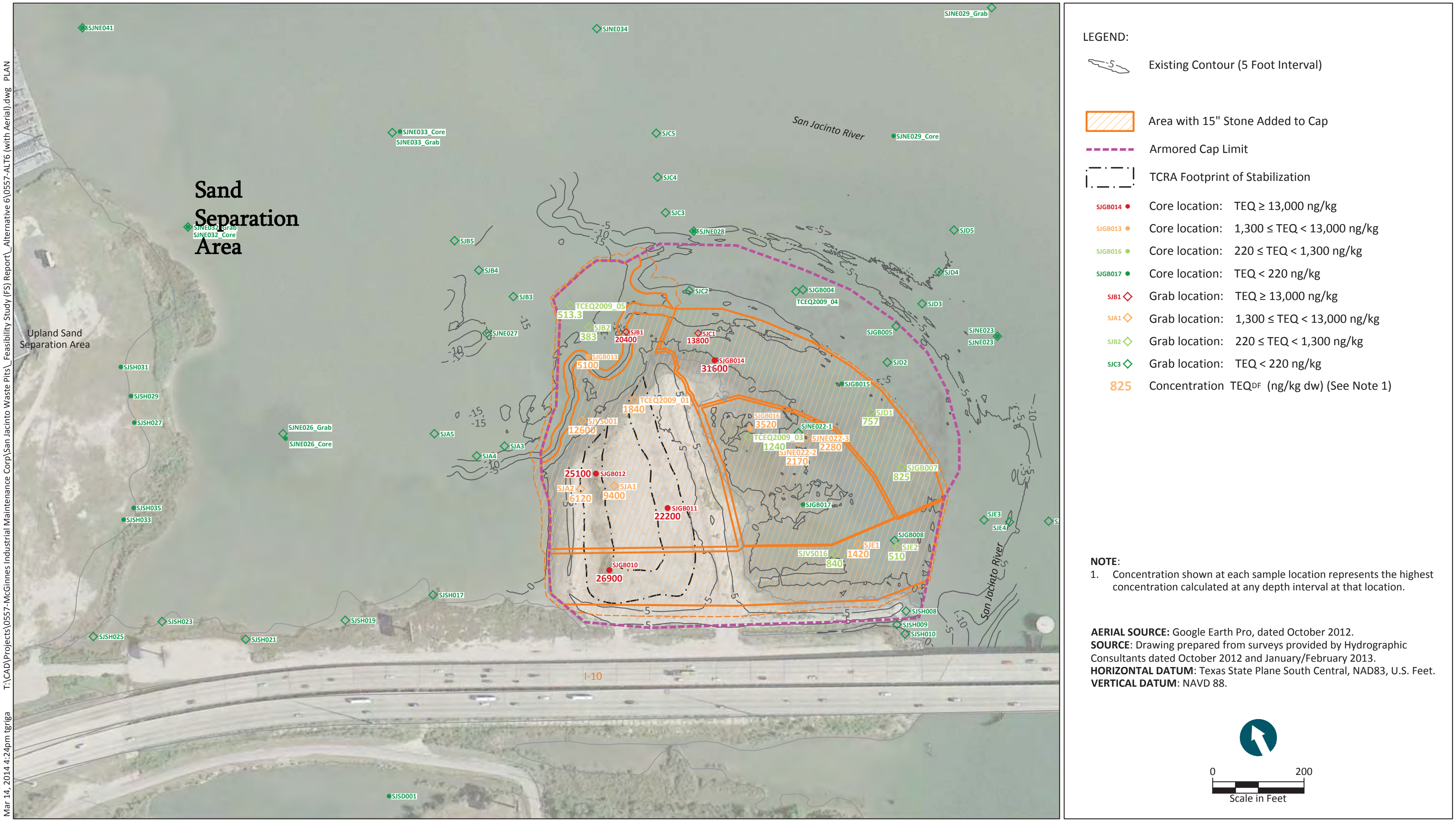
0 120
Scale in Feet

Mar 14, 2014 3:58pm tgriga T:\CAD\Projects\0557-McGinnes Industrial Maintenance Corp\San Jacinto Waste Pits_Feasibility Study (FS) Report_Alternative 3\0557-ALT3 (with Aerial).dwg PLAN

ANCHOR QEA

Figure 4-1
Plan View - Alternative 3N, Permanent Cap
Feasibility Study
San Jacinto River Waste Pits Superfund Site

077529

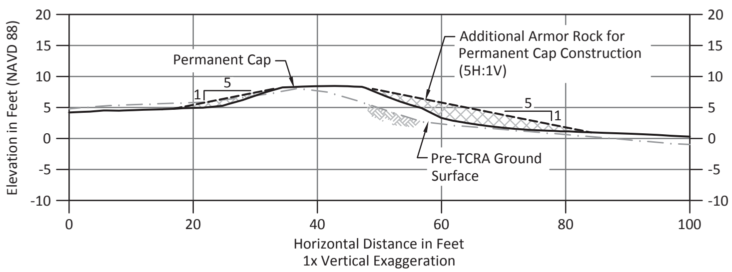


ANCHOR QEA

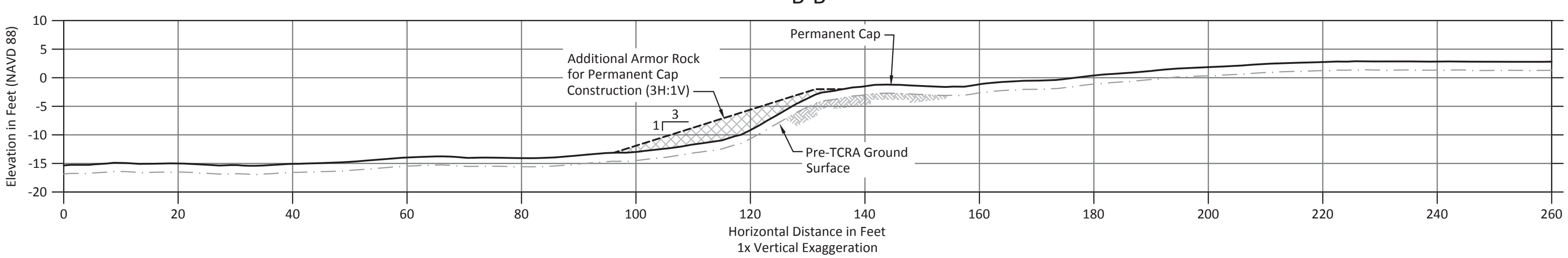
Figure 4-1a
Plan View - Alternative 3aN
Feasibility Study
San Jacinto River Waste Pits Superfund Site

077530

A-A'



B-B'

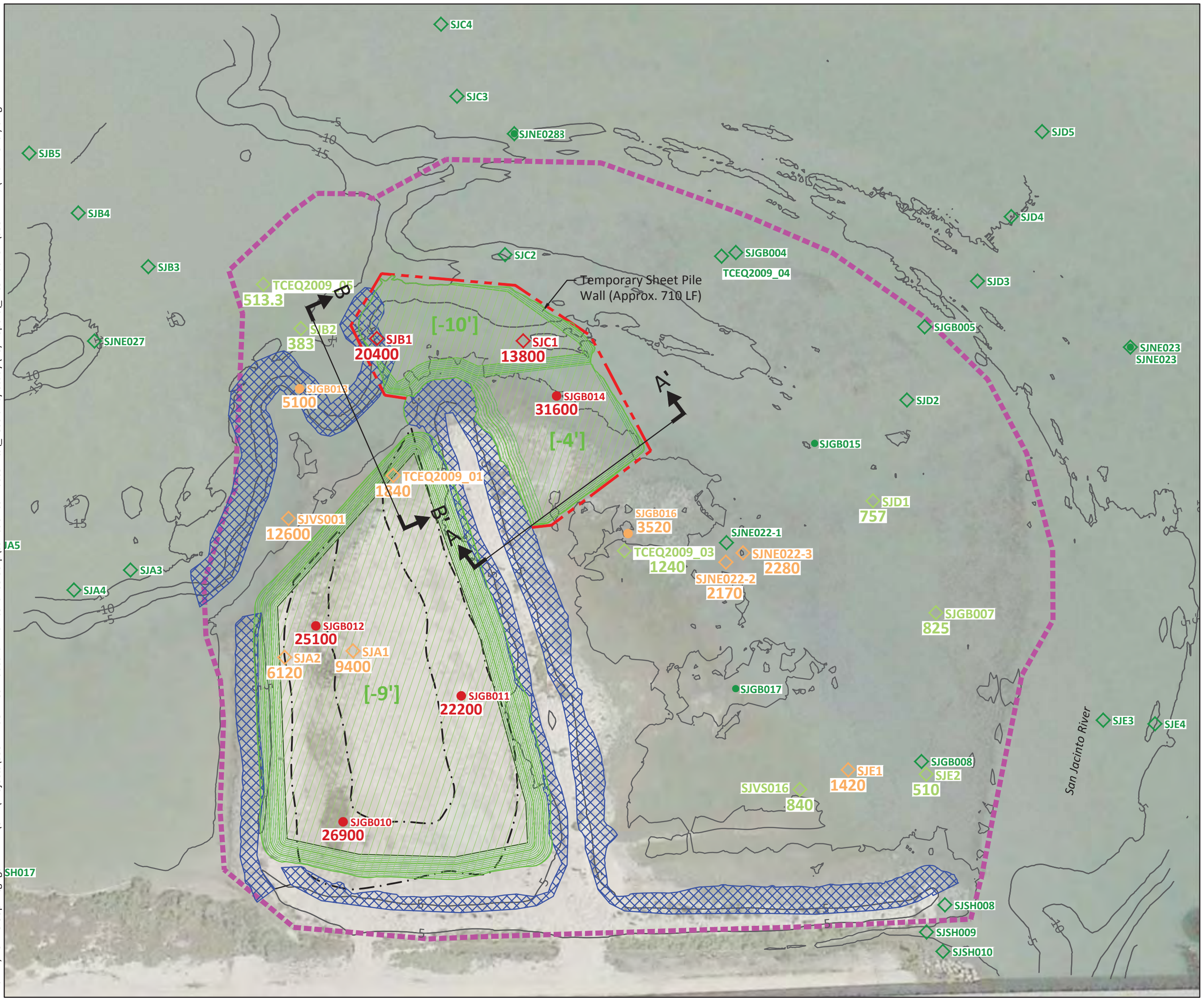


Mar 14, 2014 3:58pm tgriga T:\CAD\Projects\0557-McGinnes Industrial Maintenance Corp\San Jacinto Waste Pits_Feasibility Study (FS) Report_Alternative 3\0557-ALT3 (with Aerial).dwg SECTION

ANCHOR QEA

Figure 4-2
Cross Section A-A' - Alternative 3N
Feasibility Study
San Jacinto River Waste Pits Superfund Site

077531



LEGEND:

- Existing Contour (5 Foot Interval)
- [-4'] Target Solidification Elevation (NAVD 88)
- Solidification Area
- Temporary Sheet Pile Wall
- Armored Cap Limit
- Area of Additional Rock Placement for Flattening Slopes to 5H:1V on berms and 3H:1V in the Northwest Area
- TCRA Footprint of Stabilization
- SJGB014● Core location: TEQ ≥ 13,000 ng/kg
- SJGB013● Core location: 1,300 ≤ TEQ < 13,000 ng/kg
- SJGB016● Core location: 220 ≤ TEQ < 1,300 ng/kg
- SJGB017● Core location: TEQ < 220 ng/kg
- SJB1◇ Grab location: TEQ ≥ 13,000 ng/kg
- SJA1◇ Grab location: 1,300 ≤ TEQ < 13,000 ng/kg
- SJB2◇ Grab location: 220 ≤ TEQ < 1,300 ng/kg
- SJC3◇ Grab location: TEQ < 220 ng/kg
- 825 Concentration TEQ_{DF} (ng/kg dw) (See Note 1)
- A A' Cross Section Location (See Figure 4-4)

NOTE:
1. Concentration shown at each sample location represents the highest concentration calculated at any depth interval at that location.

AERIAL SOURCE: Google Earth Pro, dated October 2012.
SOURCE: Drawing prepared from surveys provided by Hydrographic Consultants dated October 2012 and January/February 2013.
HORIZONTAL DATUM: Texas State Plane South Central, NAD83, U.S. Feet.
VERTICAL DATUM: NAVD 88.

0 120
Scale in Feet

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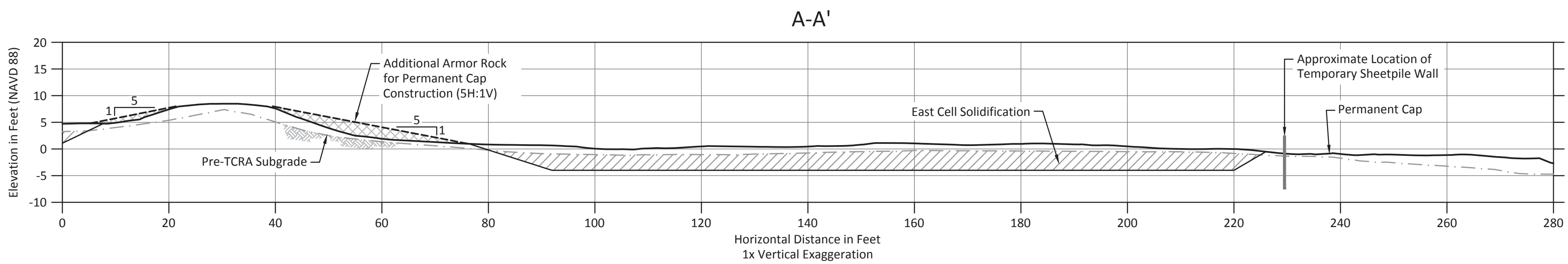
ANCHOR QEA

Figure 4-3
Plan View - Alternative 4N
Feasibility Study
San Jacinto River Waste Pits Superfund Site

077532



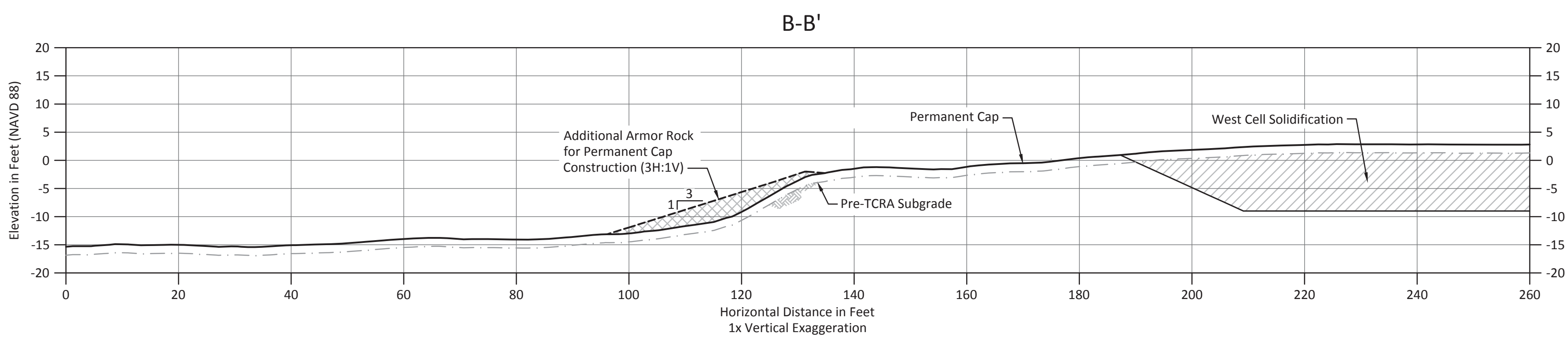
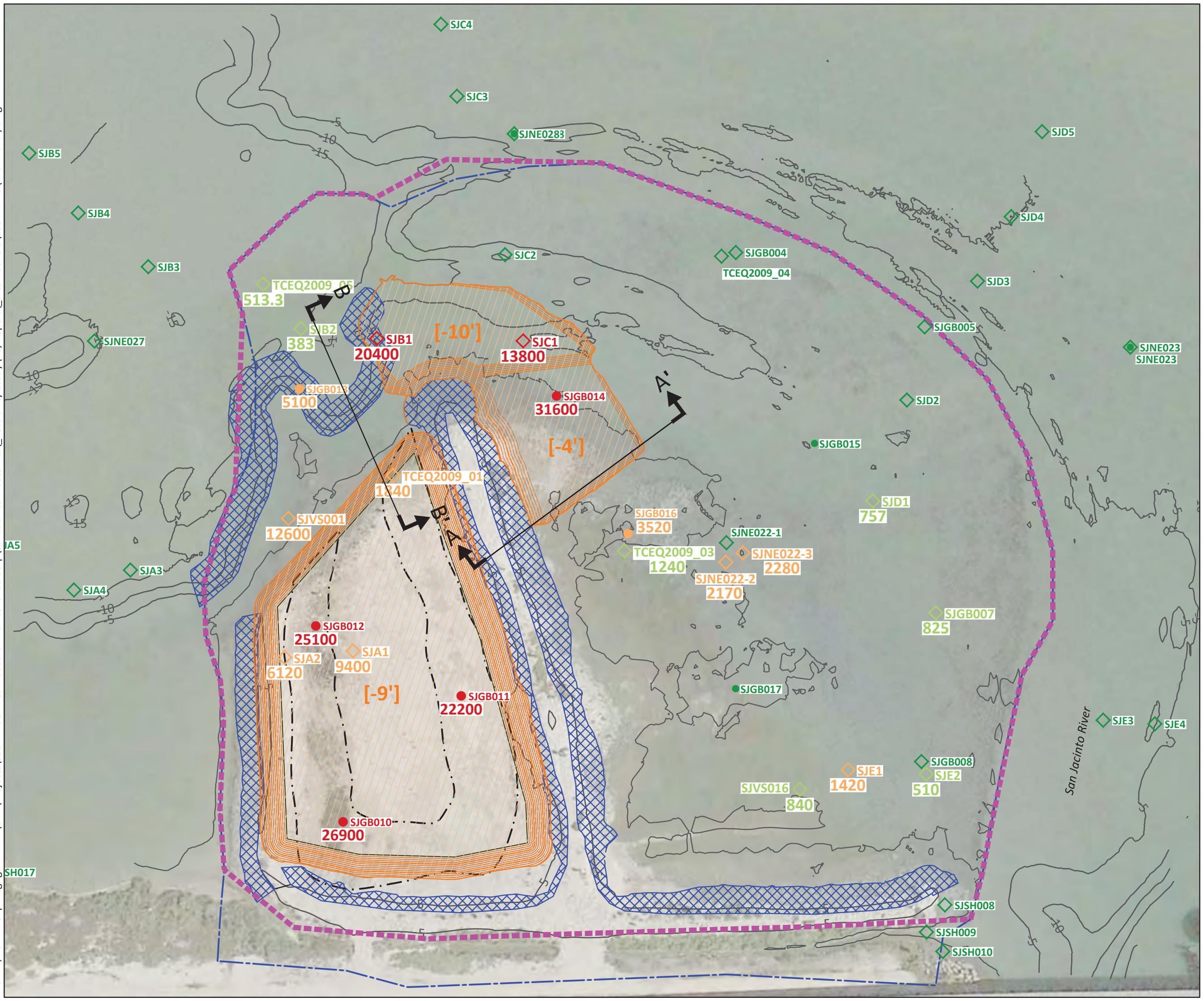


Figure 4-4
Cross Sections A-A' and B-B' - Alternative 4N
Feasibility Study
San Jacinto River Waste Pits Superfund Site



LEGEND:

Existing Contour (5 Foot Interval)	
[-4']	Target Cut Elevation (NAVD 88)
	Removal Area
	Armored Cap Limit
	Area of Additional Rock Placement for Flattening Slopes to 5H:1V on berms and 3H:1V in the Northwest Area
	TCRA Footprint of Stabilization
SJGB014●	Core location: TEQ ≥ 13,000 ng/kg
SJGB013●	Core location: 1,300 ≤ TEQ < 13,000 ng/kg
SJGB016●	Core location: 220 ≤ TEQ < 1,300 ng/kg
SJGB017●	Core location: TEQ < 220 ng/kg
SJB1◇	Grab location: TEQ ≥ 13,000 ng/kg
SJA1◇	Grab location: 1,300 ≤ TEQ < 13,000 ng/kg
SJB2◇	Grab location: 220 ≤ TEQ < 1,300 ng/kg
SJC3◇	Grab location: TEQ < 220 ng/kg
825	Concentration TEQ_{DF} (ng/kg dw) (See Note 1)
A A'	Cross Section Location (See Figure 4-6)

NOTE:

1. Concentration shown at each sample location represents the highest concentration calculated at any depth interval at that location.

AERIAL SOURCE: Google Earth Pro, dated October 2012.
SOURCE: Drawing prepared from surveys provided by Hydrographic Consultants dated October 2012 and January/February 2013.
HORIZONTAL DATUM: Texas State Plane South Central, NAD83, U.S. Feet.
VERTICAL DATUM: NAVD 88.

0 120
Scale in Feet

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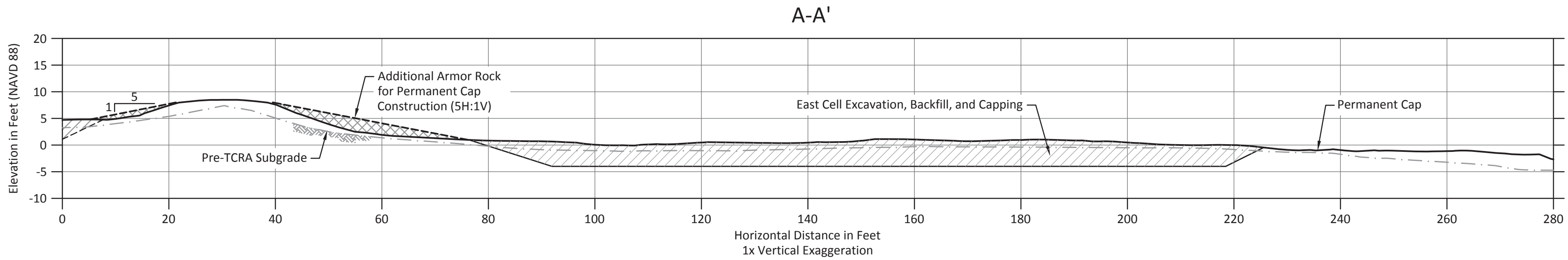
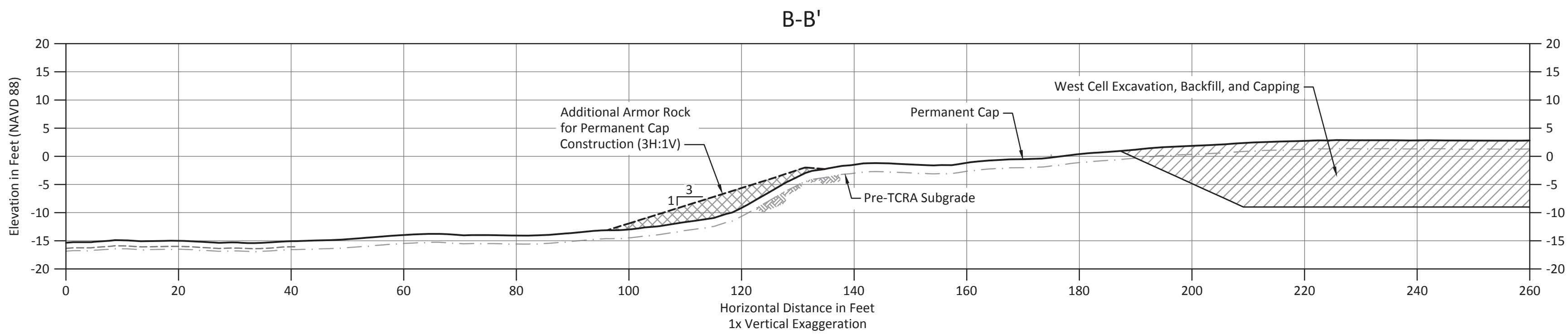
ANCHOR QEA

Figure 4-5
Plan View - Alternative 5N
Feasibility Study
San Jacinto River Waste Pits Superfund Site

077534





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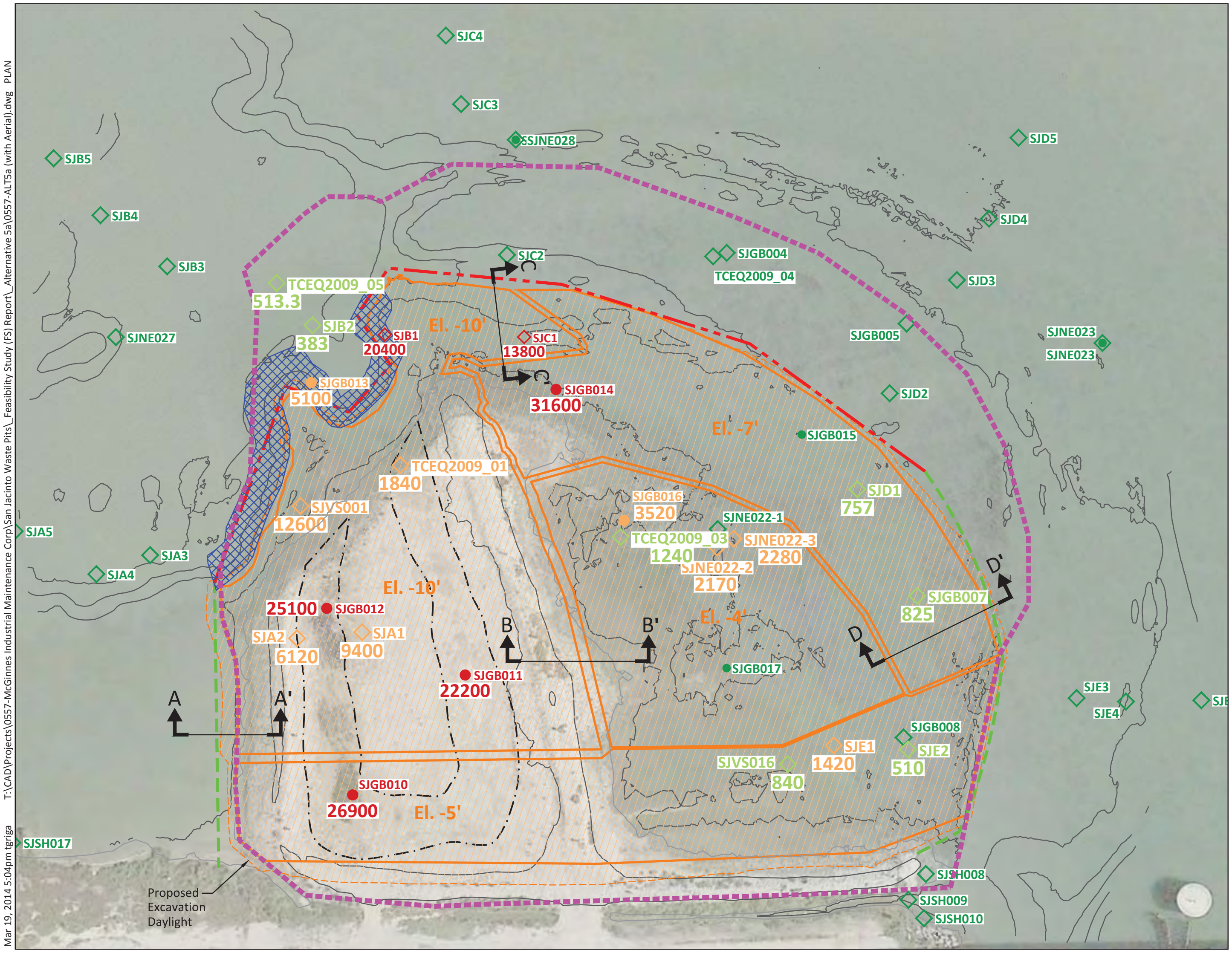
ANCHOR QEA

Figure 4-6
Cross Sections A-A' and B-B' - Alternative 5N
Feasibility Study
San Jacinto River Waste Pits Superfund Site



LEGEND:

- Existing Contour (5 Foot Interval)
- [-4'] Target Cut Elevation (NAVD 88)
- Removal Area
- Area of Additional Rock Placement for Flattening Slopes to 3H:1V in the Northwest Area
- Armored Cap Limit
- Sheet Pile Wall
- Containment Berm
- TCRA Footprint of Stabilization
- SJGB014 ● Core location: TEQ ≥ 13,000 ng/kg
- SJGB013 ● Core location: 1,300 ≤ TEQ < 13,000 ng/kg
- SJGB016 ● Core location: 220 ≤ TEQ < 1,300 ng/kg
- SJGB017 ● Core location: TEQ < 220 ng/kg
- SJB1 ◇ Grab location: TEQ ≥ 13,000 ng/kg
- SJA1 ◇ Grab location: 1,300 ≤ TEQ < 13,000 ng/kg
- SJB2 ◇ Grab location: 220 ≤ TEQ < 1,300 ng/kg
- SJC3 ◇ Grab location: TEQ < 220 ng/kg
- 825 Concentration TEQ_{DF} (ng/kg dw) (See Note 1)
- A A' Cross Section Location (See Figure 4-8)

NOTE:
1. Concentration shown at each sample location represents the highest concentration calculated at any depth interval at that location.

AERIAL SOURCE: Google Earth Pro, dated October 2012.
SOURCE: Drawing prepared from surveys provided by Hydrographic Consultants dated October 2012 and January/February 2013.
HORIZONTAL DATUM: Texas State Plane South Central, NAD83, U.S. Feet.
VERTICAL DATUM: NAVD 88.

0 120
Scale in Feet

ANCHOR QEA

Figure 4-7
Plan View - Alternative 5aN
Feasibility Study
San Jacinto River Waste Pits Superfund Site

077536

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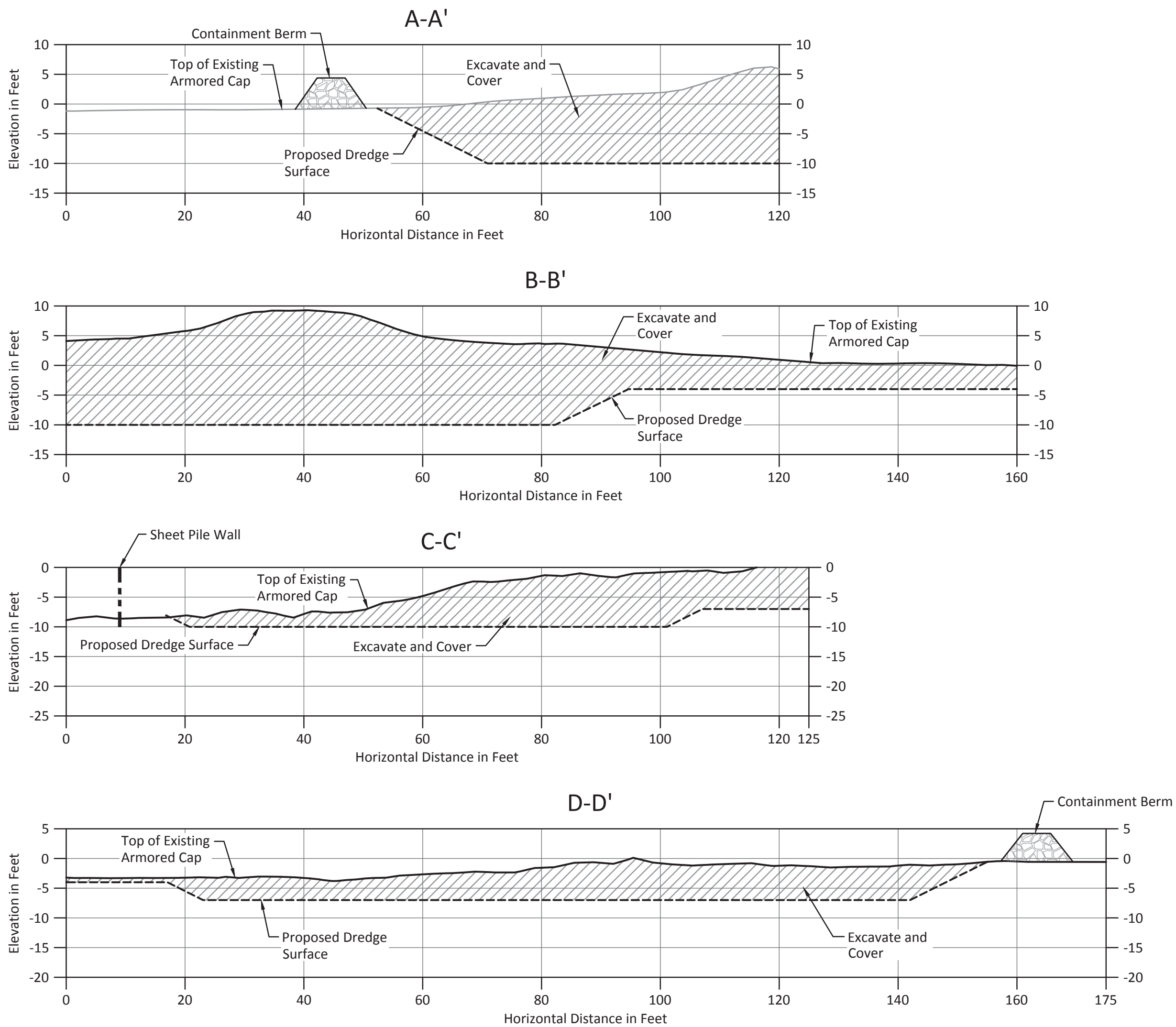

ANCHOR QEA

Figure 4-8
Cross Sections A-A' through D-D' - Alternative 5aN
Feasibility Study
San Jacinto River Waste Pits Superfund Site

077537

LEGEND:

-5	Existing Contour (5 Foot Interval)
[-4']	Target Cut Elevation (NAVD 88)
	Removal Area
	Armored Cap Limit
	TCRA Footprint of Stabilization
SJGB014 ●	Core location: TEQ ≥ 13,000 ng/kg
SJGB013 ●	Core location: 1,300 ≤ TEQ < 13,000 ng/kg
SJGB016 ●	Core location: 220 ≤ TEQ < 1,300 ng/kg
SJGB017 ●	Core location: TEQ < 220 ng/kg
SJB1 ◇	Grab location: TEQ ≥ 13,000 ng/kg
SJA1 ◇	Grab location: 1,300 ≤ TEQ < 13,000 ng/kg
SJB2 ◇	Grab location: 220 ≤ TEQ < 1,300 ng/kg
SJC3 ◇	Grab location: TEQ < 220 ng/kg
825	Concentration TEQ_{DF} (ng/kg dw) (See Note 1)
A A'	Cross Section Location (See Figure 4-8)

NOTE:

1. Concentration shown at each sample location represents the highest concentration calculated at any depth interval at that location.

AERIAL SOURCE: Google Earth Pro, dated October 2012.
SOURCE: Drawing prepared from surveys provided by Hydrographic Consultants dated October 2012 and January/February 2013.
HORIZONTAL DATUM: Texas State Plane South Central, NAD83, U.S. Feet.
VERTICAL DATUM: NAVD 88.

0 200
Scale in Feet

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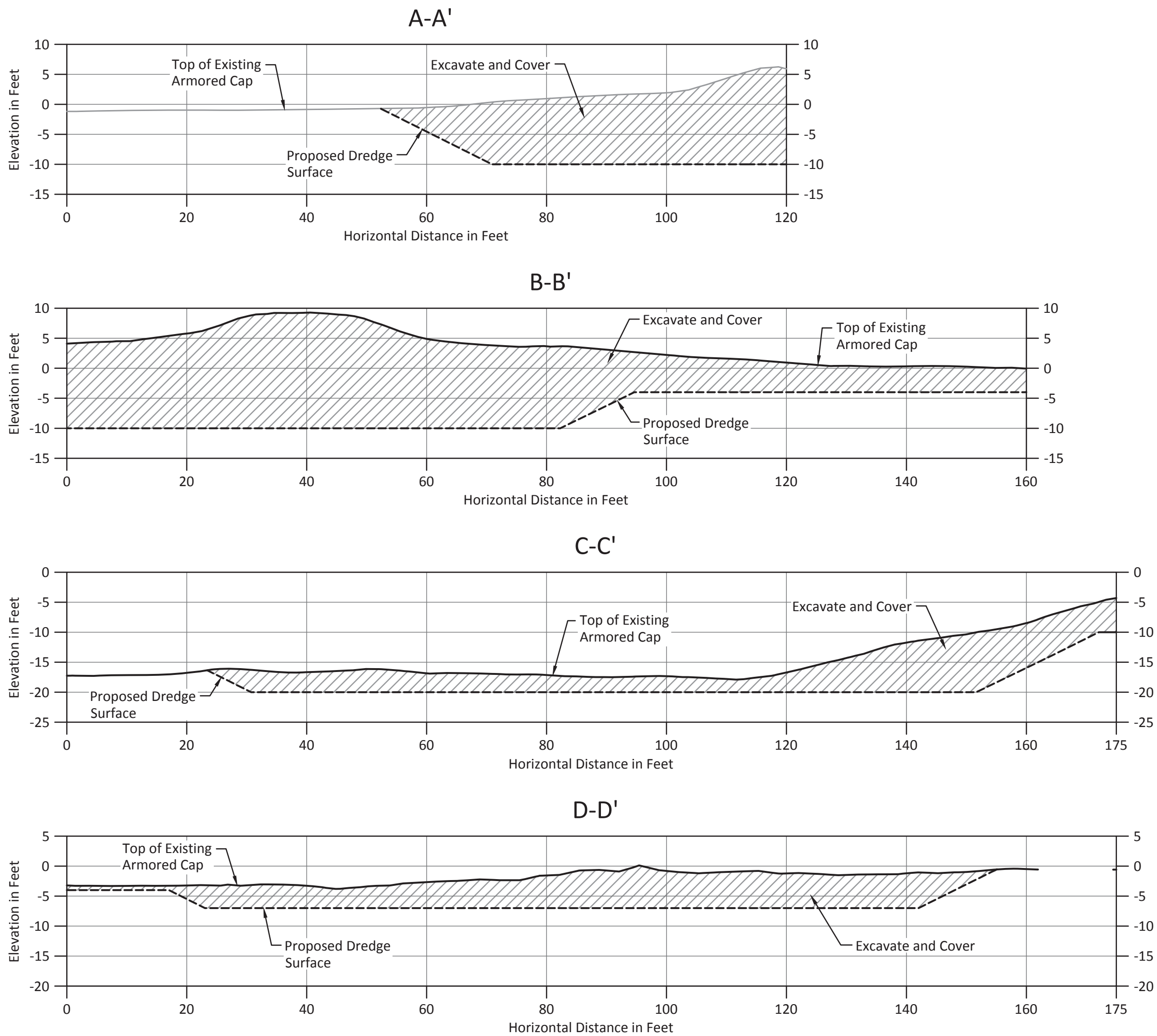
Mar 14, 2014 4:24pm tgriga

ANCHOR QEA

Figure 4-9
Plan View - Alternative 6N
Feasibility Study
San Jacinto River Waste Pits Superfund Site

077538

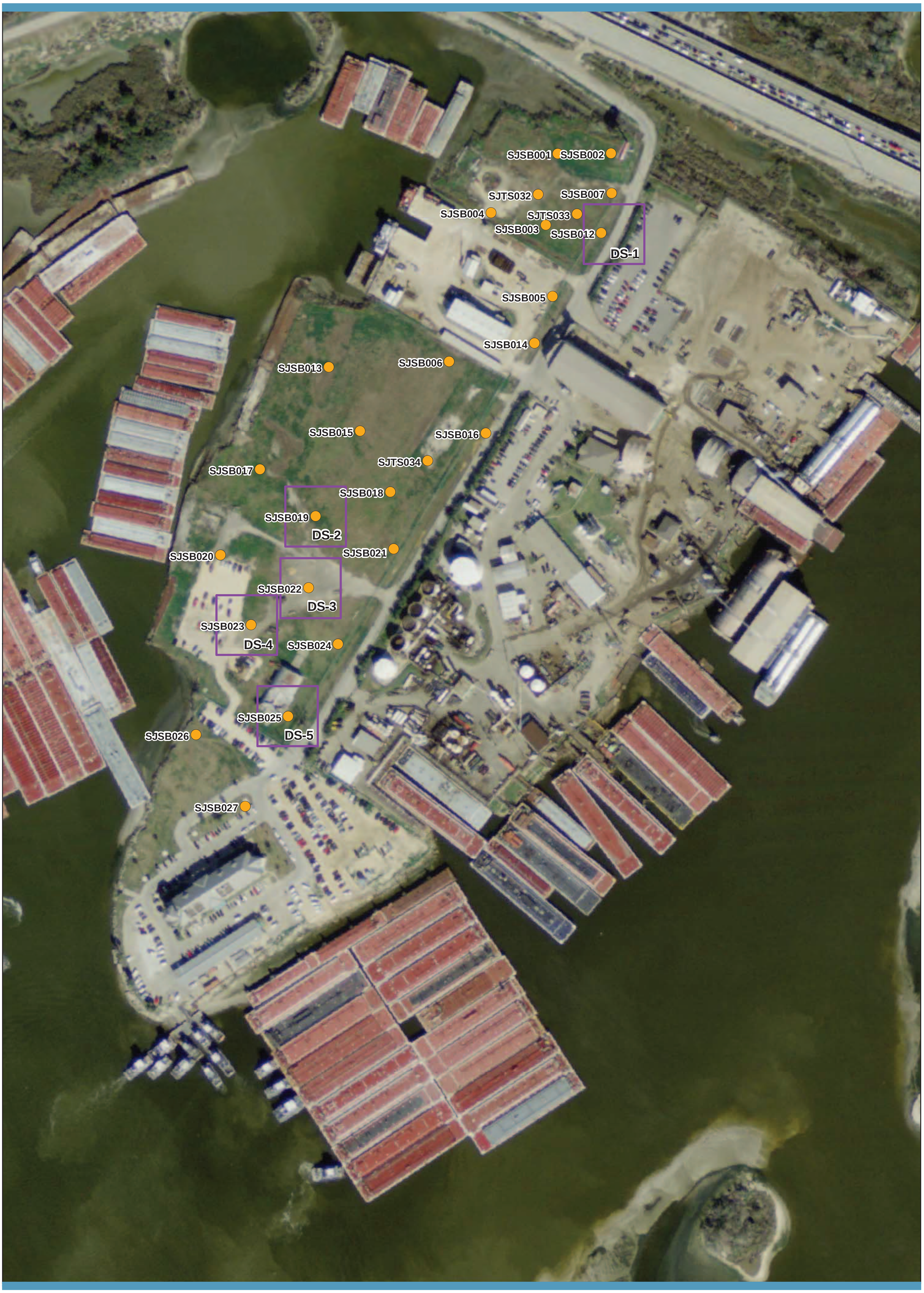


Mar 19, 2014 5:20pm tgriga T:\CAD\Projects\0557-McGinnes Industrial Maintenance Corp\San Jacinto Waste Pits_Feasibility Study (FS) Report_Alternative 6\0557-ALT6 (with Aerial).dwg SECTIONS

ANCHOR QEA

Figure 4-10
Cross Sections A-A', B-B', C-C', and D-D' - Alternative 6N
Feasibility Study
San Jacinto River Waste Pits Superfund Site

077539



Surface and Subsurface Soil Sample Location

Exposure Unit for Deep Soils, 0-10 feet

0 400

Feet

FEATURE SOURCES:
Aerial Imagery: 0.5-meter 2008/2009 DOQQs - Texas Strategic Mapping Program (StratMap), TNRIS

Figure 4-11
Exposure Unit for Soils, Area of Investigation
on the Peninsula South of I-10, 0-10 feet
San Jacinto River Waste Pits Site

Modified from: Integral Consulting Inc. and Anchor QEA, LLC. 2013. Baseline Human Health Risk Assessment, San Jacinto River Waste Pits Superfund Site.
Prepared for: McGinnes Industrial Maintenance Corporation, International Paper Company, and U.S. Environmental Protection Agency, Region 6. May.

077540

INTERIM-FINAL FEASIBILITY STUDY REPORT

APPENDIX A:

EVALUATION OF THE SAN JACINTO WASTE PITS FEASIBILITY STUDY REMEDIATION ALTERNATIVES

U.S. ARMY CORPS OF ENGINEERS
ENGINEER RESEARCH AND DEVELOPMENT CENTER

SAN JACINTO RIVER WASTE PITS SUPERFUND SITE

ERDC Letter Report

Environmental Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Evaluation of the San Jacinto Waste Pits Feasibility Study Remediation Alternatives

August 2016

Earl Hayter, Paul Schroeder, Natalie Rogers, Susan Bailey, Mike Channell, and Lihwa Lin

077542

ERDC Letter Report

Evaluation of the San Jacinto Waste Pits Feasibility Study Remediation Alternatives

Earl Hayter, Paul Schroeder, Natalie Rogers, Susan Bailey, Mike Channell

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Lihwa Lin

Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Letter Report

Prepared for U.S. EPA, Region 6
Dallas, TX 75202

077544

Abstract

The U.S. Army Engineer Research and Development Center (ERDC) is providing technical support to the US Environmental Protection Agency (EPA), the goal of which is to prepare an independent assessment of the Potentially Responsible Parties' (PRP) remedial alternative designs for the San Jacinto River Waste Pits Superfund Site, Texas. Specific objectives of this study are the following:

1) Perform an assessment of the design and evaluation of the remediation alternatives presented in the Feasibility Study.
2) Identify other remedial action alternatives or technologies that may be appropriate for the Site.
3) Evaluate the numerical models used by the PRP's modeling contractor for the Site.
4) Assess the hydraulic conditions in and around the San Jacinto River, and utilize surface water hydrologic, hydrodynamic, and sediment transport models appropriate for the Site in performing the assessment.

This report presents the results from 18 tasks that were identified by EPA for the ERDC to perform to accomplish the stated goal and objectives. The results are summarized in the Executive Summary section which precedes the reports on the 18 tasks.

Contents

Figures and Tables

Figures

Tables

Preface

This study was performed at the request of the U.S. Environmental Protection Agency (EPA) – Region 6 by the Environmental Laboratory (ERDC-EL) of the US Army Corps Engineer Research and Development Center (ERDC), Vicksburg, MS.

At the time of publication, the Deputy Director of ERDC-EL was Dr. Jack E. Davis and the Director of ERDC-EL was Dr. Elizabeth C. Fleming. Commander of ERDC was COL Bryan S. Green. The Director was Dr. Jeffery P. Holland.

Unit Conversion Factors

Multiply	By	To Obtain
Feet	0.3048	meters
miles (U.S. nautical)	1,.852	kilometers
miles (U.S. statute)	1.609347	kilometers
Acres	4,046.873	Square meters
cubic yards	0.7645549	cubic meters
Knots	0.5144444	Meters per second

Summary and Conclusions

Numerous tasks were performed to assess the remediation alternatives presented in the Feasibility Study, as well as to identify any other remedial action alternatives, technologies or BMPs that may be appropriate for the Site. In addition, the technical evaluation included a) an assessment of hydraulic conditions in and around the San Jacinto River, b) an evaluation of the numerical models used by the PRPs for the Site, and c) use of surface water hydrologic, hydrodynamic, and sediment transport models appropriate for the Site in performing the assessment. Tasks 2, 3, 5, 7, 8, 9 and 10 addressed the permanence of the capping - Alternative 3N. Tasks 4, 6, 11, 16, 17 and 19 addressed the effectiveness of the capping - Alternative 3N. Tasks 16 and 17 also addressed the effectiveness of dredging Alternative 6N (including the components of Alternatives 4N, 5N, and 5aN). Tasks 11, 12, 13, 14, 15 and 18 addressed the short-term impacts of remediation, particularly by dredging.

Site Conditions and Anchor QEA Model Evaluation

As stated in Task 2, the San Jacinto River (SJR) is a coastal plain estuary. The San Jacinto River Waste Pits are located in a FEMA designated floodway zone, which is essentially the 100-year floodplain for the SJR. The base flood elevation, which is the water surface elevation resulting from a 100-year flood, has been determined by FEMA to be 19 feet (5.8 m) for the waste pits. The low lying Waste Pits are also subject to flooding from storm surges generated by both tropical storms (*i.e.*, hurricanes) and extra-tropical storms. Storm surges generated in the Gulf of Mexico propagate into Galveston Bay and into the Lower SJR.

The Anchor QEA model framework and the individual models were evaluated in Task 3. This included an assessment of the assumptions included in the framework as well as the assumptions made in applying the hydrodynamic, sediment transport, and contaminant transport and fate models. Evaluation of some of these assumptions were performed in part by applying ERDC's LTFATE surface water modeling system to the SJR estuary and comparing the results obtained by the two model frameworks.

The conclusion reached from the expanded sensitivity simulation performed for Task 4 is that most (but not all) of the assumptions included in the Anchor QEA model framework result in higher values of net erosion. However, the two factors that most effect the net change in bed elevation, those being the upstream sediment loads and the use of uncoupled hydrodynamic and sediment transport models, result in higher uncertainties in the findings reported by AQ from their sediment transport and contaminant transport modeling.

Permanence of Capping

The evaluations performed to address the permanence of the existing repaired TCRA cap with the proposed modifications outlined in the capping Alternative 3N showed that the cap is expected to be generally resistant to erosion except for very extreme hydrologic events, which could erode a sizable portion of the cap. The most severe event simulated was the hypothetical synoptic occurrence of Hurricane Ike and the October 1994 flood, with a peak discharge of approximately 11,000 cms (390,000 cfs) occurring at the time of the peak storm surge height at the Site. Approximately 80 percent (12.5 acres) of the 15.7 acre TCRA cap incurred severe erosion during the simulated extreme (hypothetical) storm. The maximum scour depth in any grid cell within the cap boundary during this hypothetical extreme event was 2.4 ft (0.73 m). Replacement of the armor materials with a median size of at least D_{50} = 12 inches would be needed to greatly reduce the amount of scour that occurs during such an extreme event.

Some localized disturbances of the cap may occur from bearing capacity failures of the soft sediment, gas entrapment by the geomembrane or geotextiles, or barge strikes, requiring maintenance or repair. The expected releases from these localized disturbances would be expected to be very small, more than a thousand times smaller than releases from removal of the contaminated sediment as predicted for dredging Alternative 6N or a new Alternative 6N* with enhanced resuspension BMPs, even if these disturbances are not quickly repaired.

These issues related to cap permanence can be addressed by additional modifications to Alternative 3N, including upgrading the blended filter in the Northwestern Area to control sediment migration into the cap, upgrading the armor stone size in vulnerable areas by doubling its D_{50} to prevent movement during very severe hydrologic and hydrodynamic events, thickening of the armor cap to at least 24 to 30 inches across the site to minimize the potential for disturbance by anthropogenic activities or gas entrapment in submerged areas where a geotextile filter was used , and installing pilings to protect the cap from barge strikes.

Tasks 2, 3, and 7 showed that the armored cap is predicted to have long-term reliability from scour related processes except under very severe hydrologic and hydrodynamic events. It is recognized that the uncertainty associated with estimates of the effects of some of the potential failure mechanisms, e.g., propwash, stream instability, is very high. Task 5 showed that the slope improvements proposed in Alternative 3N provides the recommended factor of safety for slope stability if properly constructed. Task 8 showed a low probability of barge strikes that would impact the integrity of the cap. Additionally, Task 8 showed that if the cap were impacted, the accumulative potential releases of contaminated sediment would be very much smaller than the releases from the complete removal Alternative 6N when compared with the predicted releases provided in Tasks 11 and 12. A major barge strike, which would be predicted to occur once in 400 years, would impact less than 1% of the cap area and potentially release less than 0.1% of the contaminated sediment, which is less than 25% of the releases predicted for the new full removal Alternative 6N*. Task 9 identified institutional and engineering controls to ensure permanence by controlling activities at the site. Task 10 showed that reliability has been routinely achieved at other armored sites and facilities.

Effectiveness of Capping

The evaluations performed to address the effectiveness of the existing repaired TCRA cap with the proposed modifications outlined in the capping Alternative 3N showed that the cap is expected to be highly effective in controlling the flux of contaminants and reducing the exposure concentration of contaminants in the water column. The exposures and flux at the site will be much less than from the surrounding sediments at concentrations below the PCL. The quality and quantity of deposition that occurs in the future will greatly influence the overall recovery of the surrounding sediments back to background conditions.

Task 19 estimated that the net sedimentation rate (NSR) at the site is 1.3 cm/yr ± 0.8 cm/yr. Even this modest predicted net sedimentation rate on the cap is predicted to maintain the cap's effectiveness. Task 6 confirmed that the primary requirement of the cap is to control the resuspension of sediment particulates, which requires a filter between the sediment and armor cap material. A geomembrane or geotextile filter is present in all areas except in the deeper waters where a blended filter media was incorporated with the armor cap material as in the Northwestern Area. The blended filter and cap construction in the more steeply sloped areas should be examined for adequacy (*i.e.*, presence and thickness) and integrity (*i.e.*, no separation or grading of sediment particle sizes during construction) to provide isolation of the sediment from bioturbators. Based on the permanence evaluation these areas need to be upgraded with larger armor stone and can be upgraded with other materials to filter, seal and sequester the contaminated sediment to ensure long-term effectiveness in these areas. Task 11 showed the expected resuspension and short-term releases from capping are virtually non-existent, with only some pore water releases from the overburden induced consolidation. In comparison, at least 0.1% of the contaminant mass and most likely at least 0.3% and possibly much more of the contaminant mass would be released by removal operations as shown in Tasks 11 and 12. Task 16 showed the expected long-term releases from capping are to be very small in the absence of cap erosion or a major disturbance by a barge strike and comparable to long-term releases from dredging residuals with a well-constructed single layer residuals cover, and better than the residuals cover if mixing with residuals or erosion occurs. Long-term releases from all alternatives would satisfy the PCL and water quality criteria. Task 17 showed that the cap effectively controls bioaccumulation.

Effectiveness of Dredging

The effectiveness of removal activities rely on residuals management through either excavation in the dry or capping/covering/backfilling. Task 16 showed that best construction practices as well as erosion control for residuals management are needed for removal alternatives to achieve the same level of long-term effectiveness as capping alternatives, based on predictions of the long-term contaminant flux and bioavailable contaminant concentrations in the bioactive zone. Task 16 estimated the long-term releases from various removal activities with alternative residuals management practices. Task 17 showed that the removal with residuals management can effectively control bioaccumulation.

Impacts of Remediation

The short-term impacts of remediation activities are primarily related to resuspension of sediment, erosion of residuals, and the concurrent release of contaminants. Enhancement of the TCRA cap under Alternative 3N would be expected to produce very little impacts, while Task 14 showed that full removal under Alternative 6N would be expected to significantly increase short-term exposures to contaminants. As much as 3.3% of the contaminant mass is predicted to be released when using silt curtains as the resuspension release BMP; however, excavating the Western Cell in the dry and containing the rest of the site in a sheet pile wall could reduce the resuspension release to 0.3%. Excavation of the Western Cell in the dry or within a sheet pile enclosure is critical for reducing short-term impacts if removal is performed because 75% of potential releases originate from the Western Cell. Enclosure of only shallow water areas (elevations above about -3 ft NAVD88) with a sheet pile wall will reduces releases nearly as well as enclosing the entire TCRA cap area since the high sediment $TEQ_{DF,M}$ concentrations are nearly all in these shallow areas. Tasks 14 and 16 showed that full removal as proposed in Alternative 6N would set back the natural recovery of the site back to existing conditions by up to two decades depending on the BMPs used upon considering the time required for design, construction and assimilation of the releases into the sediment bed below the bioactive zone. The setback for Alternative 6N if only silt curtains are used as the resuspension BMP may increase a measurable area of the sediment in the immediate vicinity of the cap area to a concentration exceeding the PCL. The new Alternative 6N* with enhanced BMPs, despite its much smaller short-term releases, would still set back the natural recovery of the site back to existing conditions by up to a decade considering the time required for design, construction and assimilation of the releases into the sediment bed below the bioactive zone. However, the setback for Alternative 6N* may not increase a sizeable area of the sediment outside the cap area to a concentration exceeding the PCL. These short-term releases that are incorporated into the surrounding sediment bed would subsequently be available for redistribution during erosion events from high flows or storm events.

Tasks 11 and 12 predicted and compared the short-term releases of solids and contaminants for the various removal alternatives. The releases represent a significant increase in exposure (more than two orders of magnitude greater than pre-remediation exposures) during the period of active removal operations or period of exposed residuals. Existing releases throughout the site are estimated to be up to 5 mg/year of dioxin-related contaminants without an erosion event, while the original full removal Alternative 6N and the new full removal Alternative 6N* are predicted to release about 20,000 mg and 2,000 mg, respectively, during remediation activities covering a period of up to two years. Fish tissue contaminant concentrations are directly related to the releases to the water column, but are also related to the entirety of their food sources which are largely impacted by the water column concentrations and releases. Consequently, depending on the BMPs employed and the feeding range of the fish species, fish tissue contaminant concentrations would be expected to be dozens times (for the new full removal Alternative 6N*) and perhaps hundreds times (for the original full removal Alternative 6N) greater than existing tissue concentrations for several years before returning to near existing values. Upon comparison with Task 16 long-term post-remediation predictions, the short-term releases during remediation predicted in Tasks 11 and 12 are comparable to the expected long-term releases across the entire site over the 500 years following remediation, and more than 100 times the predicted releases from an intact cap over the 500 years following placement. Similarly, the short-term releases for the new full removal Alternative 6N* is about 400,000 times greater than the releases from the intact cap for the same period and area and about 2500 times than the releases from stable sediment of the same area at the PCL. Tasks 14 and 16 showed that the short-term releases will be completely dispersed throughout the site or transported downstream, and areas immediately adjacent to the site would largely recover to the PCL from the releases of Alternative 6N using a silt curtain in a decade in areas of higher deposition. However, the releases could be redistributed in time over a larger area by future erosion events and impact long-term recovery rates. Additionally, use of other BMPs with Alternative 6N such as sheet pile containment enclosures to reduce releases would achieve the PCL in these adjacent areas in a few years. The new Alternative 6N* would be expected to have only limited areas exceeding the PCL.

Task 15 found that the construction of any of the proposed Alternatives is not expected to cause any flooding in the vicinity of the SJR Waste Pits Site, and therefore should not require the implementation of any flood control measures during the construction of any of the Alternatives under consideration by the EPA Site team.

Task 18 showed that, depending on the selection of BMPs, flooding and high flow conditions during removal operations would significantly increase the erosion of sediment residuals. A silt curtain would not be able to withstand the forces of high flow or waves and therefore the bottom shear stresses would not be controlled. Consequently, Task 18 found that increased erosion would result in sediment and contaminant releases during full removal that are several times greater than that predicted in Task 14 without the high flow event when using a silt curtain as the resuspension BMP. Releases predicted in Task 14 were up to 3 percent of the mass of dioxin present in the waste pits. Releases from flood flows over the containment structure regardless of the removal alternative will be dependent on the height of the containment structure and the flood stage but up to releases may be up to five times greater than the overall short-term releases predicted in the absence of the overtopping. All operations (armor cap removal, dredging to project depth, and residuals management) would need to be performed on an incremental area before progressing to the next increment if a silt curtain were used as the resuspension BMP. If a sheet pile wall designed to withstand the flood and storm conditions but allowed for equalization of the water surface inside and outside of the containment structure were used as the resuspension BMP, recently formed dredging residuals would be expected to be eroded by the bottom shear stresses resulting from flow through the gaps and over the walls, depending on the magnitude of the flooding. However, very limited erosion of exposed sediment would be expected. Recently formed residuals could contain up to about 1% of the contaminant mass. Without effective isolation by containment structures or when the containment elevation is less than about +5 NAVD88, it would be advisable to perform the removals in small sections at a time such that the armor stone and geotextile within the small section would be removed and then the sediment removed and a thin layer of sacrificial fill placed before advancing to the next section and repeating the process.

Project Background, Objectives and Tasks

Background

The San Jacinto River Waste Pits Superfund Site (Site) consists of several waste ponds, or impoundments, approximately 14 acres in size, built in the mid-1960s for the disposal of paper mill wastes as well as the surrounding areas containing sediments and soils potentially contaminated by the waste materials that had been disposed of in these impoundments. The impoundments are located immediately north and south of the I-10 Bridge and on the western bank of the San Jacinto River in Harris County, Texas (see Figure 1-1).

Large scale groundwater extraction has resulted in regional subsidence of land in proximity to the Site that has caused the exposure of the contents of the northern impoundments to surface waters. A time-critical removal action was completed in 2011 to stabilize the pulp waste material in the northern impoundments and the sediments within the impoundments to prevent further release of dioxins, furans, and other chemicals of concern into the environment. The removal consisted of placement of a temporary armor rock cap over a geotextile bedding layer and an impermeable geomembrane in some areas. The total area of the temporary armor cap is 15.7 acres. The cap was designed to withstand a 100-year storm event.

The southern impoundments are located south of I-10 and west of Market Street, where various marine and shipping companies have operations (see Figure 1-1). The area around the former southern impoundments is an upland area that is not currently in contact with surface water.

The members of the ERDC-EL Project Delivery Team (PDT) have provided technical assistance to the Site's Remedial Project Manager (RPM) for the past three years that consisted of 1) an evaluation of modeling performed by the modeling contractor for the Potentially Responsible Parties (PRP), 2) an evaluation of the design of the temporary armor cap, and 3) review of the Feasibility Study submitted by the PRP.

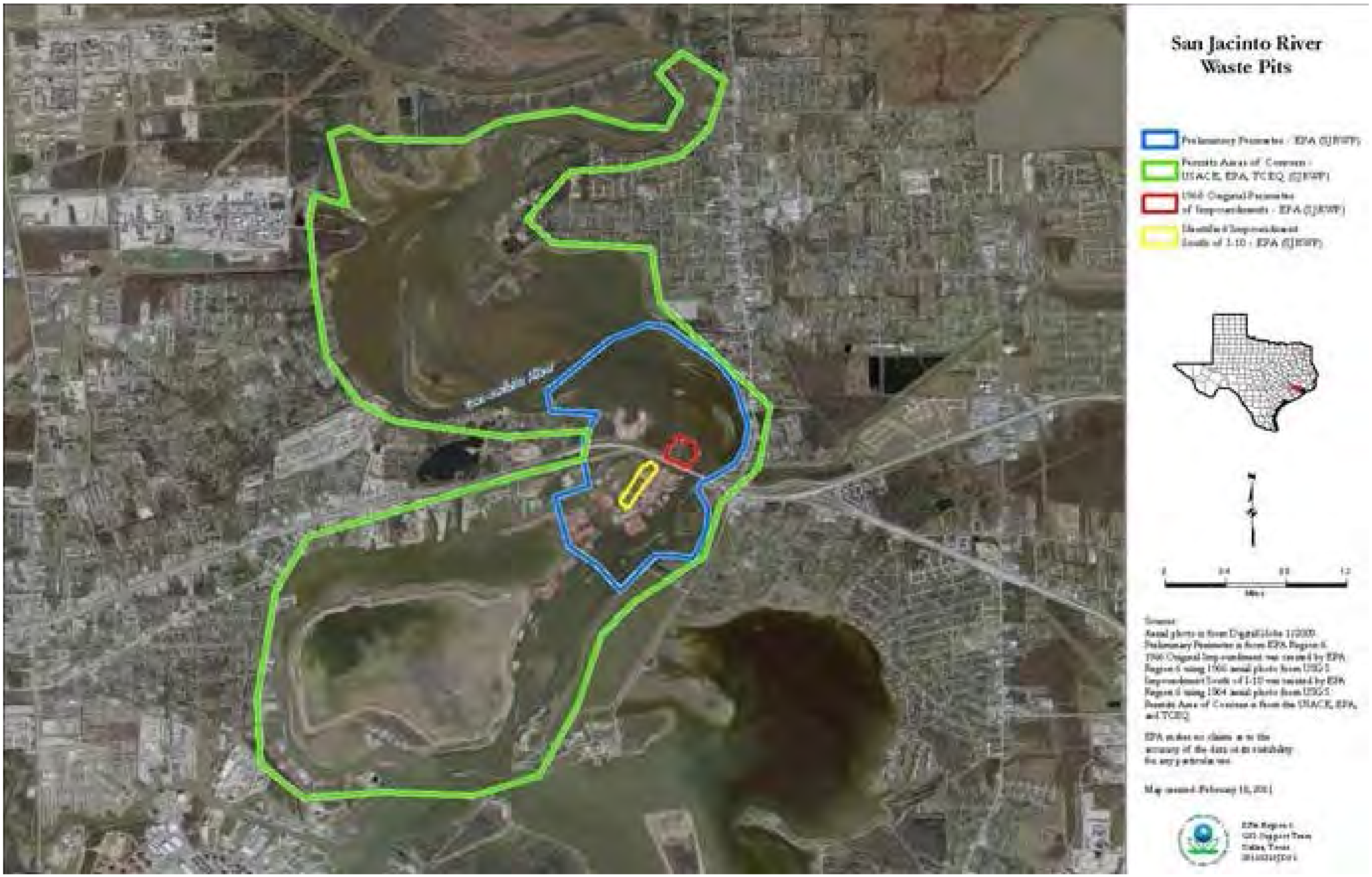


Figure 1-1 San Jacinto River Waste Pits Superfund Site

Goal and Objectives

The goal of this study is to provide technical support to US Environmental Protection Agency (EPA), including preparing an independent assessment of the PRP's designs and submittals regarding the San Jacinto River Waste Pits Superfund Site. Specific objectives of this study are the following:

1) Perform an assessment of the design and evaluation of the remediation alternatives presented in the Feasibility Study.
2) Identify other remedial action alternatives or technologies that may be appropriate for the Site.
3) Evaluate the numerical models used by the PRP's modeling contractor for the Site.
4) Assess the hydraulic conditions in and around the San Jacinto River, and utilize surface water hydrologic, hydrodynamic, and sediment transport models appropriate for the Site in performing the assessment.

Study Tasks

The following specific tasks were identified by EPA for the PDT to perform to accomplish the stated goal and objectives.

Task 1: Site Visit and Planning Meeting. This task was performed in November 2014.

Task 2: Perform an assessment of the San Jacinto River flow/hydraulic conditions and river bed scour in and around the Site for severe storms, hurricanes, storm surge, etc., using surface water hydrology model(s) appropriate for the Site. In the assessment include an evaluation of potential river bed scour/erosion in light of the historical scour reports for the Banana Bend area and for the San Jacinto River south of the I-10 Bridge.

Task 3: Perform an evaluation of the models and grid cell sizes used by the PRPs for the Site, and include a discussion of any uncertainties in the model results. The evaluation should include a review of the model assumptions regarding bed shear stress, water velocities, and scour.

Task 4: Provide an uncertainty analysis of the model assumptions (flow rates, boundary representation, sediment transport, sedimentation rates, initial bed properties, etc.). Uncertainties should be clearly identified and assessed including sediment loads at the upstream Lake Houston Dam.

Task 5: Perform a technical review of the design and construction of the entire existing cap as it is currently configured. Identify any recommended enhancements to the cap.

Task 6: Assess the ability of the existing cap to prevent migration of dioxin, including diffusion and/or colloidal transport, through the cap with and without the geomembrane/geotextile present.

Task 7: Assess the long-term reliability (500 years) of the cap under the potential conditions within the San Jacinto River, including severe storms, hurricanes, storm surge, subsidence, etc. Include in the assessment an evaluation of the potential for cap failure that may result from waves, propwash, toe scour and cap undermining, rock particle erosion, substrate material erosion, stream instability, and other potential failure mechanisms. Reliability will be based on the ability of the cap to prevent any release of contaminated material from the Site. Also discuss any uncertainty regarding the long-term reliability and effectiveness of the existing cap.

Task 8: As part of the cap reliability evaluation, assess the potential impacts to the cap of any barge strikes/accidents from the nearby barge traffic.

Task 9: Identify what institutional/engineering controls (*e.g.*, deed restrictions, notices, buoys, signs, fencing, patrols, and enforcement activities) should be incorporated into the remedial alternatives for the TCRA area and surrounding waters and lands.

Task 10: Identify and document cases, if any, of armoring breaches or confined disposal facility breaches that may have relevance to the San Jacinto site evaluation.

Task 11: Assess the potential amount or range of sediment resuspension and residuals under the various remedial alternatives including capping, solidification, and removal.

Task 12: Identify and evaluate techniques, approaches, Best Management Practices (BMPs), temporary barriers, operational controls, and/or engineering controls (*i.e.*, silt curtains, sheet piles, berms, earth cofferdams, etc.) to minimize the amount of sediment resuspension and sediment residuals concentrations during and after dredging/removal. Prepare a new full removal alternative that incorporates the relevant techniques identified as appropriate.

Task 13: Assess the validity of statements made in the Feasibility Study that the remedial alternative with removal, solidification, and placing wastes again beneath the TCRA cap has great uncertainty as to implementation and that such management of the waste will result in significant releases.

Task 14: Provide a model evaluation of the full removal Alternative 6N identified in the Feasibility Study as well any new alternative(s) developed under Task 12 (Identify and evaluate techniques …) above. Include modeling of sediment resuspension and residuals.

Task 15: Evaluate floodplain management and impact considerations of construction, considering Alternatives 3N, 5aN, 6N, and any new alternative(s) developed under Task 12, in the floodplain and floodwaters pathway and how that would impact flood control, water flow issues and obstructions in navigable waters. This includes impact on changes to potential flooding and any offsets that are needed due to displacement of water caused by construction in the floodway (height or overall footprint) including effects at the current temporary TCRA cap and any potential future remedial measures.

Task 16: Project the long-term (500 years) effects of the capping alternative (3N) compared to the full removal alternative (6N) on water quality.

Task 17: Assess the potential impacts to fish, shellfish, and crabs from sediment resuspension as a result of dredging in the near term and for the long term.

Task 18: Assess the potential for release of material from the waste pits caused by a storm occurring during a removal/dredging operation; identify and evaluate measures for mitigating/reducing any such releases.

Task 19: Estimate the rate of natural attenuation in sediment concentrations/residuals and recommend a monitoring program to evaluate the progress. Discuss the uncertainty regarding the rate of natural attenuation.

Task 2

Statement

Perform an assessment of the San Jacinto River (SJR) flow/hydraulic conditions and river bed scour in and around the Site for severe storms, hurricanes, storm surge, etc., using surface water hydrology model(s) appropriate for the Site. In the assessment include an evaluation of potential river bed scour/erosion in light of the historical scour reports for the Banana Bend area and for the SJR south of the I-10 Bridge.

Methodology

This task was performed by first reading all identified resources (*e.g.*, reports, journal papers, local sources including newspapers) that describe the hydrologic and hydraulic conditions in the Lower SJR. This information assisted in performing the requested assessment of the SJR hydrodynamic regime. Taking into account the historical scour reports for the Banana Bend area and for the SJR south of the I-10 Bridge, the evaluation of the potential river bed scour/erosion was performed by applying ERDC's LTFATE modeling system to simulate the flood conditions during the October 1994 flood which had a return period of approximately 100 years.

Hydrology and Hydrodynamics of the San Jacinto River

The lower SJR is classified as a coastal plain estuary. Dyer (1997) gives the following definition of an estuary: "An estuary is a semi-enclosed coastal body of water which has a free connection to the open sea, extending into the river as far as the limit of tidal influence, and within which sea water is measurably diluted with fresh water derived from land drainage." Land drainage is from the SJR watershed which is a 4,500 square mile area in Harris County, TX. Bedient (2013) reports that this watershed drains an average of approximately two million acre-feet (2.47 km^3) of runoff per year. The SJR connects to Galveston Bay which has open connections to the Gulf of Mexico.

The SJR Waste Pits are located in a FEMA designated floodway zone, which is essentially the 100-year floodplain for the SJR. The base flood elevation, which is the water surface elevation resulting from a 100-year flood, for the waste pits has been determined by FEMA to be 19 feet (5.8 m). The low lying Waste Pits are also subject to flooding from storm surges generated by both tropical storms (*i.e.*, hurricanes) and extra-tropical storms. Storm surges generated in the Gulf of Mexico propagate into Galveston Bay and into the Lower SJR. Storm surge modeling conducted by NOAA predicted that category 3 and 5 hurricanes that hit Galveston Bay during high tide would produce surge levels of 23 ft (7.0 m) and 33 ft (10.1 m), respectively, at the Site. In addition, eustatic sea level rise and subsidence also contributes to the vulnerability of the Site. The combined effect of sea level rise and subsidence is reflected in the 1.97 ft (0.6 m) increase in relative sea level rise recorded over the past 100 years in Galveston Bay (Brody *et al*. 2014).

The dynamic nature of the flow regime in the SJR estuary is exemplified by the flood that occurred from October 15-19, 1994. The flood was caused by rainfall that ranged from 8 to more than 28 inches during this five-day period and caused severe flooding in portions of 38 counties in southeast Texas (USGS 1995). The 100-year flood was equaled at three of the 43 streamflow gauging stations in the 29 counties that were declared disaster areas after the flow, and it was exceeded at 16 stations. The exceedance of the 100-year flood at the 16 stations ranged from a factor of 1.1 to 2.9 times the 100-year flood. In addition, at 25 of the 43 stations, the peak stages during the flood exceeded the historical maximums (USGS 1995). This flood had a 360,000 ft^3/s (cfs) (10,194 m^3/s (cms)) peak streamflow, 27.0 ft (8.2 m) peak stage, and current velocities greater than 15 ft/s (4.6 m/s) at the USGS gage station No. 08072050 on the SJR near Sheldon, TX when up to eight feet of scour was reported in the reach of the SJR south of the I-10 Bridge. However, no official documentation of this amount of scour was found during our extensive literature search. The photo on the report front cover shows the inundated Site during this flood.

As another example, Hurricane Ike, which was a category 2 hurricane, hit Galveston Bay on September 15, 2008. While this hurricane was less than a 100-year storm, it produced a large storm surge that completely inundated the Site and generated a peak flow rate of 63,100 cfs (1,787 cms) at the Lake Houston Dam. The peak stage at the USGS Station No. 08072050 during Hurricane Ike was 14.2 ft (4.33 m). Tropical Storm Allison hit the Galveston Bay area on June 10, 2001, and generated a peak flow rate at the Lake Houston Dam of 80,500 cfs (2,280 cms). USGS Station No. 08072050 was not installed until October 1, 2007, so the peak stage during Allison is not known.

Evaluation of Potential River Bed Scour

As stated previously, the evaluation of the potential river bed scour/erosion was performed by applying ERDC's LTFATE modeling system to simulate the flood conditions during the October 1994 flood. LTFATE is a multi-dimensional modeling system maintained by ERDC (Hayter *et al.* 2012). The hydrodynamic module in LTFATE is the Environmental Fluid Dynamics Code (EFDC) surface water modeling system (Hamrick 2007a; 2007b; and 2007c). EFDC is a public domain, three-dimensional finite difference model that contains dynamically linked hydrodynamic and sediment transport modules. The sediment transport module in LTFATE is the SEDZLJ sediment bed model (Jones and Lick 2001; James *et al.* 2010). A detailed description of LTFATE is given in Appendices A – C. Appendix A contains a general description of the modeling system, Appendix B contains a detailed description of EFDC, and Appendix C contains a description of SEDZLJ. The setup of LTFATE for this estuarine system is described in Task 3.

The hydrodynamic module in LTFATE was used to simulate the time period September 1 – 30, 1994 using the hydrodynamic input files generated by AQ. This simulation produced a hydrodynamic hot start file that was used to simulate the October 1 – 31, 1994 time period during which sediment transport was also simulated. The simulation showed that the Site was completely inundated during the flood (as seen on the photo on the report cover) which occurred during October 16-21, 1994. This flood was greater than the 100-year flood, and resulted from heavy rainfall in a 38-county area of southeast Texas caused by the remnants of Hurricane Rosa. A maximum of 6.0 ft (1.83 m) of scour was predicted to occur in the reach of the SJR around and a short distance downstream of the substructure of the two Interstate-10 bridges. The estimated uncertainty in this maximum scour depth is +/- 2.5 ft (0.76 m). The National Transportation Safety Board reported that based on sonar tests at "12 locations in the main channel for distances up to 130 feet south of the east-bound Interstate 10 bridge", "about 10-12 feet of scour" occurred during this flood (NTSB 1996). Buried pipelines in that reach were undermined, which means that they were buried less than 10-12 feet below the river bed. Once the pipelines are partially exposed due to scour of the overlying sediment, local scour processes would have caused enhanced scouring around the exposed pipelines, ultimately leading to their complete undermining. As such, it is highly likely that the measured 10-12 feet of scour in that vicinity was the result of river bed erosion as well as the local scour around the undermined pipelines. LTFATE only simulated river bed erosion and not local scour, so the fact that only half the amount of the measured scour was predicted to occur was not surprising.

For the simulation of the October 1994 flood, the TCRA cap was present in the model grid. The representation of the TCRA cap in the grid is described in the Task 3 report. The entire cap was submerged during portions of the simulated flood. The maximum scour depth in any grid cell within the cap boundary during this extreme event was 1.5 ft (0.70 m). The estimated uncertainty in this maximum scour depth is +/- 0.62 ft (0.19 m). An average 90 percent of the 12 inch layer of Armor Cap A material was eroded. This heavily eroded area represented approximately 3 of the 15.7 acres. However, an average of only 15 percent of the 12 inch layer of Armor Cap B and B/C materials were eroded, and none of the Armor Cap D was eroded. After the flood had passed, the net erosion depth at any location on the cap did not exceed 0.90 ft (0.28 m). The net erosion depth was calculated as the difference between the pre-flood elevation minus the post-flood elevation in each grid cell. The net erosion depth was less than the maximum scour depth because during the falling limb of the flood, deposition of sediment occurred over the entire cap. Thus, the final bed elevations at the end of flood hydrograph were higher than the minimum elevations which occurred towards the end of the rising limb of the hydrograph.

Task 3

Statement

Perform an evaluation of the models and grid cell sizes used by the PRPs for the Site, and include a discussion of any uncertainties in the model results. The evaluation should include a review of the model assumptions regarding bed shear stress, water velocities, and scour.

Methodology

This task was performed in two steps. The first step consisted of evaluating AQ's models, which included evaluating the impact of the assumptions included in AQ's model framework for their hydrodynamic and sediment transport models, and the second step consisted of setting up ERDC's LTFATE modeling system whose framework does not contain as many assumptions. The second step was performed to quantify the differences between the two modeling systems during select high flow events. As stated previously, LTFATE is described in Appendices A – C. The work performed on this task is described below.

Evaluation of AQ's models

The model evaluation process began with the transfer of AQ's model files, including source code, scenario inputs and outputs, and calibration/validation data, and modeling reports to the EPA and the PDT. The review and evaluation of the models included evaluation of model inputs, verification of model code, and benchmarking of model results. More specifically, the methodology used in performing this evaluation was the following:

1. Modeling System Application: Review the application of the AQ models to the SJR estuarine system; specifically evaluate the procedures used to setup, calibrate and validate the models as well as the assumptions included in the AQ model framework.
2. Model Evaluation: a) Evaluate model input files (including model-data comparisons) used for calibration and validation run of both models. b) Verify that the model codes are correctly representing the simulated hydrodynamic and sediment transport processes. c) Benchmark the models by running the models using

the calibration/validation input files and comparing results with those given in AQ's Modeling Report.

Modeling System Application

The applications of the hydrodynamic and sediment transport model components of the AQ modeling system to the SJR are discussed in this section.

The application of AQ's Environmental Fluid Dynamics Code (EFDC) to the SJR model domain was thoroughly reviewed, taking into consideration the constraints of their modeling framework. Specific concerns (the first sentence for each concern is bolded) related to the application of their hydrodynamic and sediment transport models are discussed below.

The location of the downstream boundary of the model domain. As noted by several reviewers, the chosen location required the use of interpolated tidal boundary conditions. EPA's comments to AQ on this subject included the following:

> "The hydraulic regime at the confluence of the Houston Ship Channel at the SJR (Battleship Texas gauge station) is fundamentally different than that which occurs at the mouth of the SJR at Galveston Bay (Morgan's Point gauge station). While approximately symmetrical tidal currents can be expected at both the Battleship Texas and Morgan's Point gauge stations during non-event periods, the symmetry should not exist during periods of flooding. A decoupling of water surface elevations between stations is expected during flood events due to a local heightening of water surface elevation from increased freshwater flow at the mouth of the Houston Ship Channel compared to that of the more tidal-influenced, more open marine environ of Galveston Bay (*e.g.*, Thomann, 1987). Consequently, the water surface elevation response at the downgradient model domain boundary (Battleship Texas) would be significantly different than the water surface elevation response downstream at Galveston Bay (Morgan's Point) during a flood or surge event. As such, the use of data from Morgan's Point may be inappropriate for use in calibrating the subject model."

Regarding this issue, Anchor QEA (2012) states that "sensitivity analysis was conducted to evaluate the effect of using WSE data collected at

Morgan's Point on hydrodynamic and sediment transport model predictions (see Section 4.4)." In Section 4.4 it states the following:

> "Analysis of the effects of data source for specifying WSE at the downstream boundary of the model was accomplished by simulating 2002 using data collected at the Lynchburg gauge station. This year was chosen because it was the only year during which Battleship Texas State Park or Lynchburg WSE data are available and one or more high-flow events (*i.e.*, 2-year flood or greater) occurred. Cumulative frequency distributions of bed elevation changes within the USEPA Preliminary Site Perimeter for the base case and sensitivity simulations are compared on Figure 4-59. Differences in bed elevation change between the two simulations are between -2 and +2 cm over of the bed area in the USEPA Preliminary Site Perimeter (Figure 4-60, bottom panel). A one-to-one comparison of bed elevation changes for each grid cell within the USEPA Preliminary Site Perimeter is presented on Figure 4-60. Overall, the data source for specifying WSE at the downstream boundary of the hydrodynamic model has minimal effect on sediment transport within the USEPA Preliminary Site Perimeter."

The PDT disagrees with the approach used in this analysis of the effects of data source for the WSE. With the differences in the hydrodynamic regimes during floods as described by several of EPA's reviewers, the PDT disagrees with AQ's justification that is based on differences in simulated bed elevation changes within the Site. Just because the differences in bed elevation changes over a one year simulation using the two different WSE data sources were within ± 2 cm does not indicate that the circulation pattern in the estuary was correctly simulated. If it was not, then the fate of eroded contaminated sediment would be different. As such, the PDT still believes that the more appropriate boundary location would have been in the vicinity of Morgan's Point due to the NOAA tidal station (Number 8770613) at that location. This is where the downstream boundary for the LTFATE model domain was located.

Decoupled hydrodynamic and sediment transport models. The main limitation of AQ's model framework is the use of decoupled hydrodynamic and sediment transport models. This limits its applicability to flow conditions when large morphologic changes (relative to the local flow depth) due to net erosion and net deposition do not occur. Thus, it is not capable of simulating morphologic changes during large flood events, such as the previously described October 1994 flood. Anchor QEA (2012) states that "model reliability is not significantly affected by not incorporating direct feedback between the hydrodynamic and sediment transport models into the modeling framework, with approximately 8% of the bed area experiencing relative increases or decreases in potential water depth of greater than 20%." However, since these results, *i.e.*, "8% of the bed area …", were obtained using a modeling framework that did not account for changes in bed elevation due to erosion and deposition, which means that those results are in question, they cannot be used to justify not including direct feedback into the modeling framework.

Floodplain areas. Anchor QEA (2012) states that "Floodplain areas (*i.e.*, areas that only get inundated during high flow events) were incorporated into the rectangular numerical grid to adequately represent extreme events in the vicinity of the USEPA Preliminary Site Perimeter." However, more of the floodplain should have been included in other portions of the model grid to correctly represent the flows throughout the estuarine system during the extreme floods simulated during the 21-year model simulation, *e.g.*, the October 1994 flood. The 100-year floodplain was represented in the LTFATE model grid.

Two-Dimensional depth averaged model. It states in Section 2.3 of Anchor QEA (2012) that "the two-dimensional, depth-averaged hydrodynamic model within EFDC was used, which is a valid approximation for the non-stratified flow conditions that typically exist in the San Jacinto River". No salinity data are presented to support this assumption. Stating that models of other estuaries in Texas have used depth-averaged hydrodynamic models is not an acceptable technical justification for this assumption.

Use of hard bottom in the HSC and in the upper reach of the SJR. Regarding this issue, EPA commented that "a justification for assuming the sediment bed was hard bottom in the SJR channel downstream of Lake Houston Dam and in the HSC shall be added to the report. How far downstream in the river channel was a hard bottom assumed? In addition, the report shall comment on potential impacts of these assumptions on sediment and contaminant transport processes in proximity to the Superfund site." In response, the following text was added to Section 4.2.2:

> ".. the numerical grid was extended up to Lake Houston for hydrodynamic purposes (*i.e.*, to ensure that the tidal prism of the San Jacinto River is properly represented in the model). The sediment bed was specified as hard bottom in this portion of the San Jacinto River because: 1) no significant dioxin bed sources exist within this region (see Section 5.2.5.2); and 2) sparse data were available for specifying bed properties (*i.e.*, there is a large uncertainty in bed type and composition). Thus, specification of the sediment bed in the San Jacinto River channel between the dam and Grennel Slough as cohesive or non-cohesive (*i.e.*, erosion and deposition fluxes were calculated) was not necessary to meet the objectives of this study." This justification seems technically justifiable. However, the discussion of sensitivity analyses results along the San Jacinto River does not take into account the hard bottom assumed for this river between the Lake Houston dam and Grennel Slough. For example, in the second paragraph of Section 5.3.3.2.1 it states "due to flux from sediments [porewater diffusion and erosion]". These processes do not occur to a hard bottom. The appropriate portions of Section 5.3.3.2.1 should have been rewritten (as stated in two previous reviews of this report) to account for the fact that, for example, porewater diffusion, sediment bed mixing, and erosion do not occur in the hard bottom reach. In addition, the procedure used to make "slight adjustments .. to the water column concentrations during calibration to avoid "double counting" of contaminant inputs" needs to be more thoroughly described.

Regarding the hard bottom assumption for the Houston Ship Channel (HSC), the report states the following:

> "With respect to the HSC, specifying the sediment bed as hard bottom was valid because sufficient data were available to specify water column chemical concentrations within the HSC (see Section 5.2.3). It is not necessary to simulate erosion and deposition processes in the HSC because water column chemical concentrations in the HSC can be specified using data, which is all that is necessary for the chemical fate and transport model. Simulating erosion and deposition fluxes within the HSC would not have improved the predictive capability of the chemical fate and transport model within the USEPA Preliminary Site Perimeter."

These explanations are not justifiable, at least not without quantifying the effects of this assumption using a sensitivity analysis. It states that water column chemical concentration data are available for the HSC. Are there data for all 21 years of the model simulation? While the assumption that "simulating erosion and deposition fluxes within the HSC would not have improved the predictive capability of the chemical fate and transport model within the USEPA Preliminary Site Perimeter" may be valid, a sensitivity test should have been run to quantitatively justify this assumption.

Delineation of the sediment bed. It states in Section 4.2.2 of Anchor QEA (2012) that the sediment bed in a given area was specified as cohesive if the median particle diameter, D_{50}, is less than 250 μm and if the combined clay and silt content is greater than 15 percent. Unless the fraction of clay size sediment is the majority of the combined clay and silt content, it is unlikely if sediment with only these two criteria are cohesive in behavior. More justification needs to be given to support this assumption as it would definitely have an impact on the erosion and transport of sediment in the SJR estuary.

Calibration of the hydrodynamic model. The comparison of measured and simulated depth-averaged velocities shown in Figures 3-23 – 3-25 indicates that the model is under predicting the maximum velocities during both ebb and flood tides, but more so during the latter. In particular, the poor agreement seen during the period July 3 – 4 indicated the model did not accurately represent the combined tidal and riverine flows during this high flow event. The impact that the location of the downstream boundary in the AQ model had on these comparisons is not known. This was investigated using the LTFATE model. Based on these comparisons of the simulated versus measured velocity times series, the PDT does not completely agree with the last sentence in this section that states 'the calibration and validation results demonstrate that the model is able to simulate the hydrodynamics within the Study Area with sufficient accuracy to meet the objectives of this study'.

Calibration of the sediment transport model. How were the two qualitative conclusions made in the last two sentences of the fourth paragraph of Section 4.3 ("Overall, the model predicts net sedimentation with reasonable accuracy' and 'The general pattern of net sedimentation is qualitatively consistent with known characteristics of the Study Area') arrived at? The PDT comes to a different conclusion when examining the comparisons shown in Figs. 4-24 and 4-25, especially for two of the three stations within EPA's Preliminary Site Perimeter. It seems that the model does not predict net sedimentation with reasonable accuracy. This conclusion remains the same even after reading the discussion of the effect of spatial scale on model results in the last paragraph in Sec 4.5. Finally, what are the known characteristics of the Study Area that are mentioned in the last sentence?

Other factors/processes not represented in the modeling. These include the following: wind waves and the effects of barges and propwash on sediment resuspension at the Site. The text that was added to Section 4.1 of Anchor QEA (2012) explaining why wind-wave resuspension is not simulated is valid for non-storm conditions. However, it should have been evaluated in the sensitivity analysis for simulated storm conditions. Regarding the effects of barges and propwash, it is noted that AQ commented that "The potential effects of ship and barge traffic on sediment transport within the USEPA Preliminary Site Perimeter will be evaluated during the Feasibility Study."

Model Evaluation – Hydrodynamic Model

The AQ hydrodynamic model for the SJR was benchmarked for model output integrity and reliability. These verification and benchmarking tasks were intended to ensure that the hydrodynamic model correctly simulates the riverine and estuarine circulation in the SJR estuary. The evaluation consisted of the following three steps:

1. Model inputs were reviewed to verify consistency with what is documented in Anchor QEA (2012). As a component of this, model-data comparisons were performed for the hydrodynamic input files to insure that the correct parameterizations were used in the model.

2. Model output integrity was verified for selected simulations by recompiling the AQ source code, re-running these simulations with the generated executable, and comparing the model results from these simulations to the model results provided by AQ.

3. Verification of model calculations was accomplished by reviewing model outputs. This review focused on model calculations that were specific to the SJR model domain.

Verification of Model Inputs

Model inputs for bathymetry, inflows, and downstream tidal boundary conditions are based on site-specific data. The goal of the review was to insure the inputs were correctly specified in the model input files. All the hydrodynamic input files were checked, and no problems were identified. Specifically, the input files which described the computational grid were checked to insure the SJR model grid was correctly represented, and the bathymetric data included in the files were correct. Selected model simulation input files, including flow and stage boundary condition files, were also checked for consistency. No inconsistencies were found during these checks, so the model inputs for the hydrodynamic model were successfully verified.

Verification of Model Calculations

The hydrodynamic model for the SJR is based on the EFDC model, which is an open source model supported by EPA Region 4, and which has been applied to many rivers, estuaries, other water bodies worldwide. The AQ version of EFDC was compiled on a Windows computer using the FORTRAN Compiler for Windows by Intel and on a Linux server using the Intel FORTRAN Compiler for LINUX. These recompilations were performed to verify that the AQ version of EFDC could be successfully compiled on different computers using different operating systems (*i.e.*, Windows and Linux). The results obtained using the code executable received from AQ were identical (to within machine precision) with the results obtained using the two recompiled codes. The recompiled code run on the Windows computer was run in full debug mode, but no runtime errors occurred. The conclusion from this task is that the AQ version of EFDC was successfully verified.

Benchmarking of Model Outputs

The 21-year hydrodynamic model simulation was benchmarked to insure that model outputs provided by AQ were reproduced. This simulation was performed using the recompiled code on a Windows computer. The 21-

year simulation was successfully completed without any runtime errors, and comparisons of the output from this simulation with that produced using the code executable provided by AQ were identical (to within machine precision). The conclusion from this task is that the AQ version of EFDC was successfully benchmarked.

Model Evaluation - Sediment Transport Model

The AQ sediment transport model was benchmarked for model output integrity and reliability. These verification and benchmarking tasks were intended to ensure that the sediment transport model correctly simulates the represented sediment transport processes. The evaluation consisted of the following three steps:

1. Model inputs were reviewed to verify consistency with what is documented in Anchor QEA (2012). As a component of this, model-data comparisons were performed for the sediment transport input files to insure that the correct parameterizations were used in this model.
2. The model output integrity was verified for selected simulations by recompiling the AQ source code, re-running these simulations with the generated executable, and comparing the model results from these simulations to the model results provided by AQ.
3. The verification of model calculations was accomplished by reviewing model outputs. This review focused on model calculations that were specific for the SJR modeling system.

Verification of Model Inputs

The following sediment transport model inputs are based on site-specific data, and should be consistent across all model simulations.

- Effective particle diameter for each size class
- Cohesive resuspension parameters (τ_{cr}, A, n)
- D_{90} (used for skin friction calculation)
- D_{50} (used for initial grain size distribution calculations, as well as other sediment transport calculations)
- Initial grain size distribution
- Dry bulk density

The verification of model inputs for the sediment transport model used consisted of the following components:

1. The values used for the input parameters listed above were reviewed to insure they were within the expected ranges, *i.e.*, ranges of these parameters reported in the literature. The values of all these model inputs used in the sediment transport modeling fell within the expected ranges and/or were the same as given in Anchor QEA (2012).

2. All of the input files for the sediment transport model were checked to verify that the values of the parameters listed above were consistently used. This check revealed that the same values were used for these parameters in all the input files.

3. The time series of solids loading for the sediment transport model were plotted using the model input time series to identify any unusual or outlying solids load inputs. No problems were noted, and the time series were as described in Anchor QEA (2012).

In conclusion, no inconsistencies or incorrect values were found during these checks, so the model inputs for the sediment transport model were successfully verified.

Verification of Model Calculations

The various processes and rate calculations included in the sediment transport model (*e.g.*, settling speed, probability of deposition, resuspension rate) all feed into the computation of the erosion and deposition fluxes for each particle size class in each grid cell at every model time step. Along with velocity and water surface elevation time series for every grid cell that are calculated by the hydrodynamic model, calculated time series of the erosion and deposition fluxes along with the resulting time series of water column concentrations of suspended sediment in every grid cell are passed to the contaminant transport and fate model. These hydrodynamic and sediment transport time series are used to drive the contaminant model. Considering that the transport and fate of highly hydrophobic chemicals (such as PCBs) that are mostly sorbed to particulate organic matter (POM), and that varying fractions of POM are typically adsorbed to sediment particles, in particular clay and silt size particles, the fate of hydrophobic chemicals are typically governed to a significant degree by the transport and fate of these solids. As such, verification of the calculations of erosion and deposition fluxes of solids in the model is essential.

The calculations of the sediment transport model were checked using the following two tasks:

1. The model code was reviewed to verify that the sediment transport model computes erosion and deposition fluxes correctly.

2. Values of the following parameters and variables that were used in the calculation of erosion and deposition fluxes were printed out during a model run to verify that correct values for the parameters being used in the calculations and that variables (*e.g.*, near-bed suspended sediment concentration) were being calculated correctly.

   a. Deposition flux components: settling speeds of the sediment size classes, probabilities of deposition, and near-bed suspended solid concentrations.

   b. Erosion flux components: critical shear stresses, erosion rate for the non-cohesive solid classes, and the erosion rate for the cohesive size class.

The finding from the first task was that the model code was correctly calculating the specified erosion and deposition fluxes, and the findings from the second task were that a) the correct parameter values were being used, and b) the correct values of relevant variables were being calculated by the model. Therefore, the conclusion from this task is that the sediment transport related calculations performed by AQ's sediment transport model were successfully verified.

Benchmarking of Model Outputs

The 21-year sediment transport simulation was benchmarked to insure that model outputs provided by AQ were reproduced. This simulation was performed using the recompiled code on a Windows computer. The 21-year simulation successfully finished without any runtime errors, and comparisons of the output with that produced using the code executable provided by AQ were identical (to within machine precision). The preliminary conclusion from this task is that the AQ sediment transport model was successfully benchmarked.

Application of LTFATE

Model Setup

Model Domain

The model domain (highlighted in blue) chosen for LTFATE is shown in Figure 3-1. As seen, the downstream boundary is adjacent to Morgan's Point, and includes the 100-year floodplain (FEMA designated floodway zone) as identified by FEMA.

Model Grid

Figures 3-2 and 3-3 show zoomed in views of the orthogonal curvilinear model grid in proximity to the Site and the downstream boundary at Morgan's Point. The average grid sizes at the Site and at the downstream boundary are 18m by 18m and 50m by 65m, respectively. The average deviation angle from orthogonal for the entire grid is 3.7 degrees, which is acceptable and insures that mass loss of water and transported constituents due to too large a degree of non-orthogonality does not occur.

Bathymetry Data

The same bathymetry data used by AQ (as documented in Appendix A in Anchor QEA (2012) were used in constructing the LTFATE grid.

Boundary Conditions

The same boundary conditions used by AQ in their hydrodynamic and sediment transport models were used in LTFATE. For the hydrodynamic model, the measured water surface elevations at the NOAA tidal station at Morgan's Point were applied to all the wet cells across the downstream open water boundary. The simulated freshwater inflows to the SJR estuary from Lake Houston and the bayous along the Houston ship channel (HSC) represented in the AQ model were also included in LTFATE. The same salinity boundary conditions were used as were used by AQ. Due to the lack of salinity data over the water depth at the downstream boundary, the LFATE model was run in a two-dimensional, depth-averaged mode like AQ's model.

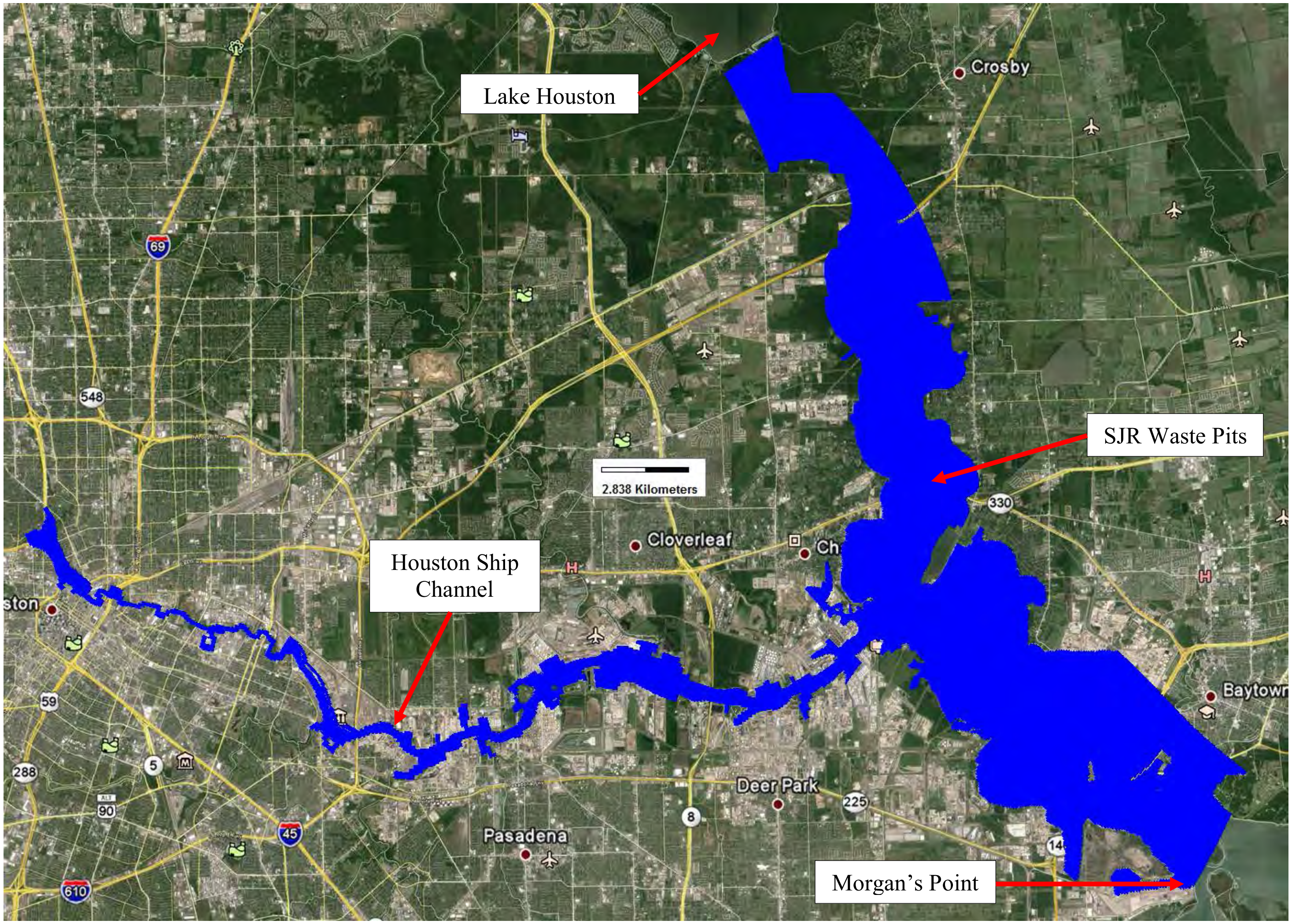


Figure 3-1 LTFATE San Jacinto River Model Domain

Figure 3-2 Grid in Proximity to the SJR Waste Pits Site

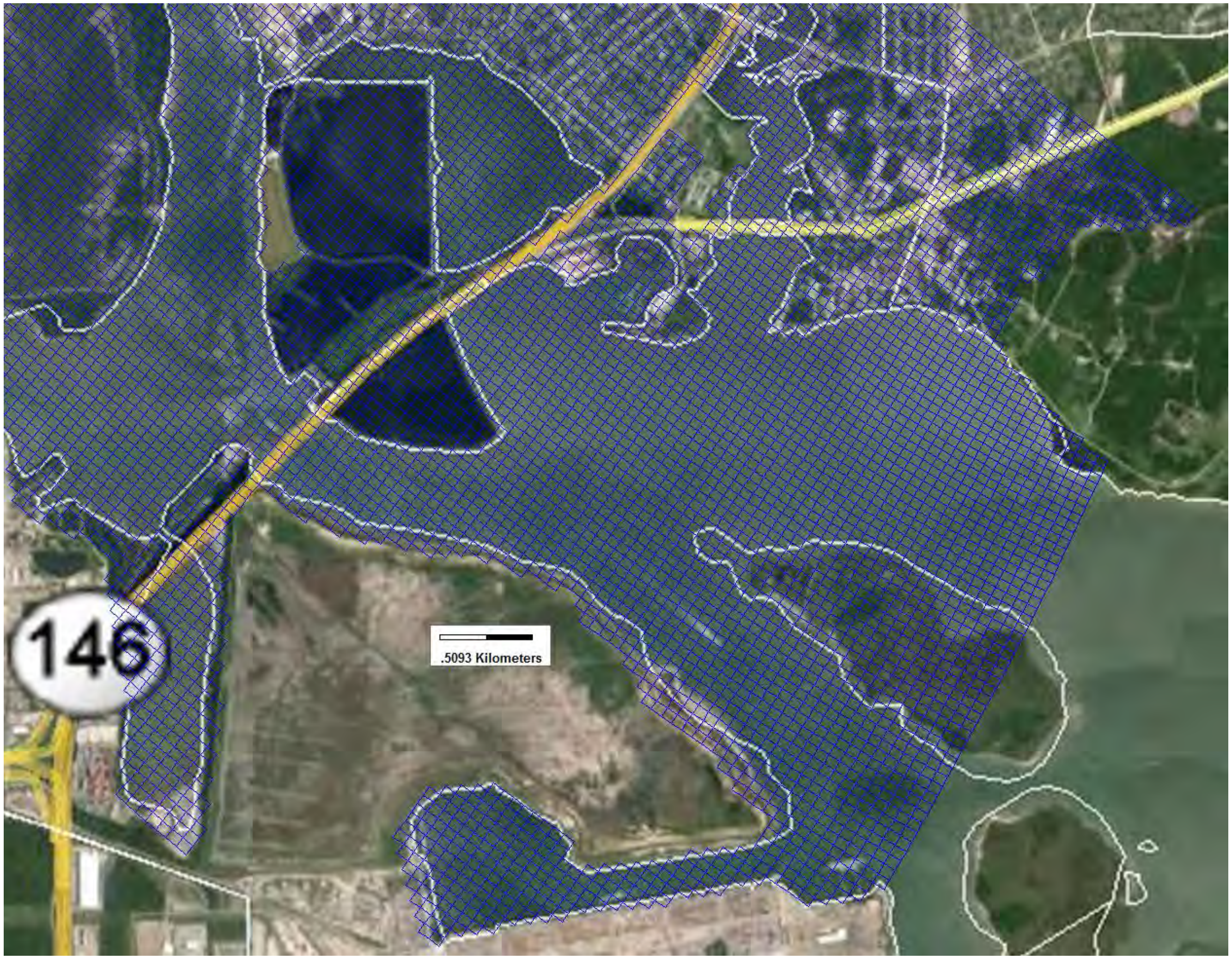


Figure 3-3 Grid in Proximity to the Downstream Boundary

Initial Sediment Bed

In specifying the initial sediment bed, the same four sediment size classes that AQ used were used in the SEDZLJ module in LTFATE. One difference between AQ's version of SEDZLJ and that used in LTFATE is that in the latter, the grid cells are not defined as being either cohesive or noncohesive and then not allowed to change during the model simulation as in the AQ version. In the LTFATE version, whether the surficial sediment is cohesive or noncohesive in behavior is determined for every active (*i.e.*, wet) grid cell during each time step. This enables the changing nature of natural sediment beds due to the varying composition of suspended sediment as well as sediment being transported as bedload to be represented. It was assumed that floodplain cells have an initial hard bottom, *i.e.*, they cannot erode. However, sediment is allowed to deposit on inundated floodplain cells, and the deposited sediment is allowed to resuspend if the bed surface of these cells is subjected to a high enough bed shear stress while the floodplain cell is wet. This is also different from the methodology used by AQ as their model does not allow sediment being carried in suspension to deposit on cells (whether they are floodplain or wet cells) that have a hard bottom.

To represent the TCRA cap, the 196 grid cells that are located within cap boundaries were assigned the Armor Cap material designated in Figure 6-1 (Armor Cap As-Built) in Anchor QEA (2012). The D_{50} sizes and thicknesses used in the grid cells are 3, 6, 6, 8 and 8 inches for the Armored Cap A (recycled – 12 inches thick), Cap B/C (recycled – 12 inches thick), Cap C (natural– 12 inches thick), Cap D (natural – 18 inches thick), and Cap D (natural – 24 inches thick), respectively.

Model Debugging

To insure that both the hydrodynamic and sediment transport modules in LTFATE were setup correctly and no runtime errors occurred, the model was run in full debug mode (Using the Intel FORTRAN compiler) for three days. The reason that it was run for only three days is that the compile code runs much slower in debug mode than it does in optimized mode.

Simulated Processes

The differences between LTFATE and AQ's sediment transport model are the following: 1) Bedload transport is simulated in LTFATE but not in AQ's sediment transport model; 2) The effect of bottom slope on bedload transport and erosion rates is accounted for in LTFATE but not in AQ's sediment transport model. The methodology described by Lick (2009) to include the effect of bed slope on erosion rates and bedload transport is incorporated in the LTFATE version of SEDZLJ. The bed slopes in both the x- and y-directions are calculated, and scaling factors are applied to the bed shear stress, erosion rate, and bedload transport equations. A maximum adverse bed slope is specified that prevents bedload transport from occurring up too steep an adverse slope.

Calibration of the Hydrodynamic and Sediment Transport Models

The same data sets used to calibrate the AQ hydrodynamic model (ADCP surveys conducted June 13 – July 7, 2010 and May 10 – July 13, 2011) were used to calibrate LTFATE. To date, the optimum agreement in the simulated and measured water levels and depth-averaged velocities was achieved using a globally averaged value of 0.1 cm for z_0 = effective bed roughness that represents to total bottom roughness due to both skin friction and form drag. The root-mean-square error (RMSE), which represents the standard deviation of the model error, in the water surface elevations for the 2010 and 2011 periods were 4.05 cm and 4.55 cm, respectively. The RMSE error in the depth-averaged velocities for the 2010 and 2011 periods were 0.12 m/s and 0.11 m/s, respectively. These results were comparable to the calibration results obtained by AQ, and were deemed satisfactory to perform the modeling related tasks in which LTFATE was used (as opposed to AQ's models) to perform the modeling. A refinement of the hydrodynamic model calibration using the ADCP data collected by the USGS in proximity to the SJR Waste Pits in February 2015 and delivered to the EPA and the ERDC PDT in May 2015 is still underway. At this time, it is not anticipated that any significant changes to the model calibration will be necessary.

Likewise, the same data AQ used to calibrate their sediment transport model was used to calibrate LTFATE, with the main metric being the net sedimentation rate. The calibration of the sediment transport model in

LTFATE again yielded comparable results to those obtained by AQ's model. Specifically, the same 16 year period (1995 -2010) that AQ ran for calibrating their sediment transport model was run using LTFATE. The same range of net sedimentation rates (NSR) inside the SJR site perimeter (i.e., 0 to 1 cm/yr) was obtained using LTFATE as it was using AQ's model, and both models showed a small area of net erosion along the eastern boundary of the site. Taking into account the uncertainties in the LTFATE modeling performed, both models yielded similar NSR results to those shown in Figures 4-22 and 4-23 in Anchor QEA (2012).

Evaluation of Assumptions in AQ's Model Framework

The results from the evaluation of the impact of the assumptions included in AQ's model framework for their hydrodynamic and sediment transport models are presented in this section. The major items identified in the *Modeling System Application* section under **Evaluation of AQ's Models** were evaluated, and the findings are presented below.

<u>The location of the downstream boundary of the model domain</u>

As noted previously, the chosen location for the downstream boundary in AQ's models required the use of interpolated tidal boundary conditions. The effect of driving the hydrodynamic model using interpolated boundary conditions was evaluated by examining the differences between the water surface elevations and current velocities at the Site predicted by the two models over a lunar month. The average difference in water surface elevations was 5 cm, and the average difference in current magnitudes and directions were 3 cm/s and less than 5 degrees. These small differences are well within the uncertainty envelope of the hydrodynamic model when applied to a complex estuary such as the SJR. As expected, the differences in these parameters became significant in proximity to the location of AQ's boundary as well as in the eastern end of the Houston Ship Channel. This comparison quantified that the location of AQ's boundary was located sufficiently far from the SJR Site so as to not impact the results of either their sediment transport or contaminant transport models in proximity to the Site.

<u>Decoupled hydrodynamic and sediment transport models</u>

The main limitation of AQ's model framework is the use of decoupled hydrodynamic and sediment transport models. This does result in the AQ model predicting smaller amounts of net erosion and higher amounts of net deposition since the effect of changes in bed elevations due to erosion and deposition is not accounted for in the decoupled hydrodynamic model that AQ uses. As a result, more uncertainty should be attached to morphologic changes predicted by their sediment transport model. This higher level of uncertainty, along with the higher level of uncertainty associated with their hydrodynamic model results since the latter does not account for bed elevation changes (and therefore changes in water depths) during a model run, should be propagated into the uncertainty associated with the results from their contaminant transport model since the latter is driven to a large degree by the results from both the hydrodynamic and sediment transport models. While the quantification of this uncertainty is beyond the scope of this study, one of the consequences is that the use of decoupled hydrodynamic and sediment transport models often yield higher quantities of net deposition. The latter, when used in the contaminant transport model, usually result in faster decreases in concentrations of COCs in the sediment bed than actually occur. The latter is caused by the deposition of sediment with lower COC concentrations on top of the contaminated sediments, thus causing the average concentrations in the bed to decrease due to the mixing of the surficial sediments by bioturbators, etc.

Floodplain areas

The actual 100-year floodplain that was represented in the LTFATE model grid produced a better representation of the flooded conditions at occur in the SJR estuary during extreme riverine floods and tropical storm induced storm surges than that represented by AQ's models. However, the maximum flow velocities in proximity to the SJR Waste Pits simulated by LTFATE for an out-of-bank event were slightly lower than those simulate by AQ's model since the flood was more confined to the river/channel in AQ's model than in LTFATE.

Two-Dimensional depth averaged model

Due to the lack of vertical salinity data to be able to quantify the degree of salinity-induced stratification and the combination of hydrologic conditions and tidal flows during which at least partially stratified flows occur in the SJR estuary, it was decided to run LTFATE in the depth-average mode like AQ did with their models. Thus, both models assumed that the SJR estuary was well mixed, so it was not possible to quantify the impact of this assumption. This assumption is thought to have negligible impact on the predicted sediment transport during a severe event such as a flood or storm surge because the combined energy from the waves and wind-, river- and tide-generated flows would be more than sufficient to vertically mix the water column.

Use of hard bottom in the HSC and in the upper reach of the SJR

The effect of this assumption in AQ's model framework was tested by determining the differences in the composition and thickness of the sediment bed at the SJR Site as predicted by AQ's models and LTFATE in which a hard bottom was not assumed in these two waterways. The differences were within the range of uncertainty associated with these models. The uncertainty associated with the limited sediment data in these waterways that were used to specify the sediment bed properties in LTFATE was included in this analysis. As a result, this assumption was not found to have a significant impact on the results obtained by AQ's models.

Task 4

Statement

Provide an uncertainty analysis of the model assumptions (flow rates, boundary representation, sediment transport, sedimentation rates, initial bed properties, etc.). Uncertainties should be clearly identified and assessed including sediment loads at the upstream Lake Houston Dam.

Methodology

It is standard to evaluate the effects of uncertainties in model inputs using a sensitivity analysis. Thus, this task was performed by expanding on the sensitivity analyses performed by AQ with their models. A review of the analysis that AQ performed is given below, followed by a critique of their analysis, and then a description of the expanded sensitivity analysis being performed for this task is given.

AQ Sensitivity Analysis

The sensitivity analysis performed by AQ evaluated the effects of varying input parameters for both the sediment transport model and the hydrodynamic model. These analyses are summarized below.

The sensitivity analysis performed by AQ evaluated the effects of varying the following sediment transport model input parameters: erosion rates, incoming sediment load at the Lake Houston Dam, and the effective bed roughness as quantified by the value of D_{90}. The latter was only increased by a factor of two, whereas the incoming sediment load was varied by $\pm$ 2. Both changes are with respect to the base case simulation. Lower and upper-bound parameters that were based on the erosion rate ratio values for the Sedflume cores, with the lower-bound being Core SJSD010 and the upper-bound being Core SJSF003. AQ evaluated the effects of possible interactions among the three input parameters using a factorial analysis. The latter produced eight model simulations that accounted for all of the possible combinations of the upper and lower bounds of the three parameters. The results of these eight model simulations were compared "using the sediment mass balance for the Study Area as the metric for quantitative comparison". Figure 4-44 in Anchor QEA (2012) shows the predicted sediment mass balance for the entire model domain over the 21-year model simulation, and the trapping efficiency was determined to be

17 percent. Trapping efficiency is calculated as the percentage of the incoming sediment load that is deposited in the model domain. Seven of the eight sensitivity simulations had positive trapping efficiencies, *i.e.*, they were net depositional over the 21-year simulation period, whereas one of the simulations was net erosional so no trapping efficiency was calculated for that simulation. The seven positive trapping efficiencies ranged from 6 to 24 percent (see Figure 4-49 in Anchor QEA (2012)). AQ also presents comparisons of the gross erosion rate, the gross deposition rate, and the rate of net change for the entire model domain and the Site Perimeter, respectively, in Figures 4-50 and 4-51 for the base case and eight sensitivity simulations. Their findings from these sensitivity simulations were the following: 1) Changes in the upstream sediment load had the largest effect on the net deposition over the 21-year simulation; and 2) The effects on both net erosion and net deposition due to the variations in erosion rate parameters and the effective bed roughness were of similar magnitude, and most importantly, were significantly less than the effect from varying the incoming sediment load from Lake Houston.

The sensitivity analysis performed by AQ evaluated the effects of varying the following hydrodynamic model input parameters: channel bathymetry in the vicinity of Grennel Slough, water inflow at the Lake Houston Dam, salinity at the downstream boundary, and the water surface elevation (WSE) at the downstream boundary. The effects of these input parameters on both the hydrodynamic and sediment transport models were determined by simulating conditions for 2008 (during which Hurricane Ike occurred) for both the base case (using the original input parameters) and the sensitivity model runs. The differences between the base case and the different sensitivity runs were quantified by determining the differences in bed elevation changes within the Site Perimeter at the end of the one-year model simulations. Results from this analysis are described next.

The channel bathymetry in the vicinity of Grennel Slough was modified by eliminating two areas that created a cutoff in the channel due to spatial interpolation of the bathymetric data. Analysis of the model simulation of 2008 found that the original bathymetry that contained the two cutoffs had negligible effect on the hydrodynamics and sediment transport within the Site.

As discussed in Anchor QEA (2012), the water releases at the Lake Houston Dam were estimated for the period of the 21-year simulation prior to July 1996. The impact of the method used to estimate the inflows into the SJR on the model results was evaluated by using the same method to estimate the inflows for 2008 and running the models for that year. The results from this analysis revealed that the method used for estimating the inflows prior to July 1996 had relatively minor effects on the sediment transport simulations within the Site perimeter.

A constant salinity of 16 psu was used at the downstream boundary for the 21-year simulations. The effect of the salinity value used for the downstream boundary on sediment transport simulations at the Site was investigated by simulating 2008 using both a salinity boundary condition of 16 and 0 psu. These two simulations were compared and negligible impacts on the sediment transport results were found. This is not a surprising result when using a depth-averaged model.

The effect of the WSE used at the downstream boundary was investigated in the following manner. The year 2002 was simulated using the WSE obtained from data collected at the Morgan's Point tidal gauge station as well as using the WSE data collected at the Battleship Texas State Park/Lynchburg station. The bed elevation changes for each grid cell within the Site Perimeter were compared between these two model simulations, and minimal differences were found. Thus, AQ concluded that the WSE data used at the downstream boundary in their model did not have a significant impact on the sediment transport results in proximity to the Site.

Critique of the AQ Sensitivity Analysis

Overall, the sensitivity analysis performed by AQ is the best method for attempting to put bounds on the uncertainty in results obtained from any transport and fate modeling study. The use of trapping efficiency as a metric for quantifying the results from the sensitivity analysis is thought to be somewhat limited in its usefulness. However, the finding that the largest source of uncertainty in the sediment transport modeling is the estimated sediment loading from the Lake Houston Dam is not surprising. As the USGS commented in their review, "to improve the model, better sediment load information from Lake Houston Dam is necessary." However, having more accurate sediment loading data may or may not improve the model's ability to predict sediment transport in the SJR estuary. This same thought is conveyed in USGS's comments 29 and 37.

As discussed in Task 3, it is the opinion of the PDT that the largest source of uncertainty is the application of a model framework that does not account for morphologic feedback between the sediment transport and hydrodynamic models to a water body such as the SJR. The SJR estuary is subjected to aperiodic large hydrologic events, *i.e.*, floods and hurricanes, such as the three significant events that occurred during the 21-year simulation period, during which significant sediment transport and large scale scour and sedimentation occurred in certain portions of the estuary. The unquantified uncertainty in applying a non-morphologic modeling system to such a system limits the usefulness of the sensitivity analysis performed using the non-morphologic models. In addition, the other issues discussed in Task 3, *e.g.*, inclusion of the 100-year floodplain in the model grid, location of the downstream boundary, definition used to classify sediment as cohesive, use of a hard bottom in the HSC, etc., are believed to further increase the uncertainty in the model results. A better model framework to use at the SJR would have been the one that AQ used in simulating primarily noncohesive sediment transport in the Tittabawassee River, Michigan in which a quasi-linkage routine was added between the sediment transport and hydrodynamic models. In both water bodies, the magnitude of the morphologic changes is within one order of magnitude of the water depths, thus necessitating the linkage between the hydrodynamic and sediment transport models.

Expanded Sensitivity Analysis

In an attempt to better quantify the uncertainty associated with the model framework and the other issues listed above and in Task 3, an expanded sensitivity analysis is being performed as a component of this project. It is being performed using the LTFATE modeling system that was setup to represent the SJR estuary model domain. A description of the methodology used in performing the expanded sensitivity analysis is described next.

The effects of changes in the following parameters on results with the LTFATE modeling system were investigated using a sensitivity analysis approach similar to the factorial analysis methodology used by AQ:

- Simulation of bedload
- Different classification of cohesive sediment
- Sediment loadings at the Lake Houston Dam
- Use of a non-hard bottom in the HSC and upper SJR

Table 4-1 lists the nine sensitivity simulations that were run, with Run 1 representing the Base Case (defined as that being closest to AQ's model setup). The September – November 1994 time period was used for these nine model runs. While many different simulation periods could have been used for this analysis, including the 21-year period that AQ used, the extreme event of record was chosen to differentiate the differences among these nine sensitivity simulations under this extreme event during which the sediment load being transported through this estuary was enormous. The inclusion of the 100-year floodplain in the model grid and the use of the dynamically linked hydrodynamic model and sediment transport model option in LTFATE were used in all nine sensitivity simulations.

Table 4-1.
Sensitivity Simulations

Sensitivity Run	Bedload Simulated	Different cohesive sediment classification	Inflow sediment loadings	Hard bottom in the HSC and upper SJR
1	No	No	AQ	Yes
2	No	Yes	AQ	Yes
3	No	No	Upper Bound	Yes
4	No	No	Lower Bound	Yes
5	No	No	AQ	No
6	Yes	No	AQ	Yes
7	Yes	Yes	AQ	Yes
8	Yes	Yes	AQ	No
9	Yes	Yes	Upper Bound	No

Using a similar approach to that used by AQ, the sediment mass balance inside the northern impoundments was used as the metric for the quantitative comparison of the results of the nine sensitivity simulations.

Figure 4-1 shows the results from the three month simulation for the nine sensitivity runs. The numbers (1 through 9) at the top of each bar are the sensitivity run numbers shown in Table 4-1. As expected, all nine simulations showed negative net bed elevation changes (*i.e.*, net erosion) over this three month period. The plotted net bed elevation changes represent the spatially averaged values for the portion of the grid inside the northern impoundments. Net bed elevation change is defined as the difference in bed elevation in a given grid cell from that at the beginning of the simulation to that at the end. As such, the net bed change does not represent the maximum depth of erosion that occurred during the simulated three months. In all cases, the maximum erosion depth was about twice that of the net change. The net change was smaller due to the net deposition that occurred at the site for the period of the model simulation that followed the peak of the 100-year flood.

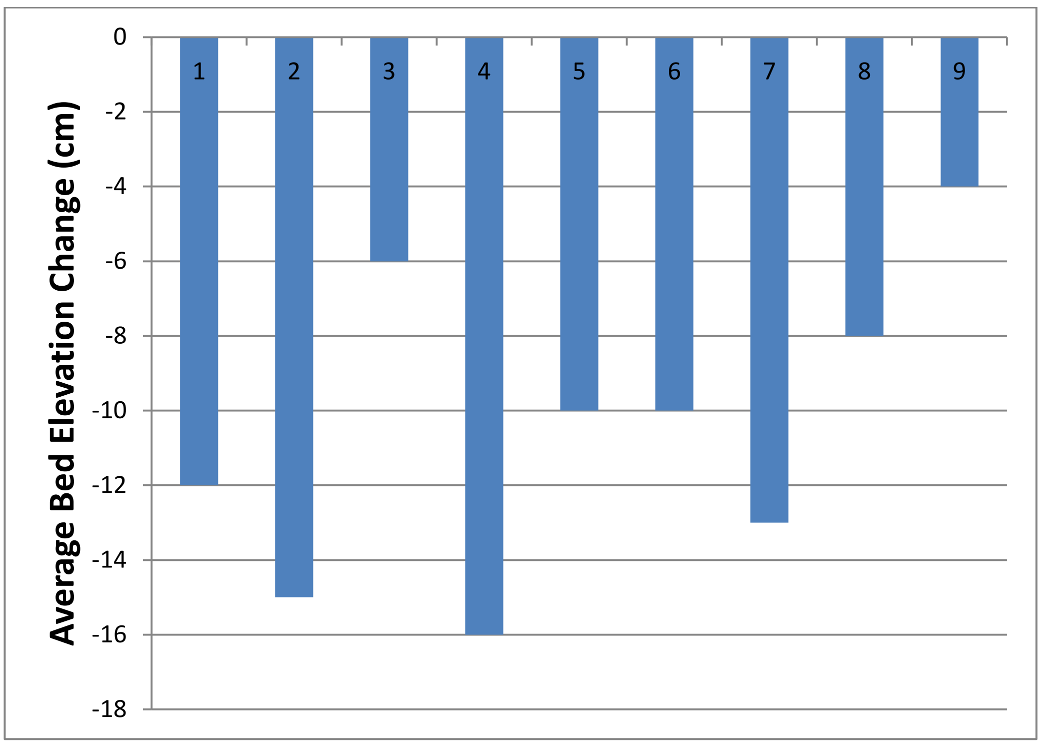


Figure 4-1 Average Change in Bed Elevation within the Northern Impoundments for the nine Sensitivity Simulations

These nine sensitivity simulations agreed with the conclusions reached by AQ in their model sensitivity analysis. For example, as seen by comparing Runs 3 and 4, decreases in the upstream sediment load causes more net erosion due to less sediment being transported to the SJR estuary, which in turn results in smaller quantities of sediment being deposited at the Site following the simulated flood. In addition, the following conclusions were developed from the results shown in Figure 4-1.

- The use of a hard bottom in the upper SJR also decreases the sediment load transported downstream, thus resulting a higher amount of net erosion (as seen by comparing Runs 1 and 5).

- The simulation of bedload transport of the noncohesive sediment size classes is seen to slightly decrease the amount of net erosion (as seen by comparing Runs 1 and 6). The reason for this is that bedload transport increases the quantity of sediment that is simulated to be transported to the site, and the lower flow velocities within the boundaries of the Site result in net deposition of the sediment transported as bedload.

- The used of AQ's cohesive sediment classification in their version of the SEDZLJ layered sediment bed model results in less net erosion than the traditional cohesive sediment classification used in the SEDZLJ model in LTFATE (as seen by comparing Runs 6 and 7). This is because AQ's cohesive sediment classification results in the bed surface being more resistant to eroding forces than that used in LTFATE.

The general conclusion reached from this expanded sensitivity simulation is that most (but not all) of the assumptions included in the AQ model framework result in higher values of net erosion. However, the two factors that most effect the net change in bed elevation, those being the upstream sediment loads and the use of uncoupled hydrodynamic and sediment transport models, result in higher uncertainties in the findings reported by AQ from their sediment transport and contaminant transport modeling.

Task 5 and Task 6

Statements

Perform a technical review of the design and construction of the entire existing cap as it is currently configured. Identify any recommended enhancements to the cap.

Assess the ability of the existing cap to prevent migration of dioxin, including diffusion and/or colloidal transport, through the cap with and without the geomembrane/geotextile present.

Background

Design and construction of the existing TCRA cap was divided into three sections, each of which has different cap components. The Western Cell is generally above the water line; the Eastern Cell is mostly covered with less than 5 ft (1.5 m) of water; and the Northwestern Area is mostly in greater than 10 ft (3.0 m) of water. The Western Cell cap is composed of a geotextile filter, a geomembrane, a protective geotextile cushion and armor stone. The Eastern Cell has a geotextile filter and armor stone. The Northwestern Area has predominantly granular filter blended with armor stone. These three sections were further subdivided into subsections with varying armor stone. The cap is presently built with some slopes steeper than 1V:3H. The thicknesses of the armor stone is at least twice the D_{50} of the stone. The armor stone is sized for limited movement during storm events having a return period of up to 100 years. The capped sediment consists predominantly of a soft, compressible, organically rich sludge.

Western Cell

The Western Cell should largely be physically stable provided that all surfaces have a slope flatter than 1V:3H, all areas of potential high bottom shear stress with a slope steeper than 1V:5H are covered in natural stone, the design bottom shear stresses are properly modeled, and no significant localized deformations occur to disrupt the geomembrane. Soft sediments were solidified/stabilized prior to cap construction. The design and construction followed standard practice for land-based operations. The geotextiles were overlapped and geomembrane seams were welded. The armor stone, geotextiles and geomembrane effectively isolates environmental receptors from the contaminated sediment. The geotextiles used in the design provide adequate protection for the geomembrane to prevent puncture and to provide long-term chemical isolation. The geomembrane will control infiltration, seepage and tidal pumping along with their associated dissolved and colloidal transport of contaminants. The geomembrane also controls diffusion and resuspension, effectively isolating the contaminants. No groundwater transport in the sediment under the cap across the site is anticipated based on the topography of the region, location of the site, and permeability of the sediment.

The long-term reliability of the Western Cell can be improved by providing greater resistance to armor stone movement. Flattening of slopes steeper than 1V:3H and providing a gradual transition between the slopes are recommended to increase the factor of safety and provide for long-term stability. Increasing the armor stone size by two inches is also recommended to provide stability during the most severe hydrodynamic and hydrologic events.

Eastern Cell

The Eastern Cell should largely be physically stable provided that all surfaces have a slope flatter than 1V:3H, all areas of potential high bottom shear stress with a slope steeper than 1V:5H are covered in natural stone, the design bottom shear stresses are properly modeled, and no significant localized deformations occur to disrupt the geotextile. The design and construction followed standard practice for water-side operations. The geotextiles were overlapped and secured in place during placement of the armor cap. The geotextiles were rolled out and advanced gradually during armor cap placement to maintain their positioning. The armor stone and geotextile effectively isolates environmental receptors from the contaminated sediment. The Eastern Cell does not contain a geomembrane to control resuspension and the advective and diffusive fluxes of contaminants. However, being submerged in relatively flat environs without regional surficial groundwater upwelling, no significant advective flux is anticipated to provide transport of dissolved or colloidal contaminants.

A small quantity of porewater with dissolved and colloidal contaminants would have been expelled in the short term following the cap placement from consolidation and compression of the sediment under the pressure loading imposed by the armor cap. This contaminant mass release would have been very small compared to the resuspension releases prior to capping, but likely to be several times greater than the diffusive releases during the same period. Resuspension of contaminated particles is not expected because the geotextile will provide a filter to control particle movement and prevent translocation of the capped sediment to the surface. Therefore, contaminant transport would be restricted to porewater expulsion and diffusion. The releases from the armor cap would not pose concerns for toxicity and bioaccumulation because the releases would be much less than background releases outside the cap where resuspension of particles with sorbed contaminant is on-going along with diffusion.

The diffusive flux of contaminants from the capped area is very small compared to resuspension releases of contaminated particulates prior to capping; however, the diffusive releases from the sediment are largely unimpeded by the cap. The armor cap material does not have a significant quantity of organic carbon to retard contaminant transport in the short term; however, sedimentation will increase the organic content in the armor as new materials deposit in the pore space between the armor stones. In addition, the large pore structure of the armor cap material would permit a large exchange of water within the cap, preventing the formation of a concentration gradient to slow the diffusion in the short term until the pore spaces are filled with new deposits. Results of cap pore water testing by D. Reible on the TCRA cap using solid phase micro extractions (SPMEs) was generally unable to detect any contaminants of interest in the cap pore water. Nevertheless, addition of an amendment like AquaGate™ or SediMite™ to fill the pore spaces and provide activated carbon to sequester the contaminants could further reduce the potential contaminant releases from diffusion throughout the life of the cap. A product like AquaGate™ or Aquablok™ would also provide added protection from erosion by providing cohesion between granular particles upon infiltration, swelling and filling the large pores of the Armor Cap C and D materials, and perhaps also the pores among the recycled concrete particles of the Armor Cap A and B/C materials following raining of the AquaGate™ particles onto the armor cap materials.

Thin armor caps with a geotextile placed on an organic sediment having a flat slope such as the cap built in most of the Eastern Cell would be subject to disruption by gas generation. The geotextile resists gas transmission at low pressures due to its air entry properties. Over time the geotextile may become clogged by fine-grained deposition and biological excretions. The generated gas pressures may build to a point where local disturbances of submerged caps less than 24 inches thick may occur.

The long-term reliability of the Eastern Cell can be improved by providing greater resistance to armor stone movement. Flattening of slopes steeper than 1V:3H and providing a gradual transition between the slopes are recommended to increase the factor of safety and provide for long-term stability. Increasing the armor stone size by two inches is also recommended to provide stability during the most severe hydrodynamic and hydrologic events. Increasing the thicknesses of sections of the cap that are continuously submerged to at least 24 inches is recommended to avoid localized disruptions of the armor cap.

Northwestern Area

The design and construction of the cap in the Northwestern Area is very different than the other two cells and does not provide the same level of confidence in its long-term stability and performance. The area is largely capped with twelve inches of non-uniform recycled concrete blended with granular filter material at a ratio of 4:1. The D50 of the recycled concrete was specified to be 3 inches (7.6 cm). Slopes within the Northwestern Area are as steep as 1V:2H. The cap was placed in layers proceeding from deep water to shallow water, following standard construction practices for water-side operations.

Placement of recycled concrete with a blended filter on slopes steeper than 1V:3H, and perhaps as flat as a 1V:5H slope, promotes separation of the sand-sized particles and perhaps gravel-sized particles from the larger concrete particles. The finer particles would have a tendency to move down the slope before coming to rest, coarsening the cap on the upper portion of the slopes and reducing the effectiveness of the filter on the upper slope. Without a filter being placed on soft sediments (having low bearing capacity) prior to placement of the armor material, the larger particles of recycled concrete would embed themselves in the sediment and promote mixing of the cap with the sediment, thereby limiting the isolation of the sediment. Use of a blended filter would tend to be less effective on very soft sediments than a separate granular filter.

Additionally, the weight of the armor stones and cap may be sufficient to extrude very soft sediment through the large pores between armor stone unless a sufficient quantity of properly sized filter media is in place. To ensure physical stability of the cap, the cap and blended filter should be placed on a slope no greater than 1V:3H, and preferably 1V:5H. It is likely that the filter is inadequate in places and additional capping media will be needed to upgrade the cap performance and prevent future sediment exposure.

Mixing of the sediment with the capping media and inadequate filtration due to loss of the finer fraction of the capping media (sands and perhaps gravel) due to separation during placement may allow exposure of the sediments to the water column, leading to releases by resuspension of sediment particles in addition to diffusion and porewater expulsion. Additionally, bioadvection of sediment may translocate sediment particles to the surface where the sediment can be resuspended. Burrowing to a depth of 12 to 15 inches (30.5 to 38.1 cm) may be expected in the absence of a geotextile or a geomembrane. Thickening the cap in the Northwestern Area and providing adequate filter media to restrict translocation of sediment particles would virtually eliminate the potential resuspension releases.

Regardless of whether resuspension releases occur, there are potential contaminant releases by diffusion, porewater expulsion, tidal pumping and groundwater seepage. Like the Eastern Cell, the Northwestern Area does not contain a geomembrane to control the advective and diffusive flux of contaminants. However, being submerged in relatively flat environs without regional surficial groundwater upwelling without regional surficial groundwater upwelling, no significant advective flux by groundwater seepage is anticipated to provide transport of dissolved or colloidal contaminants. A small quantity of porewater with dissolved and colloidal contaminants would have been expelled in the short term following the cap placement from consolidation and compression of the sediment under the pressure loading imposed by the armor cap. This contaminant mass release would have been very small compared to the resuspension releases prior to capping, but likely to be several times greater than the diffusive releases during the same period. Therefore, contaminant transport is restrictive to porewater expulsion and diffusion. The diffusive flux of contaminants from the capped area is very small compared to resuspension releases of contaminated particulates prior to capping; however, the diffusive releases from the sediment are largely unimpeded by the cap. The releases from the armor cap would not pose concerns for toxicity and bioaccumulation because the releases would be much less than background releases outside the cap where resuspension of particles with sorbed contaminant is on-going along with diffusion.

The armor cap material does not have a significant quantity of organic carbon to retard contaminant transport. In addition, the large pore structure of the armor cap material would permit a large exchange of water within the cap by tidal pumping, preventing the formation of a concentration gradient to slow the diffusion. Cap pore water testing by D. Reible on the TCRA cap using solid phase micro extractions (SPMEs) was generally unable to detect any contaminants of interest in the cap pore water. Nevertheless, addition of an amendment like AquaGate™ or SediMite™ could further reduce the potential contaminant releases from diffusion by the addition of activated carbon to sequester the contaminants and restrict the exchange of water within the cap. The activated carbon could provide *in situ* treatment of sediment particles mixed into the cap during placement or bioadvected after placement, limiting resuspension releases as well as diffusive and advective releases from the cap in the Northwestern Area where the filter may not be performing as well as desired, allowing some intermixing of cap material with the sediment. A product like AquaGate™ or Aquablok™ would also provide added protection from erosion by providing cohesion between granular particles and filling the pores of the recycled concrete of the Armor Cap A material. The long-term releases from the armor cap are presented in Task 16. The predictions in Task 16 show that an intact cap would not pose concerns for toxicity and bioaccumulation because the peak releases by diffusion would be much less than the releases from an exposed sediment having a contaminant concentration equal to the PCL where resuspension of particles with sorbed contaminant would be on-going along with diffusion.

The long-term reliability of the Northwestern Area can be improved by providing greater resistance to armor stone movement. Flattening and coarsening of slopes steeper than 1V:3H and providing a gradual transition between the slopes are recommended to increase the factor of safety and provide for long-term stability. Alternatively, ribbing with larger stone or terracing could be used to stabilize the slope while restricting the resulting cap thickness and slope length. The Armor Cap A material is unlikely to be stable under the most severe hydrodynamic and hydrologic events. Increasing the armor stone size to a D_{50} of 6 inches (15 cm), and probably larger in shallow water, would be needed to prevent erosion during the most severe hydrodynamic and hydrologic events.

Conclusions

- To ensure physical stability of the cap and prevent migration of blended filter material from migrating down the slope, the cap and blended filter in the Northwestern Area should be placed on a slope no greater than 1V:3H, and preferably 1V:5H.
- The size of the armor stone in the most vulnerable areas of the cap should be increased by 2 to 3 inches in diameter. This is especially true in the Northwestern Area.
- Thickening the cap in the Northwestern Area would virtually eliminate the potential resuspension releases by bioturbation. Maintenance of an adequate filter between the contaminated sediment and the armor stone is critical to control contaminant releases. Use of a product like Aquablok™ could fill the voids between armor stone and seal the cap, restricting erosion of the armor stone and blended filter media.
- Thickening of the cap in the Eastern Cell is needed to control disruption of the geotextile and consequently the armor cap by gas generation. A minimum of 24 inches of armor cap thickness is needed.
- Addition of an amendment like AquaGate™ or SediMite™ could further reduce the potential contaminant releases from diffusion or advection by the addition of activated carbon to sequester the contaminants and restrict the exchange of water within the cap. However, diffusive releases should be quite small regardless and very little advection is predicted. Results of cap pore water testing by Reible on the TCRA cap using SPMEs support these conclusions.

Task 7

Statement

Assess the long-term reliability (500 years) of the cap under the potential conditions within the San Jacinto River, including severe storms, hurricanes, storm surge, subsidence, etc. Include in the assessment an evaluation of the potential for cap failure that may result from waves, propwash, toe scour and cap undermining, rock particle erosion, substrate material erosion, stream instability, and other potential failure mechanisms. Reliability will be based on the ability of the cap to prevent any release of contaminated material from the Site. Also discuss any uncertainty regarding the long-term reliability and effectiveness of the existing cap.

Methodology

The methodology used to assess the long-term reliability of the cap is given below.

1) Evaluate bed shear stresses generated by the October 1994 flood.

2) Estimate the erosion potential resulting from the time series of these bed shear stresses.

3) To evaluate potential scour of the cap due to propwash generated by ship traffic in proximity to the cap the following methodology should be used: a) detailed information on ship traffic (*e.g.*, average ship power, size, draft, propeller(s) diameter and type (*i.e.*, ducted or non-ducted), ship speed) are needed; b) develop an empirical propwash relationship using available ship information; c) calculate the bed shear stress using the method given by Maynord (2000); and d) calculate potential bed erosion using the method given by Maynord (2000).

4) The following events were also qualitatively evaluated as part of the assessment of the long-term reliability:

   a. Cap undermining caused by toe erosion.

b. Erosion of the cap cause by movement of the armor rock across the surface of the cap during a large flood and the possible erosion of the substrate material below the cap.

c. Changes in river flow dynamics and channel morphology during a high flow event caused by a major flood or hurricane.

Uncertainty Discussion

The uncertainty regarding this assessment of the long-term reliability and effectiveness of the existing cap will first be discussed. It is the PDT's professional judgment that the uncertainty inherent in any quantitative analysis technique used to estimate the long-term (500 years) reliability of the cap is very high. This includes the empirical analyses developed by, among others, Blaauw and van de Kaa (1978), Maynord (2000), and Lam *et al.* (2011) to estimate the potential scour of the cap due to propwash generated by ship traffic since a lot of the site data needed to perform this analysis were not available. The estimated uncertainty associated with the propwash analysis is at a minimum ± one order of magnitude. So, if the estimate of propwash-induced scour is 10 cm, then than range of uncertainty would be from 1 cm to 100 cm or more. This estimate of the uncertainty takes into account the lack of a complete data set for the Site and the uncertainty in the different methods themselves. Estimation of the impact of propwash on the cap will be further discussed below. The uncertainty associated with estimates of the impact of the three processes listed under the forth bullet above on the long-term reliability of the cap would be at least as large.

<u>Impact of Floods</u>

Simulation of the hydrodynamics and sediment transport during a three month period (September – November 1994) that includes the 100-year flood event was performed using LTFATE. This included calculation of the maximum bed shear stresses at the Site during the peak of that flood. Estimation of the 500-year reliability of the cap should include multiple 100-year (or bigger) flood/storm events in the analysis. Different types of events, for example a 100-year flood on the SJR and a 100-year hurricane, are going to impact the SJR Waste Pits Site differently.

The three month simulation of the 100-year flood yielded a net erosion of the finer material on the cap (with a D_{50} = 3 inches), with the maximum net erosion in any cell being less than 11 inches. During the portion of the simulated time period that started when the maximum scour occurred, there was a partial recovery of the eroded sections of the cap, *i.e.*, net deposition occurred in those sections. Once the flood wave began to decelerate, which occurred before the flow reached its peak, the load of sediment being carried by the flow began to decrease. The deposition rate during this portion of the flood hydrograph was much greater than the long-term net sedimentation rate (NSR). The latter was estimated in Task 19 to be approximately 1.3 cm/yr ± 0.8 cm/yr at the Site. This is why the average change in bed elevation of the active grid cells within the Site boundary over the three month simulation was just slightly greater than half of the maximum change in bed elevation (when the depth of scour was maximum). Assuming that any localized damage to a portion of the cap was repaired following a major flood or storm event, then it is not unreasonable to assume that in between several significant flood events over the duration of 500 years, the mean bed elevation at the Site will approach the pre-flood mean bed elevation.

Impact of Propwash

Concerns of local citizens regarding the increase of barge activity near the SJR Waste Pits Site are well known. The concerns as the PDT understand them are: 1) barges are anchored on top of the area north of the Site, 2) propwash from tug boats disturbing the northwest portion of the Site, and 3) propwash from tug boats disturbing the area north of the Site that has contamination from previous runoff events.

As discussed above, the quantitative analysis of estimating the impact of propwash on the cap involves a detailed study requiring an enormous amount of data and model development. Ziegler *et al.* (2014) describe such an effort in their discussion of the modeling they performed to simulate sediment transport processes in ship berthing areas in Mitchell Bay. Included in their model framework is a propwash model that they developed and applied as a component of their modeling study. What Ziegler *et al.* did not perform in their study was a detailed uncertainty analysis to be able to at least estimate the uncertainty in the results obtained from their new propwash model. However, they did perform a limited but very informative sensitivity analysis for the propwash model.

With regard to this study, a propwash model was developed, tested and coupled to LTFATE. This is described in detail in Appendix D. However, the data needed to fully utilize the propwash module consists of the history of vessel movements in the SJR, especially near the Site, the types (e.g., tugboats, tankers, container ships), sizes, and drafts of the vessels; the diameter, applied horsepower, depths of the propeller shafts, and number of propellers on each of the vessels; the vessel speeds and paths, and the times when the vessels pass close to the Site. This would be an enormous database, but it was not available to EPA or the PDT. As such, only a simplistic analysis could be performed. The results from this analysis, described in Appendix D, is that propwash induced scour would only damage the cap if the vessel, e.g., tugboat, moved directly over the cap during a flood event when the water depth over the cap might be deep enough to permit the tug to do so. Methods to prevent this for happening are described in Tasks 8 and 9, e.g., installing pilings around the cap.

Impact of Toe Erosion and Cap Undermining

The possibility of wave- and current-induced toe erosion that might lead to undermining of a portion of the cap would be greatly reduced if the recommended reductions in some of the cap side slopes are implemented. Enhancement of the armor rocks around the toe of the submerged cap would also lessen the possibility of toe erosion and undermining.

Impact of Storm Surges

A storm surge event was modeled during this study. It was decided to simulate Hurricane Ike, which was a ‘wet’ hurricane. Ike impacted the Galveston Bay and SJR estuary in September 2008. The most severe event simulated as a component of this task was the hypothetical synoptic occurrence of Hurricane Ike and the October 1994 flood. The results from both these model simulations are presented in this section

For simulating the impact of Hurricane Ike on the SJR Site, the model domain for LTFATE had to be expanded to include Galveston Bay to be able to simulate the propagation of the storm surge into the SJR estuary. The expanded model domain is shown in Figure 7-1. A Cartesian grid with 131,989 120m by 120m size grid cells was constructed. The time period simulated was June – September 2008. The first 2.5 months of these four months was used to spin-up the hydrodynamic model. A sediment transport model run for the last 1.5 months was hot started (for the hydrodynamic model) using the output from the spin-up simulation. Wave modeling was performed, using a one-hour time step, for the same 1.5 months using the CMS-Wave model. This modeling is described in Appendix E. The time series of wave heights, periods and directions were read during the LTFATE model run and used to calculate the current- and wave-induced bed shear stresses in the SEDZLJ sediment bed model.

The results during the peak of the storm surge at the Site showed that the sections of the TCRA Cap (mainly in the Northwestern Area and the southwestern area of the Eastern Cell) using Cap Armor A material (D_{50} = 3 inches) were completely eroded. The two sections using Cap Armor D (D_{50} = 10 inches) were only eroded an average of 15 percent of the 12 and 24 inches thicknesses. The sections using Cap Armor material B/C and C (D_{50} = 6 inches) incurred an average maximum erosion of more than 70 percent. Thus, approximately 60 percent (11 acres) of the 15.7 acre impoundment incurred severe erosion.

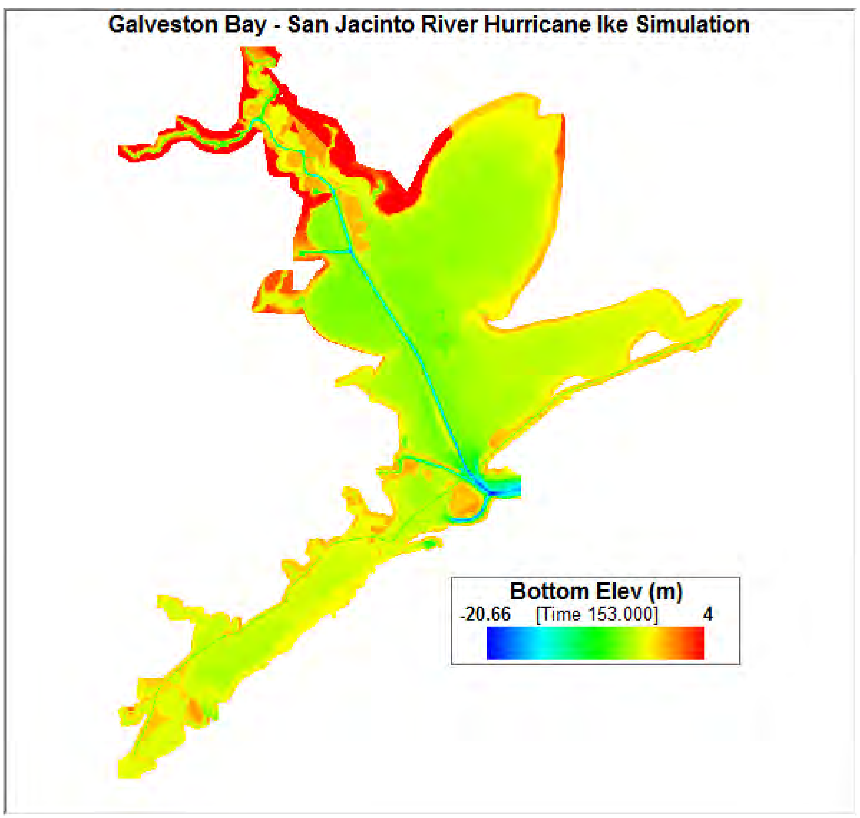


Figure 7-1Expanded LTFATE Model Domain used to simulate Hurricane Ike

The most severe event simulated as a component of this task was the hypothetical synoptic occurrence of Hurricane Ike and the October 1994 flood, with a peak discharge of approximately 11,000 cms (390,000 cfs) occurring at the time of the peak storm surge height at the Site. The maximum scour depth in any grid cell within the cap boundary during this hypothetical extreme event was 2.4 ft (0.73 m). The results during the peak of the storm surge at the Site showed that the sections using Cap Armor A (D_{50} = 3 inches) were completely eroded, while the sections using Cap Armor D (D_{50} = 10 inches) were only eroded more than 12 inches in about 25 percent of those sections. The sections using Cap Armor B/C and C (D_{50} = 6 inches) incurred a maximum erosion of more than 9 inches in about 85 percent of those areas. Thus, approximately 80 percent (12.5 acres) of the 15.7 acre impoundment was simulated to incur severe erosion, and an estimated 170 g of 2,3,7,8-TCDF (which was the only dioxin/furan congener modeled) would be resuspended. Replacement of all the Cap Armor materials with a median size of at least D_{50} = 12 inches would be needed to greatly reduce the amount of scour that occurs during such an extreme event.

Impact of Substrate Material Erosion

The modeling performed of the October 1994 100-year flood event demonstrated that there was no substantial erosion of the TCRA Cap's substrate material. However, there was substantial erosion of the Cap's substrate material during the most severe event simulated (described in the previous paragraph). The maximum erosion of the substrate material occurred in the section of the Cap where Cap Armor A was used, where up to 6 inches of this material was eroded. In this analysis, it was assumed that the geotextile underneath the Cap Armor A material would be completely removed by the overlying high flows.

Impact of Armor Rock Erosion

The modeling performed of the October 1994 100-year flood event demonstrated that there should be no dislodgement and subsequent movement of large armor rock across the surface of the cap during that event. This is based on the bed shear stresses calculated in the grid cells within the cap boundary. None of those bed shear stresses were high enough to dislodge and then transport the armor rock as bedload across the surface of the cap. However, there was dislodgement and movement of the large armor rock (Cap Armor D) during the most severe event simulated (described above).

Impact of Changes in River Morphology

Changes in channel planform morphology due to bank erosion, shoreline breaches, etc. during a high flow event caused by a major flood or hurricane is beyond the ability of existing sediment transport models to simulate. However, the LTFATE modeling performed did account for changes in morphology in the SJR estuary due to erosion and deposition.

Impact of Subsidence

The impact of continued subsidence on the integrity and reliability of the existing cap to prevent any release of contaminated material would be dependent on the long-term rate of subsidence. The latter is not well known and cannot be predicted with any reliability. In general, subsidence and the slow rise in sea level would both result in slightly deeper water depths over the Eastern Cell and Northwestern Area of the cap, but it is not believed that these effects would be substantial enough to affect the tidal, river and wind induced circulation in the SJR estuary. As such, it is not believed that the reliability of the cap would be lessened.

Reliability of Geotextile and Other Materials

Geotextiles and geomembranes when protected from UV light have been demonstrated to have design lives of hundreds of years, which should be more than sufficient to maintain separation in lieu of the anticipated deposition which should bury the armor cap completely in less than a hundred years.

Natural stone has the durability to provide long-term stability with the limited forces exerted on the stones in the SJR environment. The durability of recycled concrete is less reliable than natural stone. Recycled concrete is subject to more rapid breakdown by freeze thaw forces, but freeze thaw occurrences in submerged placement areas in the SJR would be rare. Recycled concrete is not as hard as natural stone and would be more abraded, but there are no identified natural mechanisms available to abrade the concrete. Recycled concrete also has less tensile strength than natural stone, but again there are no anticipated mechanisms to put the recycled concrete in tension. Consequently, both armor materials are expected to have long-term durability.

As is further discussed in Task 10, the damage of the western berm of the Western Cell that occurred in 2012 was not due to erosion. The failure was caused by sloughing off the geotextile when the berm became submerged due to loss of friction resulting from the loss of effective weight and the resulting decrease of the friction angle. The recycled concrete slipped down the slope until it achieved a stable slope. The slope in locations was steeper than 1V on 1H, while a stable slope would have been closer to 1V on 1.6H. The design slope was 1V on 2H, but it was not enforced during construction at all points (locally). The slope was confirmed only on a more global basis (the slope as a whole rather than all points on the slope).

Task 8

Statement

As part of the cap reliability evaluation, assess the potential impacts to the cap of any barge strikes/accidents from the nearby barge traffic.

Methodology

An assessment of the potential sediment losses from a barge strike was performed, and the short-term and long-term impacts potential impacts on the water column and ecological resources were evaluated.

Frequency of Barge Accidents/Strikes

Incidents involving barges are relatively infrequent. Annually in the U.S., approximately 20 grounding of barges, 22 collisions, and four incidents of barges being set adrift occur with medium to high severity, causing damages in excess of $50,000 (USCG 2013). An additional eight times as many low severity incidents occur annually. Most of the strikes occur during high flow or storm conditions while some result from equipment failures or errors. The size of the U.S. fleet of tugboats and towboats is about 4000 and the number of barges is over 27,000 (GlobalSecurity.org 2011). Therefore, there is about a 1 in 100 probability of a given pushboat or barge tow having a significant strike in a year or a 1 in 12 probability of a minor strike in a year, considering the effects of potential flooding and severe weather. However, the probability of striking a particular location such as the San Jacinto cap instead of the shoreline, nearby islands or bridge pilings would be a small fraction of that total probability, but perhaps as much as 25% of total probability considering the proximity of barge operations, yielding an effective probability of 1 in 400 for a significant strike in a year per pushboat or barge tow or 1 in 50 for a low severity impact strike in a year per pushboat or barge tow. Given the probability of multiple pushboats and barge tows being present in the vicinity year round due to nearby barge operations, the chance of a strike is about three times as great as that of an individual pushboat or barge tow, yielding an effective probability of 1 in 130 for a significant strike in a year or 1 in 15 for a low severity impact strike in a year. This would equate to 4 significant strikes and about 30 low severity strikes over a 500-year period. These probabilities are likely high because empty barges and pushboats would pass over the cap during large flooding events when the hydrodynamics would predict a sizable portion of the flow passing over and near the cap. Many of the strikes during high flow or flood events, when many of the accidents occur, would only strike the berms at the site and would not significantly disrupt the armor cap, requiring minor repairs.

Impacts of Barge Strikes

Background

The potential impacts of barge strikes vary greatly with the nature and location of the barge strike. River barges have 1V:3H sloped bows, flat bottoms and square sides that affect the nature and extent of damage to the cap which would be dependent on the angle of the attack and the slope of cap at the point of impact. Typical dimensions are 200'L x 35'W x 13'D. Empty barges have a draft of 1.5 ft while loaded barges have a draft of 8 to 11 ft. Therefore, a number of scenarios were examined for various locations of the site under both normal flow and high water flow conditions for Alternative 3N.

Under normal flow conditions, the water depth varies across the site such that the cap may be a couple of feet above the water level in the Western Cell, may be more than 15 feet below the water surface in the Northwestern area, and generally between 0 and 4 feet below the water surface in the Eastern Cell except in the northeastern portion of the cell where appears to be the remnants of an old channel. Only about 10 percent of the site has an elevation less than -6 ft NAVD88. Under flooding conditions, the entire site can be underwater. A flood with a 5-year or 10-year return period would have a river stage of 5 ft NAVD88, while floods with 25-year, 50-year and 100-year return periods would have predicted stages of about 8 ft, 11 ft and 14 ft NAVD88 at the site, respectively (Table 4-4 Draft Final Interim Feasibility Study Report – Appendix B: Hydrodynamic Cap Modeling, San Jacinto River Waste Pits Superfund Site, March 2014).

The interiors of the Western and Eastern Cells are relatively flat; slopes are generally about 1 to 3 percent. Slopes are very steep on the cell berms and shorelines including the Northwestern area adjacent to the Western Cell, as much as 1V:2H. In the old channel area northeast of the Western Cell slopes are steep ranging from 10 to 15% or about 1V:6H to 1V:10H.

Scenarios

Barge impact conditions can be broken into scenarios based on flow condition, bottom slope, and water depth. Additional conditions that would affect the impacts are barge loading, angle of impact and contaminant concentration. Normal flow conditions persists about 99 percent of the time and therefore should be representative of the time when common low severity impacts should occur (estimated to be about once in 50 years, not more frequent than once in 15 years). Water depths under normal flow conditions greatly restrict the conditions and locations where a strike may occur. Additionally, the currents are generally quite small in areas of moderate to very high contamination; therefore, erosion of exposed significantly contaminated sediment from barge strikes is not expected under normal flow conditions, allowing armor cap repairs without significant loss of contaminants.

Normal Flow Scenarios

Scenario 1 – Steep bottom slope (steeper than 1V:5H<5 feet), shallow water (< 5 feet). This condition occurs along the outside of the western berm of the Western Cell, the eastern side of the center berm and inside of southern berm of the Eastern Cell. Only the northern end of the center berm would be particularly susceptible to being struck by the nearby barge operations. Similarly, significant currents that could transport a free or disabled barge pass the same locale. The other sections of berm are in dead zones and circulation areas outside the main flow channels. The water depth is too shallow for the capped berms to be struck by anything other than an unloaded barge. If the berm were struck at an angle which would be most likely, a small section of the toe of the berm could be dislodged. This would expose very little sediment and potentially cause some sloughing of the existing berm, but would not pose the same risk when the berm is modified to a 1V:5H slope as planned in Alternative 3N. The impact of a barge strike under this scenario is probably very small. No control measures for barge strikes should be needed for this scenario.

Scenario 2 – Steep bottom slope (steeper than 1V:5H), deep water (>5 feet). This condition occurs only in the Northwestern Area in a 500-ft long reach of steep armor that would be particularly susceptible to being struck by the nearby barge operations. Local currents are suitable to promote a barge strike in this area from a free or disabled barge emanating from the local barge operations. The water depth is too deep for the slope to be struck by anything other than a loaded barge; a loaded barge would strike at mid-slope and potentially gouge a seam several feet wide and up to 100 feet long in the armor if the cap is struck obliquely. This potentially could cause sloughing of armor on the upper half of the slope, exposing as much as several thousand square feet of highly contaminated sediment under its existing slope of 1V:2H. However, this area of the armor cap will be modified to a 1V:3H slope as described in Alternative 3N, which will thicken the cap and improve the stability of the slope and limit the sloughing and sediment exposure to perhaps five hundred square feet.

If the barge were to strike the slope head-on, which is a potential mode of action because the currents run up the slope in portions of this area, the barge would ride up the slope until the barge is grounded or beached. The grounded barge would shear the armor layer and push armor up the slope during grounding and pull armor down the slope during barge removal, exposing perhaps as much as a thousand square feet of the sediment. The weight of the barge would drive the bottom of the armor cap under the barge into the sediment and promote mixing with the cap. Additionally, the weight of the barge on the top of the slope may induce a slope failure, pushing out the toe and uplifting sediment at the toe and exposing additional sediment.

The dominant impact of the scenario would be the renewed exposure of highly contaminated sediment since very little erosion of the exposed sediment would be expected under normal flow conditions. As such, the impact of a barge strike under this scenario is probably only moderate. The barge strike would require armor cap maintenance to limit contaminant loss and prevent sediment erosion under high flow conditions. Control measures should be considered for 500-ft reach in the Northwestern Area.

Scenario 3 – Mild to moderate (flatter than 1V:5H) bottom slope, shallow water (<5 feet). This condition occurs throughout much of the interior of the Eastern Cell and along the northern end of the site, including north of the Western Cell in the Northwestern Area. Only the northern and easternmost sections of the Eastern Cell and the area immediately north of the Western Cell would be particularly susceptible to being struck by the nearby barge operations due to the currents. Of these sections only the northern end of the center berm and the area directly north of the Western Cell would have highly contaminated sediments. The other sections of the Eastern Cell are in dead zones and circulation areas outside the main flow channels. The water depth is too shallow to be struck by anything other than an unloaded barge. The only strike potential is grounding or beaching of the barge. The grounded barge would shear the armor layer and push some of the armor material ahead of the barge up the slope during grounding and pull some armor down the slope during barge removal, exposing perhaps as much as a thousand square feet of the sediment for moderate slopes and as little as several hundred square feet for mild slopes. The weight of the barge would drive the bottom of the armor cap under the barge into the sediment and promote mixing with the cap. The impact of a barge strike under this scenario is probably very small. No control measures for barge strikes should be needed for this scenario except for the area directly north of the Western Cell and the area north and east of the northern end of the center berm. The control measures for Scenario 2 should also provide protection for these areas although it could be enhanced to provide better protection farther to the east of the northern end of the center berm.

<u>Scenario 4 – Mild to moderate (flatter than 1V:5H) bottom slope, deep water (>5 feet).</u> This condition occurs only in the Northwestern Area and in the Eastern Cell north of the center berm and east of the Northwestern Area, which would be particularly susceptible to being struck by the nearby barge operations. Local currents are suitable to promote a barge strike in this area from a free or disabled barge emanating from the local barge operations. These areas would have generally lowly to moderately contaminated sediments. The water depth is too deep for the slope to be struck by anything other than a loaded barge. The only strike potential is grounding or beaching of the barge. The grounded barge would shear the armor layer and push some of the armor material ahead of the barge up the slope during grounding and pull some armor down the slope during barge removal, exposing perhaps as much as a thousand square feet of the sediment for moderate slopes and as little as several hundred square feet for mild slopes. The weight of the barge would drive the bottom of the armor cap under the barge into the sediment and promote mixing with the cap. The impact of a barge strike under this scenario is probably very small. No control measures for barge strikes should be needed for this

scenario. The control measures for Scenario 2 would provide adequate protection for this area.

Flood Scenarios

Under flood scenarios, the water depths would tend to be 3 to 13 feet greater than under normal flow conditions. This would essentially eliminate any shallow water conditions except for the berms and shoreline; however, the potential for erosion of impacted areas becomes much greater. As such, no concerns would arise from the presence of unloaded barges except for potential strikes of the berms or shoreline, posing little to no risks. Grounding a barge during flood conditions presents much greater impacts than during normal flow periods because if the flood waters recede before the barge is removed, barge removal operations will become much more difficult and additional equipment may need to traffic over the armor cap to lighten the barge load or lift the barge off the armor cap. One uncertainty in this evaluation is the impact of flood conditions on nearby barge operations. If barge operations were suspended during all flood conditions or during just high return period floods (greater than 15 years) and no loaded barges are maintained in the area, then the risks become much smaller.

<u>Scenario 5 – Steep bottom slope (steeper than 1V:5H), shallow water (normally <5 feet).</u> This condition occurs along the outside of the western berm of the Western Cell, the eastern side of the center berm and inside of southern berm of the Eastern Cell. Only the northern end of the center berm would be particularly susceptible to being struck by the nearby barge operations, but the outside of the western berm of the Western Cell could also be struck under severe flood events. Similarly, significant currents that could transport a free or disabled barge pass both locales. The other sections of berm would be protected by the susceptible berms or would not be susceptible based on the current direction. The water depth is too shallow for the capped berms to be struck by anything other than an unloaded barge, except under severe flood conditions (greater than at least a 50-year return period). Loaded barges would likely be grounded before reaching the berms, but could become grounded on the berms under very sever flood events. Contact with the berm would be at the top, which would probably dislodge the top of the berm. This would create a 40-ft wide notch with a depth of 1 to 2 ft and expose very little sediment. The

impact of a barge strike under this scenario is probably very small. No control measures for barge strikes should be needed for this scenario.

Scenario 6 – Steep bottom slope (steeper than 1V:5H), deep water (>5 feet). This condition occurs only in the Northwestern Area in a 500-ft long reach of steep armor that would be particularly susceptible to being struck by the nearby barge operations. Local currents are suitable to promote a barge strike in this area from a free or disabled barge emanating from the local barge operations. However, under all but the low return period flood conditions (<15-year return period) the water depth is too deep for the slope to be struck by an unloaded or loaded barge. At worst, a loaded barge would strike near the top of the slope and would ride up the slope and become grounded. The grounded barge would shear the armor layer and push armor up the slope during grounding and pull armor down the slope during barge removal, exposing perhaps only several hundred square feet of the sediment. The weight of the barge would drive the bottom of the armor cap under the barge into the sediment and promote mixing with the cap. Additionally, the weight of the barge on the top of the slope may induce a slope failure since the 1V:3H slope has somewhat low factor of safety. The slope failure would push out the toe and dislodge sediment at the toe and expose additional sediment. The dominant impact of the scenario would be the renewed exposure of highly contaminated sediment and potential erosion of the exposed sediment due to the high flow conditions. The impact of a barge strike under this scenario is probably low due to small disturbance area. The barge strike would require armor cap maintenance to limit contaminant loss and prevent sediment erosion under high flow conditions. Control measures for the 500-ft reach in the Northwestern Area should be considered as presented in Scenario 2.

Scenario 7 – Mild to moderate (flatter than 1V:5H) bottom slope, shallow water (normally <5 feet). This condition occurs throughout much of the interior of the Eastern Cell and along the northern end of the site, including north of the Western Cell in the Northwestern Area. Only the northern and easternmost sections of the Eastern Cell and the area immediately north of the Western Cell would be particularly susceptible to being struck by the nearby barge operations due to the currents. Of these sections only the area directly north and northeast of the northern end of the center berm and the area directly north of the Western Cell would have highly contaminated sediments. The other sections of the Eastern Cell would be protected by the center berms or would not be susceptible based on the current direction. Under flooding conditions the water depth would be too deep to be struck by anything other than a loaded barge. The only strike potential is grounding or beaching of the barge. The grounded barge would shear the armor layer and push some of the armor material ahead of the barge up the slope during grounding and pull some armor down the slope during barge removal, exposing perhaps as much as a thousand square feet of the sediment for moderate slopes and as little as several hundred square feet for mild slopes. The weight of the barge would drive the bottom of the armor cap under the barge into the sediment and promote mixing with the cap. The worst-case impact of a barge strike under this scenario is the potential loss of up to about 50 cubic yards of susceptible highly contaminated areas because there is a significant potential for erosion of the exposed sediment during the high flow conditions of flooding events. The 50 cubic yards would represent less than 0.05 percent of the contaminated sediment, and it would be widely dispersed and diluted with the suspended solids of the flood waters. No control measures for barge strikes should be needed for this scenario, except for the area directly north of the Western Cell and the area north and east of the northern end of the center berm. The control measures for Scenario 2 would also provide protection for these areas, although it could be enhanced to provide better protection farther to the east of the northern end of the center berm as presented in Scenario 3.

Scenario 8 – Mild to moderate (flatter than 1V:5H) bottom slope, deep water (>5 feet). This condition occurs only in a small portion of the Northwestern Area and in the Eastern Cell north of the center berm and east of the Northwestern Area, which would be particularly susceptible to being struck by the nearby barge operations. Local currents are suitable to promote a barge strike in this area from a free or disabled barge emanating from the local barge operations. These areas would have generally lowly to moderately contaminated sediments. The water depth is generally too deep for the slope to be struck by even a loaded barge, except in the small portion of the Eastern Cell. The only strike potential is grounding or beaching of the barge. The grounded barge would shear the armor layer and push some of the armor material ahead of the barge up the slope during grounding and pull some armor down the slope during barge removal, exposing perhaps as little as several hundred square feet. The weight of the barge would drive the bottom of the armor cap under the barge into the sediment and promote mixing with the cap. Erosion of the exposed sediment during the high flow conditions of flooding events would be expected to occur but the contamination is only low to moderate. Therefore, the impact of a barge strike under this scenario is probably very small. No control measures for barge strikes should be needed for this scenario.

Control Measures for Barge Strikes

Pilings could be installed on 30-ft spacing along a 500-ft long reach just west of the Western Cell and Northwestern Area and also north of the Northwestern Area to prevent barge strikes by runaway barges or disabled pushboats. Other areas can be protected by signage to advise barge operators and boaters to stay clear of the cap.

Summary

The probability of a significant strike or grounding of a barge, which would expose contaminated sediment in up to 1 percent of the capped area or up to 0.1 percent of the contamination, is very low, likely less than 1 in 400 in any given year. A low severity strike would be expected to occur no more often than about once every fifty years on average, but its impact would be limited to several hundred square feet, less than 0.1% of the area, that could be readily repaired with minor releases, less than 0.005% of the contaminants.

Strikes pose significant impacts only from loaded barges and only in proximity of the Northwestern Area. Strikes on the present 1V:2H or the proposed upgraded 1V:3H slope could cause sloughing from gouging and displacement of armor and slope instability from grounding due to the added loadings on the slope from the grounded weight of the barge, exposing a sizeable area of highly contaminated sediment. Low to moderate impacts can occur in the same area from the grounding of an empty barge on the mildly sloped area above the steep slope. This would expose a relatively small area having high levels of contamination in the area immediately north of the Western Cell and directly north and east of the northern end of the center berm. The impacts of strikes during high flow flood conditions are much greater due to potential erosion of exposed sediment; however, flood conditions also increases the likelihood of barge accidents but reduces the likelihood of a strike on the cap because the water depth would be great enough to allow barges to pass over the cap without striking it. Strike protection control measures, such as pilings, caissons or a wall, could be used in a 500- to 700-ft reach along the base of the slope in the deep water (15 feet) of the Northwestern Area. These control measures could prevent all but very low impact strikes.

Task 9

Statement

Identify what institutional/engineering controls (*e.g.*, deed restrictions, notices, buoys, signs, fencing, patrols, and enforcement activities) should be incorporated into the remedial alternatives for the TCRA area and surrounding waters and lands.

Background

The site consists of several waste ponds, or impoundments, approximately 14 acres in size, built in the mid-1960s for the disposal of paper mill wastes as well as the surrounding areas containing sediments and soils potentially contaminated by the waste materials that had been disposed in these impoundments. The impoundments are located immediately north and south of the I-10 bridge and on the western bank of the San Jacinto River in Harris County, Texas (Figure 1-1).

Large scale groundwater extraction has resulted in regional subsidence of land in proximity to the site, which has caused the exposure of the contents of the northern impoundments to surface waters. A time-critical removal action was completed in 2011 to stabilize the pulp waste material in the northern impoundments and the sediments within the impoundments to prevent further release of dioxins, furans, and other chemicals of concern into the environment. The removal action consisted of placement of a temporary armor rock cap over a geotextile bedding layer and an impermeable geomembrane in some areas. The total area of the temporary armor cap is 15.7 acres. The cap was designed to withstand a 100-year storm event.

The southern impoundments are located south of I-10 and west of Market Street, where various marine and shipping companies have operations (see Figure 1-1). The area around the former southern impoundments is an upland area that is not currently in contact with surface water.

Available Engineering and Institutional Controls

Land Use Controls

Land Use Controls (LUCs) are often used at remediation sites to provide protection from exposure to contaminants. LUCs may be implemented as interim protection at sites where remediation is ongoing, or to manage residual contamination (ITRC 2008). LUCs include both engineering controls (ECs) and institutional controls (ICs). Institutional controls are defined by EPA as "non-engineered instruments, such as administrative and legal controls, that help to minimize the potential for human exposure to contamination and/or protect the integrity of a response action" (EPA, 2010). Engineering controls are physical controls that prevent exposure such as fences, barriers, signage, capping or containment. Both ICs and ECs can be used stand-alone, or can be used in conjunction with other ICs or ECs.

Institutional Controls

There are several categories of ICs, including governmental controls, proprietary controls, enforcement and permit tools, and informational devices. Governmental controls, enforced by state or local government, may include bans on harvesting fish or shellfish, zoning restrictions, ordinances, statutes, building permits, or other restrictions. Zoning may be used by local governments to designate land use for specific purposes. Government ordinances or permits may also restrict or control land uses, and outline specific requirements before authorizing certain activities (*e.g.*, building codes, drilling permit requirements). Some local ordinances place controls on access to or use of certain areas within a property. Groundwater management zones may also be used to prohibit certain groundwater uses (ITRC 2008).

Proprietary controls are based on real property law (EPA 2000). Enforceability of proprietary controls should be evaluated under applicable (state) law. Some proprietary controls are enforceable upon execution, others upon the sale or transfer of property. Examples include easements, covenants, and conservation easements. Easements are rights over the use of another's property, and include negative easements which limit uses that would otherwise be lawful. Access easements are sometimes used to ensure current and future property owners allow property access to operate, monitor, or maintain ECs or ICs. Covenants are agreements between the landowner and others connected to the land. They are typically used to establish an IC when property is transferred to another party. Use restrictions/ statutes/ environmental covenants are state statutes that provide owners of a contaminated property with authority to establish use restrictions. Conservations easements are state statutes that establish easements to conserve property or natural resources. Enforcement and permit tools include permits, administrative orders, and consent decrees which are enforceable by state or federal agencies. Most enforcement agreements are binding on only the signatories and do not bind subsequent owners. Examples include administrative orders which are issued by an environmental regulatory agency directing property owners to perform (or not perform) certain actions. Consent decrees document an administrative or judicial court's approval of the settlement of an enforcement case filed in court. These typically specify actions to be taken (or not to be taken) by the settling parties. Permits are implemented by an environmental regulatory agency and may require compliance with a statutory or regulatory provision that may impact the reuse of the property (ITRC 2008).

Informational devices provide information to the public about risks from contamination and generally are not legally enforceable. Informational devices include deed notices, state registries of hazardous waste sites, and advisories. Deed notices are filed in public land records with the property deed that provide information about potential health risks from contamination left on the property. State registries of hazardous waste sites also contain information about contaminated properties. Some state laws provide that the use of the property cannot be changed without state approval. Advisories warn the public of potential risks associated with using contaminated land surface water or groundwater, generally issued by public health agencies (ITRC 2008).

In addition to the legal mechanisms mentioned above, the Uniform Environmental Covenants Act (UECA) is a model statute that can be adopted into law by each individual state or territory (EPA 2010). The UECA provides legal framework to create, modify, enforce and terminate a valid real estate instrument (environmental covenant or IC) to restrict use of contaminated real estate or impose obligations under state law and precluded the application of traditional common law doctrines that might otherwise hinder the validity or enforcement of ICs adopted under state property law or other mechanisms (ITRC 2008). The UECA provides a legal mechanism to ensure LUCs can be readily found, maintained, and enforced over time.

EPA (2000) suggests layering ICs, using different types of ICs at the same time to enhance protectiveness. Applying ICs in series may help ensure both short- and long-term effectiveness. Using ICs in conjunction with physical barriers (ECs) to limit access is also recommended.

The three most common types of ICs at sediment sites include fish consumption advisories and commercial fishing bans, waterway use restrictions, and land use restriction/structure maintenance agreements (EPA 2005).

Fishing advisories, restrictions or bans on fishing (including shell fishing) are typical ICs. Commercial fishing bans are government controls that ban commercial fishing for specific species or sizes of fish or shellfish (EPA 2005). Rather than a complete ban, advisories may be placed on certain locations and types of fishing. Advisories inform the public that they should not consume fish from an area or should limit the number of fish meals consumed over a specific time period. Advisories and bans are usually established by state departments of health and can be administered through signs, pamphlets or other outreach materials. Warning signs should be in the language of the local community including new immigrants, and require periodic inspection and maintenance. Monitoring, enforcement and communication with local or state authorities are required. Consumption advisories are not enforceable controls and may have variable effectiveness (EPA 2005). Surveys of anglers are often helpful to evaluate whether they consume the fish they catch and whether restrictions are effective (ASTSWMO 2009). EPA's Fish Advisory Program compiles a national listing of fish advisories through its Office of Science and Technology.

Institutional controls may also be needed to protect the integrity of the remedy. Land use restrictions may be needed at near-shore or upland sites to limit or eliminate construction activities, digging or other activities that may disturb the contaminated materials. A deed restriction or notice may be adequate for an upland property, but for in-water remedies, restrictions may be more difficult due to ownership issues. Nearshore areas can, in some cases, be privately owned out to the end of piers. If privately owned, traditional ICs such as proprietary controls or enforcement tools can be considered. Federal, state and local laws place restrictions on and require permits for dredging, filling, or other construction activities in the aquatic environment. ICs may also be implemented through coordination through existing permitting processes (EPA 2005).

Restrictions on vessel traffic to establish no-wake zones or restrictions against anchoring may be necessary to protect a cap. Restrictions on easements for installation of utilities and other in-water construction may also be needed, and should be placed on navigational charts. Navigational buoys or warning flags can be used to help warn boaters (ASTSWMO 2009). Changing the navigation status of a waterway may also be necessary. Deauthorization or reauthorization of federally authorized navigation channels to a different width or depth would be required. The state may have authority to change harbor lines or the navigation status (EPA 2005).

Management

Application of LUCs require planning to a) evaluate what types of ICs are appropriate, b) determine responsible parties for various activities, c) estimate costs, and d) identify issues that may impact effectiveness. When selecting ICs, it should be considered how the controls fit into the overall remedy, and whether it can be realistically implemented. A number of activities may be needed to implement various ICs including drafting and signing documents to establish ICs or arranging technical or legal support (EPA 2010). There may be both short- and long-term expenses associated with implementation and management of LUCs. Some funding mechanisms to cover the cost associated with maintaining and monitoring LUCs include stewardship fees, oversight fees, and trust funds (ITRC 2008).

LUCs require effective management to ensure long-term effectiveness. Both institutional and engineering controls require regular monitoring and maintenance. Enforcement may be needed if ICs are breached or not properly implemented. Enforcement actions vary from state to state, but may include penalties, loss of liability protection, and lawsuits (ITRC 2008). Some states have developed tracking systems to identify LUCs in place, although the nature of the systems varies from state to state. The

UECA provides mechanisms for states to develop and maintain a registry of sites with ICs.

More detailed information on institutional controls as applied to Superfund sites, Brownfields, underground storage tanks, federal facilities and RCRA site cleanups is provided by EPA (2005, 2010).

ICs Used at Other Sites

A number of contaminated sediment sites have established institutional controls. At the Lake Hartwell Superfund Site, South Carolina, fish consumption advisories are in effect, and were implemented by posting warning signs and distribution of printed material to educate the public (EPA 1994, Magar *et al*. 2009). Fish and/or shellfish advisories are also used at the Lavaca Bay Point Comfort site in Texas (fish and shellfish), Wyckoff/Eagle Harbor, Washington, (Magar *et al*. 2009), and Marathon Battery Corporation, New York (blue crab) (EPA 2008). At Fox River, Wisconsin, fish advisories are in place to prevent ingestion of PCB-contaminated fish above 50 ppb, along with MOUs to prevent anchoring, dredging, dragging, or construction over sediment caps (Tetra Tech *et al*. 2012, Ridenour 2014). At Palos Verdes Shelf, California, a fish advisory is also in place, along with a commercial catch ban for white croaker. Components of the IC plan include public outreach and education, monitoring, and enforcement (EPA 2009, Ridenour 2014).

The Commencement Bay, Nearshore/Tideflats, Tacoma, WA also has fish consumption advisories in place to warn the public about the danger of consuming shellfish, which are relayed by placement of multi-lingual signs. The institutional control plan for the site (Washington State DNR 2007) describes the controls to be put in place as well as the responsibilities of the various entities involved. In addition to shellfish warnings, other ICs specified at Commencement Bay include restrictive covenants, and control of marine vessel navigation and anchoring through the use of no-anchor zones, and waterway navigational markers and signs regarding prohibited activities, vessel size and speed. A system is also in place to notify appropriate entities as to changes in conditions or unauthorized anchorage or trespassing. Restrictions on issuing leases, easements, rights-of-entry and use authorizations are also in place which require notification, and restrict State-owned aquatic land (SOAL) authorizations for commercial shellfish harvest in capped areas. SOAL authorizations are to include terms specifying the provisions of the Consent Decree including prohibited activities such as any activity that alters the cap, piling removal/installation, dredging/excavation and anchoring.

ICs at Pine Street Canal are specified to limit future land use, excluding residential uses and uses involving the care of children, and activities which may interfere with ongoing investigations or might cause recontamination or change hydrogeologic conditions and migration of contaminated groundwater. Excavation greater five feet is prohibited, along with the use of ground water for drinking water purposes or installation of well and any activity that may disturb the integrity of an engineering control (Burlington Land Records 2004).

In addition to the fish consumption advisory for blue crab (recommending consumption of no more than six per week), the Marathon Battery Corp. site has established ICs including deed restrictions barring excavation deeper than 15 feet, construction or use of groundwater wells, and any activity that may disturb the marsh soil cover (EPA 2008). The institutional controls for Allied Paper, Inc./Portage Creek/Kalamazoo River prohibit construction or use of wells to extract ground water, activities that may disturb the integrity of an engineering control or result in release of hazardous substances, or limit future land use (Michigan DNRE 2010).

Application of ICs and ECs to San Jacinto River Waste Pits Site

General information on ICs at contaminated sediment sites has been provided. The latest draft feasibility study (FS) (Anchor QEA 2014) lists seven potential alternatives for the final remedy including:

- Alternative 1N – No further action,
- Alternative 2N – ICs and Monitored Natural Recovery (MNR)
- Alternative 3N – Permanent cap, ICs, MNR
- Alternative 4N – Partial solidification/stabilization (S/S), permanent cap, ICs, MNR
- Alternative 5N – Partial removal, permanent cap, ICs, MNR
- Alternative 5aN – Partial removal of materials exceeding the protective concentration level (PCL), permanent cap, ICs, MNR

- Alternative 6N – Full removal of materials > PCL, ICs, MNR

Alternatives 4N, 5N, 5aN and 6N involve removal of some, or all, of the existing TCRA cap, which would expose contaminated sediments during construction. For Alternatives 4N, 5N and 5aN, the cap would be reconstructed and improved after either removal or treatment of the sediments in the affected area. Cap improvements are also included for Alternative 3N. Alternative 6N does not include cap reconstruction as it calls for removal of sediments exceeding PCL across the entire TCRA area.

All alternatives except for Alternative 1N call for implementation of additional ICs. The recommended ICs described in the FS would be used to: alert property owners of the presence of subsurface materials exceeding PCLs, describe the need for protective equipment and training if excavation of subsurface materials exceeding PCLs is required, describe management requirements for any excavated soils or sediment exceeding PCLs, describe the need to restore the armored cap following any disturbance, and establish limitations on dredging and anchoring within the footprint of the armored cap by requesting that the U.S. Coast Guard District Commander establish a regulated navigation area (Anchor QEA 2014).

Some land use controls are already in place. An advisory (ADV-49) is in place regarding consumption of fish and blue crab on the San Jacinto River (Anchor QEA 2014). Controls were implemented at the site with the TCRA armored cap installation, which is itself an engineering control. Also, a perimeter fence was installed around the perimeter of the impoundments, including a second phase of fencing installed across neighboring property to address unauthorized access that had been observed (Anchor QEA 2012). Warning signs, No Trespassing signs and USEPA Project Identification signs were installed as part of the TCRA and remain in place and are subject to ongoing monitoring and maintenance. A series of 29 buoys (25 ball float, and four regulatory) were installed along the perimeter of the Eastern Cell to warn passing vessels to keep out of the SJRWP area; though not specified, it is assumed the buoys were removed post-construction. Fifteen warning signs on steel posts in 3 ft x 3 ft concrete block are posted around the perimeter of the impoundments to be visible to passing vessels.

It appears the existing land-side fencing and warning signs provide sufficient notification and access control. Monitoring should continue to ensure these measures are maintained as long as there continues to be a risk from on-site contaminants. Security measures were implemented during TCRA cap construction, including a manned security guard shack, roving security patrol, installation of security cameras, and requirement of visitors to sign in at a security checkpoint (Anchor QEA 2012). The security equipment was demobilized upon completion. Upon commencement of further construction activities, security measures should be reinstated to protect against unauthorized entry.

It is unclear whether water-side perimeter controls are sufficient. Access to the site by boat is currently constrained to the north, west, south, and southeast by industrial use and navigational hazards (Anchor QEA 2014). As stated, warning signs on steel posts are in place to warn passing vessels. During construction, Alternatives 4N and 5aN call for sheet pile barriers, and Alternatives 5N and 6N include the use of a silt curtain as measures to control resuspension. Warnings posted outside of these measures should deter vessel traffic during construction. More robust engineering controls to restrict vessel traffic over the long term could be considered such as the use of caissons, or vessel exclusion barriers. The FS suggested a five-foot high submerged rock berm outside the perimeter of the Permanent Cap to protect from potential vessel traffic for alternatives involving the Permanent Cap (3N, 4N, 5N, 5aN). Shallow areas can be isolated using steel cable or chain with appropriate marine and land-based signage and markers to prevent vessel access. The long-term need for such measures depends on the selected alternative, and the extent to which contamination is left on-site, and the need to protect a cap. The ICs discussed in the FS included the need to establish limitations on dredging and anchoring within the footprint of the Armored Cap (Anchor QEA 2014). This would be needed for all alternatives until such time as resulting concentrations are shown to be acceptable.

According to the FS, propeller wash from tug boat operations associated with the SJRF operations could disturb sediments in the Upland Sand Separation Area, but the existing TCRA cap and proposed Permanent Cap would resist such erosive forces (Anchor QEA 2014). Alternative 6N would not result in a Permanent Cap, but instead would be covered with 6 inches of clean cover. The clean cover will not be stable when subjected to prop wash. If residual concentrations are not sufficiently low, a no-wake zone may need to be established for Alternative 6N, as well as for the Upland Sand Separation Area. Additionally, both the clean cover and residuals would be subject to erosion under high flow conditions. Since the residuals may contain as much as 5% of the contaminant mass removed by removal in the wet (dredging), a stable cover would be needed in these areas. An armored cap with a granular filter could be considered for Alternative 6N to provide stability and control long-term releases.

A TxDOT Agreement was put into place during TCRA construction in which TxDOT is required to receive a three-day notice before commencement of construction activities, and requires TxDOT to be provided notice should any future construction disturb sediments in the San Jacinto River. However, procedures are not currently in place to alert future landowners of the TCRA Site to the potential risks of exposing the capped sediment (Anchor QEA 2014). There are also no current restrictions on dredging or anchoring at the site. As called for in the alternatives including the ICs described in the FS, additional measures are needed to alert future property owners of the presence of subsurface materials exceeding PCLs and management requirements for any excavated soils or sediment exceeding PCLs. Enforcement tools such as administrative orders can be used to direct current property owners to perform certain actions such as implementing ICs (including management of excavated soils or sediment). However, most enforcement agreements are not transferred to new owners when the land is sold. Proprietary controls such as covenants may be needed to establish an IC when the property is transferred to another party. Informational devices such as a deed notice could be used to provide information about health risks from contamination left on the site to future property owners. State registries of hazardous waste sites also contain information about contaminated properties. For the nearshore areas or the upland area of the southern impoundment, more traditional ICs may be considered such as land use restrictions against construction, excavation, or other disturbances that may expose contamination. Zoning may be used to restrict land use to industrial purposes or to prohibit groundwater uses. According to the FS, groundwater is not a significant source of dioxins or furans (Anchor QEA 2014), and thus groundwater use restrictions may not be necessary. The intent of Alternative 6N is full removal of all materials exceeding PCLs for protection of the hypothetical recreational visitor, potentially allowing for less restricted future use of the property. If successful, future controls may not be necessary. However, if dredging residuals leave a layer of material exceeding PCLs, ICs will be needed to alert property owners. Easements will need to be in place both during construction and in the future to allow monitoring and maintenance of ECs.

Several of the Alternatives (3N, 4N, 5N, 5aN, 6N) will require staging areas to store clean fill material or armor stone, and areas to dewater and treat excavated cap material and contaminated sediment. The size of the staging areas depends on the alternative and the extent of the removal. Engineering and institutional controls will be needed for the staging areas if contaminated material is to be stored there. Perimeter fencing and warning signs will be needed. Silt fences will be necessary to control surface water runoff, along with coverage of stockpiled contaminated materials. The dust control measures (sprinkling) that were used during construction of the TCRA cap may be necessary to minimize dust generation from land activities and application of Portland cement.

As stated in the FS, ICs would be used to describe the need for protective equipment and training if excavation of subsurface materials exceeding PCLs is required. During the TCRA Cap construction, due to the likelihood of coming in contact with dioxin-contaminated waste, workers in the Exclusion Zone were required to have 40-hour HAZWOPER certification and Level D personal protective equipment. The same procedures would need to be implemented for any of the alternatives (4N, 5N, 5aN, 6N) involving potential exposure of contaminated material.

Summary of Recommended ICs and ECs for San Jacinto River Waste Pits Site

The recommended ICs described in the FS cover the three most common types of ICs at sediment sites include fish consumption advisories and commercial fishing bans, waterway use restrictions, and land use restriction/structure maintenance agreements (EPA 2005). The recommended ICs apply to all alternatives since sediment or dredging residuals that will exceed the PCLs will be left in place following the remediation. The recommended ICs are (Anchor QEA 2014):

1. Alert property owners of the presence of subsurface materials exceeding PCLs.
2. Describe the need for protective equipment and training if excavation of subsurface materials exceeding PCLs is required.
3. Describe management requirements for any excavated soils or sediment exceeding PCLs.
4. Describe the need to restore the armored cap following any disturbance.
5. Establish limitations on dredging, construction, dragging and anchoring within the footprint of the armored cap by requesting that the U.S. Coast Guard District Commander establish a regulated navigation area.
6. Maintain advisory (ADV-49) that is in place regarding consumption of fish and blue crab on the San Jacinto River. Maintain multi-lingual signage and public outreach activities until the tissue concentrations meet risk goals.
7. Maintain the perimeter fence that was installed around the perimeter of the impoundments, including a second phase of fencing installed across neighboring property to address unauthorized access that had been observed.
8. Maintain Warning signs, No Trespassing signs and USEPA Project Identification signs that were installed as part of the TCRA and remain in place.

Additionally, deed restrictions should be established to restrict issuing leases, easements, rights-of-entry and use including any activity that alters the cap or fill including the drilling of wells.

Task 10

Statement

Identify and document cases, if any, of armoring breaches or confined disposal facility breaches that may have relevance to the San Jacinto site evaluation.

Findings

After an extensive literature review, there appear to be no documented cases of any armored cap or armored confined disposal facility (CDF) breaches. However, there have been many occurrences of breaches and slope failures of armored dikes, jetties, and breakwaters, with some of those structures confining dredged material. These typically occurred due to ineffective filtering between the armor and core material, insufficient armor sizing for wave action velocities, and steep side slopes allowing rock to be more easily displaced. Ineffective filtering exists when the filter media is not properly sized, allowing finer sediment from below the filter layer to pass through the filter and be washed through the armor stone. Ineffective filtering allows loss of the foundation and undermining of the armor stone, ultimately resulting in failure. Table 10-1 briefly describes several cases including a description of the site, the cause of the breach, and if any repairs were made to the structure. The cases shown in Table 10-1 represent varying situations that may be of some relevance to the San Jacinto site investigation because the site is adjacent to a well-traveled waterway with significant wave action due to navigation, is subject to large storm events that may cause large inflows of water from overtopping the CDF, and has armored slopes with synthetic material acting as a filter or liner that is susceptible to tears that allow erosion to degrade the system. None of the listed cases completely breached or failed and were discovered by routine inspections. Repairs and rehabilitation measures, when documented, were easily made.

The three modes of armor failure presented above apply as well to the San Jacinto River Waste Pits TCRA armor cap. There is potentially ineffective filtering between the armor stones and the sediment in the Northwestern Area. The blended media filter used in the Northwestern Area may have not been fine enough or placed uniformly enough to prevent fine sediment from migrating into the armor cap. A cap defect that appeared in the

Table 10-1. Descriptions of Armor Breaches and Failures

Site Name/ Location	Site Details	Breach/Failure	Rehabilitation/Repairs	References
Cox Creek DMCF, MD	Reactivated facility originally built in 1960's. Consists of a containment dike roughly 5000 ft stabilized with concrete vats and slabs.	Original armoring was not sufficient in protecting against erosion from wave energy. Before rehabilitation, side slopes had eroded to 1:1	Rehabilitation from 2002 - 2006 included stabilizing the dike before replacing armor stone.	Kotulak *et al*. (2007)
Chicago CDF, Calumet Harbor, IL	17-ha nearshore CDF with a rubble mound dike constructed of a core of limestone, a synthetic membrane liner along the inside face to prevent excess migration of fine dredged material solids through the dike as it is filled, and armor stone.	The fluctuating levels during and after construction revealed that the liner was ineffective due to tears resulting from punctures during the placement of the armor stone or from the limestone core.	A sand blanket was selected as the appropriate corrective action and placed along the inside face of the dike. Further fine grained material was placed along the inside face of the dike to improve the effectiveness.	Savage (1986), Palermo, *et al.* (2000)
Port Chehalis Revetment, WA	South jetty originally built in 1929, reconstructed between 1935 & 1939 and has been improved over the years by the addition of 6 groins and a revetment wall connecting the groins.	Routinely incurs damage from winter storm wind and waves as well as overtopping resulting in erosion of the core material and the settlement and displacement of the armor.	Major rehabilitation in 1972 reinforced groins A-D, F and added groin E. Emergency repairs were made to groin E and the revetment wall after a winter storm caused significant damage in 1999. In 2010, erosion to the revetment was repaired by the addition of Class V stone and Class I filter stone. In 2013, proactive measures were taken by the addition of stone to the revetment increase the thickness of the structure.	USACE, Seattle District (2013)
Atlantic Harbor of Refuge Breakwater, NC	A 2000 ft. sand breakwater with a riprap head was constructed in 1972.	Significant erosion occurred along the southeastern face of the breakwater leading to a large escarpment of 3 ft and displacing the armor stone protection. The sand fill behind the stone eroded way undermining the rock and displacing it.	As of 1985, no rehabilitation or repairs have been made.	Sargent, USACE (1988)

Site Name/ Location	Site Details	Breach/Failure	Rehabilitation/Repairs	References
Two Mile Breakwater, Two Mile Florida	The two breakwaters were constructed in 1976 on either side of the entrance to Two Mile Channel and were designed to retain dredged material. The L-shaped dikes were built up using bottom material and were revetted with filter fabric and rubble stone.	The outer ends began eroding significantly by 1982.	Additional rubble stone was added to the ends of the breakwaters to protect against erosion.	Sargent, USACE (1988)
Siuslaw River Jetties, OR	Two entrance jetties to the Siuslaw River have been improved and altered since their original construction in 1917. The jetties were extended seaward in 1985 and spurs were added to the ocean side of each jetty. The jetty expansion and spurs were constructed of randomly placed rubble and armored with 12-19 ton stones.	Wave actions eroded the heads of each jetty where slopes were steep and armor stones were pulled down by wave action. Erosion also occurred along the jetty spurs and voids in the jetty were found.	No repairs detailed in survey; however, it is recommended that armor stones be placed in the voids and damaged areas to prevent further damage during a major storm event.	Bottin *et al.,* USACE (1999)
Yaquina Bay North Jetty, OR	Located in the Yaquina Bay on the Oregon coast, two parallel rubble mound breakwaters with the final extension of the south jetty being completed in 1972 and experiencing no major problems. The final extension of the north jetty was completed in 1966.	The north jetty routinely experiences severe wave conditions that damage the jetty. The seaward side is primarily affected with stone being removed and the jetty eroded.	The north jetty has been rehabilitated twice since the completion of the extension. In both instances, the repairs were made to the seaward side where rock had been removed below the water level. Survey recommends additional armor stones be placed to prevent future damage.	Bottin *et al.*, USACE (1999)

Site Name/ Location	Site Details	Breach/Failure	Rehabilitation/Repairs	References
Burns Harbor Breakwater, IN	The Burns Harbor located on the southern shore of Lake Michigan, includes two rubble mound breakwaters. The breakwaters were constructed with a multilayered design and random placement of armor stones consisting of rectangular-cut Indiana- Bedford limestone blocks.	Since completion of construction, extensive damage has occurred including the displacement of much of the armor stone. Inspections also noted that erosion had created large voids under the rock and that the breakwater was deteriorating. Navigation induced and wind and wave actions are the primary cause of damage to the breakwater.	In the first 19 years of operation alone, an average of 7,640 tons per year of stone were placed on the breakwater with both the lakeside and the harbor-side receiving equal distributions of stone. Construction of a submerged, offshore reef breakwater was designed to reduce wave heights along the north breakwater and decrease waves in the harbor.	Bottin *et al.*, USACE (1999)
Cattaraugus Creek Harbor, NY	Cattaraugus Creek Harbor is located on Lake Erie and consists of two breakwaters at the mouth of the creek. Both are rubble mount structures with a concrete cap on the south structure. The original armoring ranges in size from 2 - 13 tons.	Monitoring took place after construction and it was noted that damage occurred on the south breakwater primarily due to stone cracking. The loss of shattered stone resulted in adjacent stones collapsing into voids creating a steeper slope on the structure. The lakeside of the breakwater receives the bulk of the wave action and therefore carries the majority of the damage.	No repairs detailed in survey; however, it is recommended that armor stones be placed in the voids and damaged areas to prevent future damage.	Bottin *et al.*, USACE (1999)
Ocean City Inlet South Jetty, MD	The Ocean City Inlet consists of two jetties and three headland breakwaters to stabilize the pass. The south jetty was originally constructed in 1935 and an additional section was added in 1985. The new section was constructed with core stone, intermediate stone, capstone and precast concrete units to minimize sand transport.	While the added section of the south jetty has performed and help up well, the original portion of the south jetty has considerably deteriorated. The armoring stones had scattered and due to erosion, the crest of the jetty had been reduced unevenly.	No repairs detailed in survey.	Bottin *et al.*, USACE (1999)

Northwestern Area in 2015 may have resulted from ineffective filtering. Addition of more filter material or cohesive material along with more armor stone in the Northwestern Area will restrict migration of sediment through the armor cap.

Examination of the armor stability under very severe hydrodynamic and hydrologic events (100-yr hurricane) showed that the 3-inch recycled concrete placed in the Northwestern Area is insufficient to prevent erosion from the wave and current induced bottom shear stresses. The existing armor stone should be supplemented with six-inch armor stones to provide stability during the extreme storm events. In addition, some of the six-inch armor stones in Western and Eastern Cells were also insufficient. The six-inch armor stones should be supplemented with eight-inch armor stones to prevent their displacement.

Localized failures of the west berm of the Western Cell in areas of slopes steeper than 1V on 2H in 2012, which have been repaired with natural armor stone placed to flatten the slope to 1V on 3H. Alternative 3N proposes to flatten all slopes to no more than 1V on 3H. Additionally, Alternative 3N proposes to flatten the slopes of the eastern, central and western berms (the surf zones) to 1V on 5H. These slopes should be stable for armor stones of at least four inches in diameter. Enlarging the armor stone in the Northwestern Area will improve the factor of safety of its 1V:3H slope.

Task 11

Statement

Assess the potential amount or range of sediment resuspension and residuals under the various remedial alternatives and BMPs proposed in the Feasibility Study, which includes capping, solidification, and removal.

Resuspension and Residuals Estimates

After a review of the remedial actions proposed in the Feasibility Study Report, it was determined that Alternatives 4N, 5N, 5aN and 6N had some mechanisms creating a potential for resuspending contaminated sediments or for leaving residuals that may be exposed to the water column. In order to estimate and assess the potential for these releases or releases, the principal processes were identified as follows: sheet pile wall construction, sheet pile removal, removal of the TCRA armor cap materials in the wet and mechanical dredging in the wet. It was assumed that residuals would remain after mechanical dredging. The following sections detail the assumptions made, the equations used to estimate potential contaminated sediment releases and the results of the assessment.

Sheet Pile Construction and Removal

Alternatives 4N, 5aN and possibly 5N consider the use of a sheet pile wall as a means to control sediments during remedial actions. Based on the information provided in the Feasibility Study, it was determined that the sheet pile walls would need to be driven an average of 15 feet through the soft organic silt and clay layer into the sandy layer and in water depths of no greater than 10 feet. In soft sediments, sheet pile wall construction can lead to resuspension of the top soft sediment layer during wall construction if cap removal is needed to drive the sheet pile. During removal, fine-grained, cohesive sediments are subject to adhering to the walls of the sheet pile and washing off.

<u>Assumptions</u>

Many assumptions were made during this process. The assumptions used in estimating the potential disturbance from the use of sheet piles are given in Table 11-1. Based on the sediment characteristics listed in the Geotechnical Report, assumptions were made for the dry density of the loose top layer of sediment (top ¼”), the higher density soil underneath, as well as the relative “stickiness” of the soil as described in Hayes *et al.* (2007). Only the top 1/4” of sediment was considered for suspension during construction and all sediment resuspended was assumed lost. During removal, it was assumed that 50 percent of the soil adhering to the sheet pile wall would wash off and be lost. A Z-type section of sheet piling was selected due to its resistive forces and ability to better perform under loading conditions. The sheet pile wall specifications, as seen in Table 11-1, were taken from the specifications provided by Hammer & Steel. The heavy duty “Z” section has a single section width of 22 inches, depth of 9 inches and wall and flange thickness of 0.375 inches. The coating area, which is defined as the surface area required for protective coating, is 1.22 ft^2/ft^2 of wall. This area excludes the ball and the interior socket and only accounts for one side of the wall. It is described as an area to be coated per total area of wall.

Sediment characteristics were based off the initial saturated unit weight of 107 lb/ft^3, as provided in the Geotechnical Report. It was estimated, since no other sediment properties were provided, that the dry unit weight would be 60 lb/ft^3. The top ¼” of loose sediment would have a dry bulk soil density of 0.5 kg/L (500 kg/m^3) to be used in calculations, and from there, it was assumed that the underlying soil would be more dense, having a dry soil density of 950 kg/m^3. Sediment contaminant concentrations at the location of the sheet pile wall were assumed to be 1,000 ng/kg for Alternatives 4N and 5N, due to their proximity to the high concentration hot spots, and 200 ng/kg for Alternative 5aN since it is outside the 220 *ng/kg* $TEQ_{DF,M}$ contour.

It was also assumed that the sheet pile wall removal would act in a similar manner to a full bucket ascending through the water column, and using the equations found in Table 11-2, a volume of sediment per area of wall was calculated to adhere to the wall and a specified mass amount washed from the wall.

Equations

The methods used for determining the resuspended sediments can be found in Table 11-2 and are the recommended methods presented in *Resuspension Factor Approach for Estimating Dredging-related Sediment Resuspension* (Hayes *et al.* 2007) and referenced in *Technical*

Guidelines for Environmental Dredging of Contaminated Sediments (Palermo *et al.* 2008).

Table 11-1. Sheet Pile Assumptions

Property	Value	Property	Value
Dry Bulk Sediment Density (kg/L)	0.5	**Adjusted Adherence Thickness Δs (ft)**	0.0111
Top Layer Soil Density, ρ_t (kg/m^3)	500	**Sheet Pile Type**	PZ22 - Hammer Steel Heavy Duty
Dry Unit Weight (lb/ft^3)	60	**Sheet Pile Width (in)**	22
Underlying Dry Bulk Soil Density, ρ_b (kg/m^3)	950	**Sheet Pile Offset (in)**	9
Depth of Material Resuspended by Sheet Pile Construction, t (mm)	6	**Sheet Pile Thickness (in)**	0.375
Width of Material Disturbed by Sheet Pile Wall, w (Both Sides) (m)	1.8	**Surface Area (ft^2/ft of pile)**	6.47
Sediment Contaminant Concentration at Sheet Pile Wall, c (ng/kg)	1000 4N & 5N, 200 5aN	**Coating Area Wall Surface - One Side, Aw (ft^2/ft^2 of wall)**	1.22
Sediment Stickiness	Slightly -> Moderate	**Sediment Resuspended during Ascent through Water Column (%)**	50
Characteristic Adherence Thickness Δs_c (mm)	4.5	**Average Depth of Sheet Pile in Sediment, D_s (m)**	4.6

Results

Results of the sediment and contaminant mass disturbed as well as the rates of release can be found in Tables 11-3 and 11-4. Results are separated

Table 11-2. Equations Used for Resuspension Calculations during Sheet Pile Construction and Removal

Parameter	Equation
Mass Disturbed (kg)	$m = t * A * \rho_t$
Contaminant Release @ Assumed Sediment Conc. (ng)/(g)	$m_{cr} = m * c$
Volume of Sediment to Stick to Both Sides of Sheet Pile (ft³ sediment / ft² wall)	$Vs = \Delta s * Aw * 2$
Mass of Sediment / ft² of Wall (kg/ft² wall)	$m_w = Vs * \rho_b$
Mass (kg)	$m_r = m_w * L_w * D_s$
Contaminant Release (ng)/(g)	$m_{cr} = m_r * c$

into the two groups of remedial alternatives, 4N or 5N, and 5aN; their respective proposed sheet pile wall lengths of 800 L.F. for Alternatives 4N or 5N and 1200 L.F. for Alternative 5aN. The total estimated sediment mass disturbed and resuspended for both construction and removal of the sheet pile walls is approximately 5700 kg for Alternatives 4N or 5N and approximately 8500 kg for Alternative 5aN. The alternatives had an approximate total loss rate of 142 kg/day over 40 days for the hot spot remediation Alternatives 4N or 5N and over 60 days for the more extensive removal Alternative 5aN. However, the contaminant mass loss is considerably lower for Alternative 5aN because the location of the sheet pile wall had a lower sediment contaminant concentration as given in Tables 11-3 and 11-4.

TCRA Cap Removal

Removing the TCRA Cap includes first removing the armor stone and then removing the geotextile underneath. While removing the rock rip rap will result in negligible amounts of sediment resuspension, the geotextile removal will result in considerable resuspension from sediment adhering to the geotextile and washing off as it is pulled through the water column. The amount of resuspended sediments was estimated incrementally for Alternatives 5N, 5aN, and 6N. It is assumed that in Alternative 4N the TCRA cap would be removed in the dry. Alternative 5N could also be performed in the dry; the results below (see Table 11-4) are for removal in the wet.

Table 11-3. Resuspended Sediments during Sheet Pile Construction

Parameter	Alternatives	
	4N or 5N	5aN
L.F. Wall	800	1200
Mass Disturbed (kg)	1310	1970
Solids Loss Rate (kg/day)	33	33
Contaminant Release @ assumed Sed. Conc. (μg)	1310	394
Rate of Contaminant Release (μg/day)	33	6.6

Table 11-4. Resuspended Sediments during Sheet Pile Removal

Parameter	Value
Volume of Sediment to Stick to Both Sides of Sheet Pile (ft^3 sediment/ft^2 wall)	0.027
Volume of Sediment to Stick to Both Sides of Sheet Pile (m^3 sediment/ft^2 wall)	0.00076
Mass of Sediment/ft^2 of Wall (kg/ft^2 wall)	0.727
Assume 50% Washes/Falls Off (kg/ft^2 wall)	0.363
Alternatives 4N or 5N (800 L.F. Sheet Pile Wall Removal)	
Mass (kg)	4360
Rate over 40 days (kg/day)	109
Contaminant Release (μg)	4360
Rate over 40 days (μg/day)	109
Alternative 5aN (1200 L.F. Sheet Pile Wall Removal)	
Mass (kg)	6540
Rate over 60 days (kg/day)	109
Contaminant Release (μg)	1310
Rate over 60 days (μg/day)	21.8

Assumptions

It was assumed that like the process of removing sheet pile wall from the sediment bed, the geotextile will act in a similar manner as a bucket dredge in that sediment will have stuck to the fabric during TCRA cap placement, which will wash off the fabric as the fabric is pulled through the water column during its removal. Assumptions used in the calculations can be found in Table 11-5. Based on information provided in the Feasibility Study, the surface area of the geotextile was estimated to be the same as that of the cap area, as stated in Section 1 of the Feasibility Study. The sediment was assumed to be slightly to moderately sticky with an adjusted sediment thickness of 3.375 mm as used in the sheet pile wall calculations. It was also assumed that only the top soft layer of soil would adhere to the geotextile, thus a density of 500 kg/m^3 was assumed. Average sediment concentrations used for this analysis were determined using the provided sample results in the Feasibility Study. During removal, it was estimated that 50% of the sediment would wash off and that all sediment that was washed off would be lost.

Table 11-5. TCRA Cap Removal Assumptions

Parameter	Value	Parameter	Value
4N/5N Area Disturbed (acres)	3.6	**Characteristic Sediment Thickness Δs_c (mm)**	4.5
5aN Area Disturbed (acres)	11.3	**Adjusted Sediment Thickness Δs (mm)**	3.38
6N Area Disturbed (acres)	15.7	**Sediment Resuspended during Ascent through Water Column (%)**	50
Sediment Stickiness	Slightly --> Moderate	**Surface Soil Density (kg/m^3)**	500

Equations

The methods used for determining the resuspended sediments can be found in Table 11-6 and are the recommended methods presented in *Resuspension Factor Approach for Estimating Dredging-related Sediment Resuspension* (Hayes *et al.* 2007) and referenced in *Technical Guidelines for Environmental Dredging of Contaminated Sediments*

(Palermo *et al*. 2008). These methods are the same as were used to determine resuspended sediments during sheet pile wall construction and removal.

Table 11-6. Equations Used to Estimate Sediment Resuspension during Geotextile Removal

Parameter	Equation
Mass Resuspended (kg)	$m_r = \Delta s*A*\rho*\%R$
Contaminant Release (ng)/(g)	$m_{cr} = m_r*C$

<u>**Results**</u>

Results for the incremental analysis of sediment resuspended during geotextile removal can be found in Table 11-7. Alternative 5N is the smallest alternative/increment for dredging and it was analyzed as a complete entity and formed the base for each additional increment of dredging. Increment 5aN – 5N is additional increment of dredging when added to Alternative 5N forms Alternative 5aN. Alternative 5aN is the sum of the first two increments. Increment 6N – 5aN is additional increment of dredging when added to Alternative 5aN forms Alternative 6N. Alternative 6N is the sum of all increments. The average surface sediment concentration was estimated using data provided in the Feasibility Study and was averaged across the footprint for each alternative. The potential amount of sediment resuspended increases significantly in Alternatives 5aN and 6N due to their larger footprint and also results in higher contaminant mass releases.

Dredging

The removal of sediments by dredging is an effective means to removing contaminated sediments, but can also lead to exposure, releases and lasting effects if proper planning is not completed and best management practices are not used. Alternatives 5N, 5aN, and 6N require removal of sediment by dredging, although Alternative 5N can largely be executed by excavation. The following sections detail the assumptions made, methods

Table 11-7. Incremental Analysis of Sediment Resuspended during Geotextile Removal

Parameter	Alternative/ Increment 5N	Increment 5aN-5N	Alternative 5aN	Increment 6N-5aN	Alternative 6N
Area Disturbed (m^2)	14,600	31,200	45,800	17,800	63,600
Average Surface Sediment Concentration (ng/kg)	19,400	2550	7930	365	5810
Sediment Mass Resuspended (kg)	12,300	26,300	38,600	15,000	53,600
Contaminant Mass Resuspended (mg)	239	67	306	5.5	311

used, and results of the estimated releases due to dredging.

Assumptions

After a review of the site conditions and project background, it was determined that for this assessment, a mechanical clamshell dredge would be the best method of material removal, although upland areas could be removed by excavator in a landside operation. Mechanical dredging was selected due to limited staging areas available for dewatering, minimum requirements for dewatering, better control of residuals for soft sediment, and the need to use mechanical methods to remove the existing armor cap. Dredging was recommended for Alternatives 5N and 6N in the wet with a silt curtain to control sediment releases, while Alternative 5aN was also recommended to be completed in the wet but with a sheet pile wall and berm. It was described in the Feasibility Study to perform upland portions of Alternative 5aN in dry conditions; however, to assess the worst-case scenario potential, the alternative was assessed as being performed in wet conditions. Predominantly, only the Western Cell could be excavated in the dry; this constitutes about 25% of the area encompassed in Alternative 5aN but contains about 30% of the volume and about 65% of the contaminant mass. Consequently, excavating the Western Cell in the dry can greatly reduce the contaminant releases and residuals from Alternative 5aN. Predictions of releases and residuals for each release BMP for each incremental area comprising the various alternatives so that the releases and residuals can be estimated from any combination of BMP and incremental areas.

The clamshell bucket was assumed to fit the description of the characteristic clamshell bucket as described in Hayes *et al.* (2007) and the resuspension factor method was used to determine the possible resuspension for the site conditions. Sediment was assumed to be slightly to moderately sticky, with an average thickness of 4.5 mm stuck to the bucket. A review of the Feasibility Study and Geotechnical Report indicated that the average dredge depth would be 10 feet plus 1 foot of over-dredging and water depths averaging 10 feet.

Descent and ascent speeds of the dredge were reduced from the characteristic value to account for the specific site conditions of dredging from a barge and the dredge rate as specified in the Feasibility Study. These assumptions as well as assumptions for the Resuspension Factor can be found in Table 11-8.

To best analyze the possible resuspended sediment releases due to mechanical dredging, an incremental analysis was performed to assess the partial footprints of increments of each alternative, 5N, 5aN – 5N, and 6N – 5aN. As shown in Table 11-9, the volume of resuspended sediment was calculated incrementally to add the resuspension from the incremental footprint to that of the previous alternative, which had already been calculated. For example, since Alternative 5aN encompasses the entire footprint of Alternative 5N, then the dredged area for 5N could be excluded for analysis of 5aN as it has been analyzed separately. The same methodology is applied to Alternative 6N.

An average sediment concentration was calculated based on the results of the grab samples and sediment cores as shown in the Feasibility Study Figure 2-4. The sediment concentrations for each component were averaged across each component footprint.

Equations

Methods used to determine the resuspension factor and consequently, the sediment mass lost and loss rates were completed using the methods as described in Hayes *et al.* (2007) for determination of a resuspension factor based on characteristic properties. The system of equations for variables and constants can be found in Table 11-10. Once the resuspension factor was determined, the mass rate of sediment release could be determined using the equations listed in Table 11-11.

Results

Table 11-12 describes the results of the Resuspension Factor method and the resulting resuspension factor, R_c of 0.777 percent. These parameters were determined by making assumptions on dredging characteristics as previously described in Table 11-10. Resuspension would be predicted to stay in suspension for hours, long enough to be transported from the dredging site if water is allowed to be exchanged to minimize differential pressure across the sheet pile wall or silt curtain.

Table 11-8. Dredging Resuspension Assumptions

Property	Value	Property	Value
Bucket Volume, Vb (m^3)	7.65	**Characteristic Descent Velocity, Ǔd (m/s)**	1.2
Equivalent Diameter (m)	2.45	**Descent Velocity, Ud (m/s)**	1
Equivalent Surface Area (m^2)	7.24	**Characteristic Pre-dredge Water Depth, hc (m)**	8.3
Average Dredge Depth (m)	3.1	**Pre-dredge Water Depth, h (m)**	1
Sediment Removal Thickness (m)	1.2	**Characteristic Ascent Velocity, Ǔa (m/s)**	1.6
Overdredging Depth (ft)	1	**Ascent Velocity, Ua (m/s)**	1.2
Average Water Depth (m)	3	**5N f_{74} (>13000 ng/kg) (%)**	100
Sediment Stickiness	Slightly --> Moderate	**5aN – 5N f_{74} (%)**	60
fsed	2	**5aN f_{74} (>220 ng/kg) (%)**	75
Characteristic Sediment Thickness Δs_c (mm)	4.5	**6N-5aN f_{74} (%)**	50
Adjusted Sediment Thickness Δs (mm)	3.375	**6N f_{74} (>220 ng/kg) (%)**	67
In Situ Solids Concentration, Cs (kg/m^3)	950	**Dredge Rate , Ṽs (m^3/hr)**	25.5

The results of the mechanical dredging resuspension can be found in the Tables 11-13. An incremental analysis was used to estimate the potential resuspension of fine sediments for the dredging activities of each of the alternatives respective footprints. The total mass of sediment removed was calculated assuming an average density throughout the sediment of 950 kg/m^3. As the method of determining mass rate of sediment release accounts for the rate only the fine sediments (f_{74}), as seen in Table 11-11, the bulk sediment concentration was adjusted to reflect the fine sediments that are resuspended during dredging activities. The bulk sediment concentration was estimated incrementally based on sediment cores provided in the Feasibility Study and was then adjusted based on the volume of fines in the sediment. This adjustment results in a higher contaminant concentration and therefore a higher mass of contaminants resuspended as shown in the table below.

Table 11-9. Dredging Incremental Analysis Assumptions

Parameter	Alternative/ Increment 5N	Increment 5aN - 5N	Alternative 5aN	Increment 6N - 5aN	Alternative 6N
Volume Dredged (c.y.)	52,000	85,600	138,000	62,500	200,000
Area Dredged (ft^2)	157,000	335,000	492,000	192,000	684,000
Sediment Dry Mass (metric tons)	36,300	59,800	96,100	43,700	140,000
Days Required	65	107	172	78	250
Average Contaminant Concentration (ng/kg)	13,000	1,450	5,800	168	4,030

Table 11-10. Dredging Resuspension Equations

Parameter	Equation	Parameter	Equation
Characteristic Resuspension Factor, Rc (%)	$Rc = r_1+r_2+r_3+r_4$	**Resuspension Factor, R'c (%)**	$R'c = r'_1+r'_2+r'_3+r'_4$
r'_1	$r'_1 = faa*fdv*ftd*fsed*r_1$	**r'_3**	$r'_3 = [(fla*wla+fbw*wbw+fea*web)* fta+fsw*wsw]*fsed*r_3$
faa	faa = 1.025*(π/Vb)^(1/3)	**Fbw**	fbw = 1.35*(π/Vb)^(1/3)
fdv	fdv = (Ud/Ǔd)^2	**fsw**	fsw = (Ua/Ǔa)^2
ftd	ftd = (h*Ǔd)/(hc*Ud)	**Fta**	fta = (h*Ǔa)/(hc*Ua)
r'_2	$r'_2 = fbv*fec*fsed*r_2$	**r'_4**	$r'_4 = fso*fsed*r_4$
fbv	fbv = (Ud/Ǔd)^2		

Table 11-11. Sediment Loss Equations

Parameter	Equation
Mass rate of sediment release, g, (g/s)	$g = Rc*(f_{74}/100)*((\tilde{V}s*Cs)/360)$
Mass of sediment released, m (kg)	m = g(kg/day) * days required

Residuals

Residuals can be divided into two categories, generated and undisturbed. Generated residuals are the result of sediment that is dislodged from its original location, but falls, sloughs, or settles forming a new sediment layer. Undisturbed residuals are the result of failing to dredge to the bottom of contamination. Factors affecting the amount of residuals include:

- Type, size and operation of dredging equipment.
- Amount of contaminated sediment resuspended by dredging operation.
- Dispersion controls (*e.g.*, sheet piling, silt curtains).
- Contaminant concentration in surrounding areas.
- Characteristics of dredged sediment as well as underlying sediment.
- Site conditions including depths and currents.
- Extent of debris, obstructions or confined operating areas.

As there is no commonly accepted method to accurately predict post-dredging generated residuals, it is recommended by Palermo *et al.* (2008) in the Technical Guidelines for Environmental Dredging of Contaminated Sediments to assume that the residual contaminant concentration be equal to the depth-averaged contaminant concentration of the sediment removed in the last pass, which would include residuals from the previous pass. This method is detailed in Palermo *et al.* (2008) and the assumptions made, methods used, and results for this assessment are described below.

Assumptions

All forms of dredging result in some amount of residuals typically averaging between 5 and 9% lost for strongly hydrophobic contaminants (Patmont 2006) with this percent varying based on type of equipment, sediment characteristics, and number of dredge lifts. Due to the relatively small dredge depth of 10 ft, 4 dredge lifts plus a 1 ft over dredge was selected and the worst-case scenario of 9% residuals was selected due to the soft materials and tendency for mechanical clamshell dredges to lose more sediment and therefore create more residuals. It was assumed that the residuals layer would be less dense than the underlying material and would subsequently have a density of 500 kg/m^3. These assumptions are found in Table 11-14.

The assumptions made concerning the dredge lifts, layer depths, densities, and concentrations can be found in Table 11-15. Four dredge cuts of 3 ft each for lifts 1 -3 and 1 ft plus 1 ft of overdredging for lift 4 were selected. The contaminant profiles were estimated based on the concentrations in the sediment cores presented in the Feasibility Study (Figure 2-4). The various sediment cores were averaged for each of the respective incremental footprints as shown in the table below. The top 0.2-foot of sediment was assumed to be generally soft having a density of 500 kg/m^3 while the densities of the underlying sediment would increase to 950 kg/m^3 and 1000 kg/m^3 for the overdredging.

Equations

The following method used to determine the residuals was presented in Palermo *et al.* (2008) and is broken down by each dredge layer as shown in Table 11-16. The resultant is the determination of the mass, contaminant concentration and thickness of residuals layer.

Table 11-12. Resuspension Factor for Clamshell Bucket

Parameter	Value
Characteristic Resuspension Factor, Rc (%)	Rc = r1+r2+r3+r4
Loss during descent ,	0.01
Loss during bucket	0.09
Loss during ascent ,	0.15
Loss during slewing ,	0.25
r'_1 (adjusted r_1)	r'_1 = faa*fdv*ftd*fsed*r_1
Faa	0.753
Fdv	0.694
Ftd	0.434
r'_1	0.0045
r'_2 (adjusted r_2)	r'_2 = fbv*fec*fsed*r_2
Fbv	0.694
Fec	1
r'_2	0.125
r'_3 (adjusted r_3)	r'_3 = [(fla*wla+fbw*wbw+fea*web)*fta+fsw*wsw]*fsed*r_3
wla	0.2
Fla	1
Wbw	0.05
Fbw	1.004
Web	0.65
fea (assume)	1
Wsw	0.1
fsw	0.563
Fta	0.482
r'_3	0.147
r'_4 (adjusted r_4)	r'_4 = fso*fsed*r_4
fso (assume)	1
r'_4	0.5
R'c (adjusted Rc)	0.777

Table 11-13. Incremental Analysis of Total Resuspended Sediments during Mechanical Dredging

Parameter	Alternative/ Increment 5N	Increment 5aN - 5N	Alternative 5aN	Increment 6N - 5aN	Alternative 6N
Volume Dredged (c.y.)	52,000	85,600	138,000	62,500	200,000
Total Dry Sediment Mass Dredged assuming 950 kg/m^3 (metric tons)	37,800	62,200	100,000	45,400	145,000
Dry Mass of Fine Sediments Dredged (metric tons)	37,800	37,300	75,100	22,700	97,800
Days Required	65	107	172	78	250
Average Bulk Sediment Concentration (ng/kg)	13,000	1,450	5,810	168	4,040
Fine Sediment Concentration (ng/kg)	13,000	2,420	7,730	336	6,010
Fine Sediment Release Rate (kg/day)	4,510	2,710	3,390	2,260	3,040
Dry Mass of Fine Sediments Resuspended (metric tons)	294	290	584	176	760
Contaminant Mass Resuspended (mg)	3,810	702	4,500	59	4,560
Contaminant Release Rate (mg/day)	59	6.6	26	0.8	18

Table 11-14. Assumptions Made for Residuals Estimate

Parameter	Value
Dredge Plan for Mechanical Clamshell Dredge	**4 Production Passes for 10 ft Sediment and 1 ft Overdredging**
Assessment	**Worst-Case Scenario for Potential Residuals**
Residuals Left (%)	9
Assumed Residuals Density, ρ (kg/m³)	500

Results

The results of the potential residuals as determined following the methods presented in the USACE Technical Guidelines for Environmental Dredging of Contaminated Sediments (2008) can be found in Tables 11-17, 11-18 and 11-19. Table 11-17 presents the step by step incremental analysis resulting in sediment mass and contaminant mass per surface area as well as a final residual concentration and residual layer thickness. From these results and the assumed alternative surfaces areas as found in Table 11-9, sediment and contaminated mass were calculated as seen in Table 11-18. The results of the incremental analysis show that potential residual from Alternative 5N, which removes sediments greater than 13,000 ng/kg, result in a very high contaminant concentration in the residuals, well above the required PCL.

Table 11-15. Assumed Dredge Lifts for Increments 5N, 5aN, and 6N

Dredge Lifts	Cut, D (ft)	Increment 5N (Surface > 13000 ng/kg)		Increment 5aN – 5N (13000 ng/kg>Surface>220 ng/kg)		Increment 6N – 5aN (Surface<220 ng/kg)	
		Density, ρ (kg/m³)	Concentration, C (ng/kg)	Density, ρ (kg/m³)	Concentration, C (ng/kg)	Density, ρ (kg/m³)	Concentration, C (ng/kg)
1	0.2	500	15,600	500	4,310	500	198
	2.8	950	15,600	950	4,310	950	198
2	3	950	15,500	950	908	950	349
3	3	950	11,400	950	169	950	60
4	1	950	9,050	950	111	950	34
	1 Over Dredge	1000	6,660	1000	53	1000	8

Table 11-19 presents the amount of the residuals lost with the use of a turbidity curtain. It is assumed, based on prior knowledge that roughly 20% of the fine-grained remaining residuals would be lost below the turbidity curtain due to currents.

Conclusions

This assessment examined the remediation alternatives as proposed in the Feasibility Study considering the BMP options given in the FS. The analyses showed that there is the potential for significant sediment releases depending on the methods used for remediation. Any remediation, solidification or dredging, that occurs should be completed in the dry to minimize the amount of resuspension releases and residuals that may be exposed to the water column, particularly in the area slated for removal in Alternative 5N. All activities completed in the dry, having a sheet pile wall barrier protecting the water from interacting with contaminated sediment will result in very small amounts of resuspension, and will have limited exposure to the water before the permanent cap is placed over the residual layers. Activities completed in the wet will result in much greater releases and potential long-term effects based on the residuals. The predicted residuals for Alternative 5N have a quite high contaminant concentration due to an insufficient depth of dredging, which does not include overdredging of sediment below the clean-up level.

A summary of incremental sediment releases can be found in Table 11-20. This table allows for comparison of the total mass of sediments and contaminants removed by dredging to the total mass of sediments and contaminant lost with either a sheet pile wall or a turbidity curtain as a best management practice. The mass of sediment removed by dredging was calculated by assuming an average sediment density of 950 kg/m^3 and by using the incremental sediment contaminant concentrations. Table 11-21 shows the releases for the various removal alternatives if a particular BMP where applied for all of the alternatives.

Table 11-16. Method of Residuals Estimation

1st Production Pass - Composite	
Mass, M_{1c} (kg-ft/m3)	$M_{1c} = (D_{1S} * \rho_{1S}) + (D_{1B} * \rho_{1B})$
Contaminant Mass, CM_1 (ng-ft/m3)	$CM_1 = C_1*M_1$
1st Production Pass – Residuals Layer	
M_{1R} (kg-ft/m3)	$M_{1R} = \%R*M_1$
CM_{1R} (ng-ft/m3)	$CM_{1R} = \%R*CM_1$
Residual Contaminant Concentration,	$CC_{1R} = CM_{1R}/M_{1R}$
2nd Production Pass - Sediment	
M_2 (kg-ft/m3)	$M_2 = D_2*\rho_2$
CM_2 (ng-ft/m3)	$CM_2 = C_2*M_2$
2nd Production Pass - Composite	
M_{2c} (kg-ft/m3)	$M_{2c} = M_2 + M_{1R}$
CM_{2c} (ng-ft/m3)	$CM_{2c} = CM_2 + CM_{1R}$
2nd Production Pass -Residuals	
M_{2R} (kg-ft/m3)	$M_{2R} = \%R*M_{2c}$
CM_{2R} (ng-ft/m3)	$CM_{2R} = \%R *C_{2c}$
CC_{2R} (ng/kg)	$CC_{2R} = CM_{2R}/M_{2R}$
3rd Production Pass - Sediment	
M_3 (kg-ft/m3)	$M_3 = D_3*\rho_3$
CM_3 (ng-ft/m3)	$CM_3 = C_3*M_3$
3rd Production Pass - Composite	
M_{3c} (kg-ft/m3)	$M_{3c} = M_3 + M_{2R}$
CM_{3c} (ng-ft/m3)	$CM_{3c} = CM_3 + CM_{2R}$
3rd Production Pass -Residuals	
M_{3R} (kg-ft/m3)	$M_{3R} = \%R*M_{3c}$
CM_{3R} (ng-ft/m3)	$CM_{3R} = \%R *C_{3c}$
CC_{3R} (ng/kg)	$CC_{3R} = CM_{3R}/M_{3R}$
Final Production Pass - Sediment	
M_F (kg-ft/m3)	$M_F = D_F*P_F$
CM_F (ng-ft/m3)	$CM_F = C_F*M_F$
Final Production Pass - Overdredging	
M_{OD} (kg-ft/m3)	$M_{OD} = D_{OD}*\rho_{OD}$
CM_{OD} (ng-ft/m3)	$CM_{OD} = C_{OD}*M_{OD}$
Final Production Pass - Composite	
M_{Fc} (kg-ft/m3)	$M_{Fc} = M_{3R} + M_F + M_{OD}$
CM_{Fc} (ng-ft/m3)	$CM_{Fc} = CM_{3R} + CM_F + CM_{OD}$
Final Production Pass -Residuals	
M_{FR} (kg-ft/m3)	$M_{FR} = \%R*M_{Fc}$
CM_{FR} (ng-ft/m3)	$CM_{FR} = \%R *C_{Fc}$
CC_{FR} (ng/kg)	$CC_{FR} = CM_{FR}/M_{FR}$
Residual Thickness, T_R (ft)	$T_R = M_{FR}/\rho_R$

Table 11-17. Incremental Analysis of Potential Residuals

Parameter	Increment 5N	Increment 5aN -5N	Increment 6N -5aN
1st Production Pass - Composite			
M_{1C} (kg-ft/m3)	2,760	2,760	2,760
CM_{1C} (ng-ft/m3)	43,100,000	11,900,000	546,000
1st Production Pass - Residuals Layer			
M_{1R} (kg-ft/m3)	248	248	248
CM_{1R} (ng-ft/m3)	3,880,000	1,070,000	49,200
CC_{1R} (ng/kg)	15,600	4,310	198
2nd Production Pass - Sediment			
M_2 (kg-ft/m3)	2,850	2,850	2,850
CM_2 (ng-ft/m3)	44,200,000	2,590,000	995,000
2nd Production Pass - Composite			
M_{2c} (kg-ft/m3)	3,100	3,100	3,100
CM_{2c} (ng-ft/m3)	48,100,000	3,660,000	1,040,000
2nd Production Pass - Residuals			
M_{2R} (kg-ft/m3)	279	279	279
CM_{2R} (ng-ft/m3)	4,320,000	329,000	93,900
CC_{2R} (ng/kg)	15,500	1,180	337
3rd Production Pass - Sediment			
M_3 (kg-ft/m3)	2,850	2,850	2,850
CM_3 (ng-ft/m3)	32,500,000	482,000	171,000
3rd Production Pass - Composite			
M_{3c} (kg-ft/m3)	3,130	3,130	3,130
CM_{3c} (ng-ft/m3)	36,800,000	811,000	265,000
3rd Production Pass - Residuals			
M_{3R} (kg-ft/m3)	282	282	282
CM_{3R} (ng-ft/m3)	3,310,000	73,000	23,800
CC_{3R} (ng/kg)	11,800	259	85
4th (Final) Production Pass - Sediment			
M_4 (kg-ft/m3)	950	950	950
CM_4 (ng-ft/m3)	8,597,500	105,450	32,300
Final Production Pass - Overdredging			
M_{OD} (kg-ft/m3)	1,000	1,000	1,000
CM_{OD} (ng-ft/m3)	6,660,000	53,000	8,000
Final Production Pass - Composite			
M_{Fc} (kg-ft/m3)	2,230	2,230	2,230
CM_{Fc} (ng-ft/m3)	15,300,000	159,000	40,400
Final Production Pass - Residuals			
M_{FR} (kg-ft/m3)	201	201	201
CM_{FR} (ng-ft/m3)	1,370,000	14,300	3,640
CC_{FR} (ng/kg)	6,840	71	18.1
Residual Thickness, T_R (ft)	0.40	0.40	0.40

Table 11-18. Summary of Residuals Estimates

Parameter	Alternative/ Increment 5N	Increment 5aN - 5N	Alternative 5aN	Increment 6N - 5aN	Alternative 6N
Sediment Residual Mass (metric tons)	892	1,908	2,800	1,090	3,890
Contaminant Residual Mass (mg)	7,420	198	7,620	31	6,259
Contaminant Concentration (ng/kg)	8,320	104	2,720	29	1,970

Table 11-19. Potential Releases from Erosion of Residuals with a Silt Curtain Prior to Cover Placement

Parameter	Alternative/ Increment5N	Increment 5aN - 5N	Alternative 5aN	Increment 6N - 5aN	Alternative 6N
Sediment Residual Mass Erosion (metric tons)	897	1,150	2,050	550	2,600
Contaminant Residual Erosion Mass (mg)	11,700	2,840	14,600	188	14,700
Contaminant Concentration (ng/kg)	13,100	2,470	7,130	342	5,660

Table 11-20. Summary of Incremental Sediment and Contaminant Release Estimates*

Incremental Areas	BMP Options	Total mass of dry solids removed (metric tons)	Total mass of dry solids released (metric tons)	Percentage of sediment released (%)	Total mass of contaminant removed (g)	Total mass of contaminant released (g)	Percentage of contaminant released (%)
Alternative/ Increment 5N	Silt Curtain	37,800	1,200	3.18	491	15.8	3.21
	Sheet Pile Wall (Wet Removal)		312	0.83		3.82	0.78
	Sheet Pile Wall (Dry Removal)		5.7	0.015		0.0057	0.001
Increment 5aN - 5N	Silt Curtain	62,200	1,470	2.36	90.2	3.61	4.00
	Sheet Pile Wall (Wet Removal)		319	0.51		0.70	0.78
Increment 6N - 5aN	Silt Curtain	45,400	741	1.63	7.63	0.25	3.28
	Sheet Pile Wall (Wet Removal)		191	0.42		0.06	0.78

*As Alternative 4N will be performed in the dry, the only releases will be due to the sheet pile wall construction and removal and are the same as given above for Alternative 5N with a Sheet Pile Wall with Excavation in the Dry.

Table 11-21. Sediment and Contaminant Release Estimates as a Function of Selected BMP

Selected BMP	Solids Released (%)			Contaminant Released (%)		
	Alternatives			Alternatives		
	5N	5aN	6N	5N	5aN	6N
Sheet Pile Wall (Dry Removal)	0.015	NA	NA	0.001	NA	NA
Sheet Pile Wall (Wet Removal)	0.83	0.63	0.57	0.78	0.78	0.78
Silt Curtain	3.18	2.67	2.35	3.21	3.34	3.34

To determine the releases for any alternative using different BMPs for the various incremental areas, select the rows listing the selected BMP for each of the incremental areas contained in the alternative and then sum the incremental releases for the selected rows in Table 11-20. For example, for Alternative 6N using sheet pile walls and removal in the dry for Increment 5N, sheet pile walls and removal in the wet for Increment 5aN – 5N, and silt curtains for Increment 6N – 5aN, the dry solids release would be 1066 (5.7 + 319 + 741) metric tons and the contaminant release would be 0.956 (0.0057 + 0.70 + 0.25) grams. To obtain the percentages release, divide the releases by the masses removed. For this example, the solids release was 0.74% and the contaminant release was 0.16%.

This assessment presents the possible outcomes of remedial Alternatives 4N*, 5N, 5aN and 6N with very specific assumptions and site conditions. The actual sediment releases and residuals will vary depending on the actual circumstances of remedial activity. A new full removal Alternative 6N* is examined for potential releases in Task 12 with alternative BMPs.

Task 12

Statement

Identify and evaluate techniques, approaches, Best Management Practices (BMPs), temporary barriers, operational controls, and/or engineering controls (*i.e.*, silt curtains, sheet piles, berms, cofferdams constructed of earth filled caissons, etc.) to minimize the amount of sediment resuspension and sediment residuals concentrations during and after dredging/removal. Prepare a new full removal alternative that incorporates the relevant techniques identified as appropriate.

BMPs to Minimize Sediment Resuspension and Residuals during Dredging/Removal

Alternatives 4N, 5N, 5aN and 6N call for removal of a portion of the TCRA cap composed of armor stone and filter stone in the Northwestern Area, armor stone and geotextile in the Eastern Cell and armor material, geotextile and geomembrane in the Western Cell. Alternatives 5N, 5aN and 6N also call for partial or full removal of sediment. These removal operations will resuspend contaminated sediment and generate contaminated residuals which will increase the release of contaminants, requiring the implementation of Best Management Practices (BMPs) to control the release of contaminants.

<u>Resuspension, Residuals, and Release</u>

Sediment remediation techniques that disturb the sediment bed, such dredging, solidification, or treatment, have potential to expose contamination through resuspension, generation of residuals, or release of contaminants. Detailed information regarding these mechanisms with respect to dredging is provided by ERDC in the Technical Guidelines for Environmental Dredging of Contaminated Sediments (Palermo *et al.* 2008). Resuspension is the dislodgement and dispersal of sediment into the water column where finer particles and flocs are subject to transport by currents. Resuspension results in short-term release of contaminants by desorption and release of pore water. Residuals are contaminated sediments remaining in the dredging area after completion of the dredging operation and result from two main sources. Undisturbed residuals are contaminated sediments at the post-dredge surface that have been uncovered, but not removed. Generated residuals consist of sediment that

is dislodged, but not removed, and falls back into the dredging footprint where it contributes to contaminant release (Palermo *et al.* 2008).
A variety of control measures have been identified to minimize sediment resuspension, contaminant release and dredging residuals that may occur during sediment removal operations. These include both operational and engineered controls. Operational controls include actions that can be taken by the dredge operator, whereas engineered controls require a physical construction technology or modification of the dredge plant. It is pointed out in the Technical Guidelines (Palermo *et al.* 2008) that both, operational and engineered controls can reduce production rates and efficiency, can increase cost, and can even have negative impacts if used improperly, and therefore should only be applied when conditions clearly indicate their need.

Resuspension Controls

Operational Controls

Operational controls that may be considered to minimize resuspension during dredging include:

Mechanical Dredging:

- Reducing the dredging rate by slowing descent or hoist speed of wire-supported bucket
- Reducing bucket speed as it approaches sediment surface and after closing
- Prevent bucket over-penetration
- Eliminate barge overflow
- Employ aprons to catch spillage and a rinse tank to clean the bucket between cycles

Hydraulic Dredging:

- Modify cutterhead depth
- Modify rate of swing of the ladder
- Reduce speed of advance of the dredge

General:

- Adjust dredge operation according to changing site conditions
- Sequence the dredging moving upstream to down and to limit dredge traffic over exposed contaminated sediment
- Vary number of vertical cuts to increase sediment capture
- Use properly sized tugs and support equipment

- Limit barge, tender and tug traffic over exposed sediment and residuals
- Cover exposed residuals as soon as possible, minimizing the area of exposed residuals

Dredge operators are challenged to find an optimal rate to reduce resuspension and maximize production. For hydraulic dredging, resuspension is generally minimized at the same point that production is optimized.

Engineering Controls

Engineered control measures such as physical barriers can be used to reduce transport of resuspended contaminated sediment, and limit the areal extent of particle-bound contamination. However, containment of the resuspended sediment may increase residual concentrations inside the barrier. Types of physical barriers may include cofferdams, removable dams (*e.g.*, Geotubes), sheet-pile enclosures, silt curtains, silt screens, and pneumatic (bubble) curtains. Cofferdams and removable dams are generally associated with dry excavation remedies.

Silt curtains and silt screens. Silt curtains and silt screens are flexible barriers that hang down from the water surface using a series of floats on the surface and a ballast chain or anchors along the bottom. Silt "curtains" are made of low permeability materials, and as such, redirect water flow around the enclosed area. Silt "screens" are made of permeable geotextile fabrics which allow a significant fraction of the water to flow through, but retain a large fraction of the suspended solids. The terms are frequently used interchangeably, and the term "curtain" is used here to apply to both types. Silt curtains either contain or redirect the transport of resuspended sediment. Partial depth deployment from the surface to a given depth prevents spreading in the upper water column, but allows transport beneath the curtain. Full depth deployment provides greater containment, although there are potential releases from ineffective seals along the bottom, tidal fluctuations, erosion by the curtain scraping the sediment bed, erosion outside the curtain from the flow being diverted around the site, and vessel movement through gaps. It is important to note that increased concentrations of TSS or dissolved contaminants contained within the curtain are generally released upon relocation or demobilization.

Guidance on the use of silt curtains, including descriptions, deployment, configurations, and "lessons learned" is provided by Francingues and Palermo (2005). Some of the key points include:

- Silt curtains are not very effective at current velocities > 1 ½ knots (2.5 ft/sec) and are best deployed in environments where the current speeds are less than 1 ft/sec. Application at higher velocities would require special designs.
- At depths greater than 10-12 ft, loads on the curtains and mooring systems become excessive and could result in failure.
- Silt curtains are highly specialized and should be tailored to the site-specific project. Planning elements should include construction specifications, performance criteria, plans for deployment, removal, decontamination and maintenance, and monitoring plans.
- Deployment is temporary, but should remain in place until all dredging is complete, allowing for traffic in and out, and for relocation as the dredge moves.

Hydrodynamic conditions that reduce effectiveness of the silt curtain include strong currents, high winds, fluctuating water levels, excessive wave height (including ship wakes), drifting ice and debris, and movement of equipment into or out of the area. Generally, silt curtains are most effective in relatively shallow, quiescent water without significant tidal fluctuations. Silt curtains can be used either to enclose the dredging area (keeping TSS inside), or to protect sensitive areas (keeping TSS out).

Structural barriers. Structural barriers should be considered if there is uncertainty that a silt curtain will be effective, or for containment of resuspended sediments that contain highly mobile, highly toxic, or bioaccumulative contaminants. Structural walls (*e.g.*, sheet pile deflection walls) can also be used to partially shield silt curtains from high current velocities. Sheet-pile containment structures are generally more reliable than silt curtains, although the cost is significantly higher with different technological limitations. There is an increased potential for scour to occur around the outside of the containment area; however, the surrounding area could be armored to prevent scour at the base of the wall. If water levels are lowered on one side of the wall, the hydraulic loading effects may result in safety concerns; however, the wall can be designed to allow water exchange to accommodate changes is river stages or tides. Cofferdams composed of caissons anchored in a stiff, shear resistant stratum and filled with low permeability soils could be built instead of sheet pile walls to accommodate the differences in pressures resulting from dewatering the inside of the containment and allow greater excavation in the dry. The seepage through walls and the foundation pose large uncertainties in the implementability of excavation in the dry. The caissons would prevent exchange of water during removal in the wet and the associated resuspension releases but dredging residuals would still be created that would be required a residual cover. The residuals would still be a source of long-term releases and would be available to potentially erode under severe storm events. Another consideration is the resuspension and contaminant release that will occur during placement and removal. If the carrying capacity of a stream or river is changed significantly, it may make it more susceptible to flooding. Engineering design considerations include geotechnical characteristics of the sediment profile, proximity to bedrock, hydraulic head acting on the enclosure, and ice forces.

Release Controls

Controlling resuspension is the first step to controlling release of contaminants because the vast majority of dioxins and furans are associated with the sediment particles. However, additional controls may be necessary because the contaminants will partition to the water column when sediment particles are suspended in dispersions of low concentrations of total suspended solids.

For release of NAPL and floatable materials, oil booms may be used to contain contaminants. Oil booms may be supplemented with oil-absorbent materials. However, booms do not retain the soluble fraction of floatable materials that can volatilize. Monitoring for visible sheens or visibly soaked sorbent pads and changing out pads accordingly can improve effectiveness. NAPL and floatable materials are not a concern at the San Jacinto site.

Controlling release of particulate-bound contaminants is largely accomplished by controlling resuspension. However, increasing sedimentation rates will also decrease the spread of contaminants and bioavailability. Methods to improve sedimentation include: providing a zone for quiescent settling, addition of flocculants, or using containment enclosures designed as filters. Adsorbents integrated into permeable silt curtains essentially treat water as it passes through. Pilot studies may be needed to show effectiveness of these technologies.

Technology for controlling releases of dissolved contaminants is also largely limited to resuspension controls. However, dissolved contaminants may also be removed by dispersing adsorbents, such as activated carbon, inside containment enclosures. Upon settling, the adsorbents may further sequester the dissolved contaminant flux from the sediment bed and residuals. If the sediment bed or residuals were resuspended, the adsorbents would also be resuspended and then sequester the new releases. Filtering geotextiles with adsorbents used in conjunction with permeable silt curtains treat water passing through the site. Pilot studies are encouraged before application to large-scale projects.

Volatile emissions controls are limited and have not been adequately evaluated in the field. In addition to the controls mentioned above, controls for small hotspots may include: modifying the dredging schedule or sequence to dredge in winter or at night when temperatures are cooler; using hydraulic dredging to reduce concentrations at the water surface and in the air; applying surface volatilization barriers; and reducing the area of the dredge enclosure that is emitting volatiles. Other physical measures to control volatiles include covering the dredged material with physical barriers (*e.g.*, foam, mulch, plastic liner, or adsorbent mats). Dioxins and furans have both low solubility and low volatility; therefore, volatilization controls are not needed at the San Jacinto site.

Residual Controls

The nature and extent of residual contamination is difficult to estimate. Undisturbed residuals can be reduced by accurate and precise site characterization, proper establishment of the cut line, accurate and precise vertical and horizontal controls for positioning of dredge passes, accurate post-dredging bathymetric surveys, and an accurate cleanup pass. Generated residuals, however, are unavoidable, and it is accepted that a residuals layer will be present unless eroded away. The operational controls listed below may be effective for reducing residuals.

- If debris is present, a separate debris-removal operation can be considered either prior to dredging, in between passes, or prior to a cleanup pass. Little debris should be present in the contaminated sediment due to nature of the San Jacinto waste pits being a confined waste storage facility, its remoteness, and its lack of commercial or navigation activities at the site.

- Sequence dredging from upslope to downslope and upcurrent to downcurrent and to limit dredge traffic over exposed contaminated sediment.
- Limit traffic over the dredged area.
- Excavate in the dry where possible.
- Provide appropriate overdredging allowance for production cuts.
- Overdredge with a cleanup pass to reduce the residuals layer thickness and mix residuals from the underlying clean sediment with the contaminated residuals to reduce the concentration.
- Provide adequate overlap between bucket cuts with high resolution positioning controls to reduce residuals between bucket cuts.
- Terrace dredge cuts to limit sloughing.
- Eliminate bucket over-penetration and overfilling.
- Conduct rapid hydrographic surveys and sampling after dredging to provide feedback to the dredge operator.

Depending on the results of monitoring, several post-dredging control measures are available. The controls measures should be selected based on residuals' characteristics and site conditions.

A cleanup dredging pass or sweep pass may be conducted to remove the thin surficial layer of material containing residuals and minimal thickness of the underlying clean material. Performance requirements to achieve a very low residual contaminant concentration can be inefficient and costly. Limiting the number of passes and providing the option for placement of a residuals cap may bring more certainty into the cost estimating and bidding process. For thicker layers of residuals, especially undisturbed residuals, additional production dredging may be needed.

A thin layer of clean material may be placed over residuals to provide short-term isolation and long-term reduction in surficial contamination. The cover material does not need to be sand, and other materials with potential to reduce bioavailability may be preferable. Thin layer capping may be useful where residual layers are sufficiently thin with low contaminant concentrations, so that if the cover material mixes into the underlying residual, remediation action levels can still be achieved. Some mixing is likely to occur during placement, with additional mixing due to bioturbation and sediment transport processes. This would result in a lower contaminant concentration in the biologically active zone. Additional deposition of clean sediment may enhance physical and chemical isolation of the residuals.

An engineered isolation cap may be considered where substantial layers of residuals cannot be effectively removed. USEPA guidance for design of engineered caps is generally followed (USEPA 2005).

Best Management Practices for San Jacinto Proposed Alternatives

Alternatives currently being considered for San Jacinto are described in the Draft Final Interim Feasibility Study Report (Anchor QEA 2014). Within the management alternatives, a number of actions have been identified that have potential to generate resuspension, residuals, and contaminant release. The alternatives labeled as 1N (no further action) and 2N (monitored natural recovery (MNR) and institutional controls (ICs)) will leave the existing TCRA Armor Cap in place and does not include activities that would generate resuspension, residuals or release. Implementation of Alternative 3N would require enhancement of the Armored Cap including addition of armor rock to further flatten the slopes, and construction of a protective perimeter barrier to protect from vessel traffic. These activities would not expose the contaminated material and therefore would not have the potential to generate resuspension, residuals, and contaminant release. Alternative 4N calls for removal of 23% of the Armored Cap, and solidification/stabilization (S/S) of the underlying 52,000 cubic yards (cy) of contaminated material, followed by construction of a Permanent Cap. Alternative 5N also calls for partial removal of the Armored Cap and Permanent Cap construction, but also specifies excavation and off-site disposal of the 52,000 cy of contaminated material that exceed 13,000 *ng/kg* $TEQ_{DF,M}$ at any depth. More extensively, Alternative 5aN requires removal of the Armored Cap and all underlying material in high concentration areas greater than the PCL) with water depth of 10-feet or less, and materials that exceed 13,000 *ng/kg* $TEQ_{DF,M}$ at any depth. Removal for Alternative 5aN would involve 11.3 acres and 137,600 cy of contaminated material. Alternative 6N requires removal of the entire existing cap and 200,100 cy of contaminated material followed by covering with a layer of clean fill.

Activities that may generate resuspension, residuals, and contaminant release include:

- Removal of existing TCRA Armor Cap (under both submerged and upland conditions)(4N, 5N, 5aN, 6N)
- Resuspension and release from exposed, un-capped sediment (4N, 5N, 5aN, 6N)
- Solidification/Stabilization (4N)
- Sheet pile installation and removal (4N, 5aN, maybe 5N)
- Perimeter berm installation and removal (5aN)
- Removal of contaminated soil/sediment (5N, 5aN, 6N)
- Construction of Permanent Cap (4N, 5N, 5aN)
- Restoration of Armor Cap (in areas cap was removed to allow S/S (4N) or removal (5N) of material with TEQ > 13,000 *ng/kg* $TEQ_{DF,M}$)
- Addition of residuals cover/backfill (5N, 5aN, 6N)
- Installation/removal of silt curtain (5N, 6N)
- Site dewatering (4N, maybe 5N, possibly 5aN and 6N in Western Cell)
- Treatment/dewatering excavated sediment (5N, 5aN, 6N)

With dioxins as the primary COC, concerns are primarily associated with particulate-bound contaminants, rather than volatile emissions or dissolved contaminants.

Removal of Existing Armor Cap

Alternatives 4N, 5N, 5aN, and 6N involve removal of some or all of the existing TCRA Armor Cap. Armor cap would be removed from both submerged areas and areas that are not normally submerged though periodically flooded. The armor rock would be removed and stockpiled for reuse, if possible, or washed to remove adhering sediment and disposed in an upland facility. The geotextile and geomembrane would be removed and disposed as contaminated debris (Anchor QEA 2014). Removal equipment and methods were not specified. Alternatives 4N, 5aN, and potentially 5N include sheet pile enclosures, and Alternatives 5N and 6N suggest the use of silt curtain. However, the FS does not clearly specify whether the sheet pile or silt curtain would be installed before or after removal of the existing Armor Cap (Anchor QEA 2014). Dewatering is specified for submerged areas for Alternatives 4N and potentially 5N.

Resuspension is likely to occur as the sediment is disturbed upon removal of cap materials in contact with the contaminated sediment. A significant portion of the contaminated sediment may adhere to the armor rock, geotextile or geomembrane. In submerged areas, contaminated sediment that is resuspended into the water column has the potential for transport off site or for contamination of the clean cap. As part of the TCRA, solidification/stabilization (S/S) techniques were applied to the upper three feet in the Western Cell of the site prior to placement of the Armor Cap. The S/S efforts may have reduced the tendency of the contaminated sediments to adhere to the cap materials and to resuspend. In upland areas such as the Western Cell, contaminants could be transported off site via runoff or as dust.

Some contaminated material will adhere to the cap material (geotextile or armor rock) and be disposed with it. As discussed in the FS, hazardous materials (sediments, geotextile, used personal protective equipment and debris) would be packaged in accordance with Texas Department of Transportation shipping requirements and transported to a permitted landfill. Care should be taken to avoid re-use of cap material that has been contaminated with the sediment. It is difficult to understand how the armor cap material could be readily removed without snagging and disturbing the geotextile and sediment, particularly if performed underwater. The entire cap within the sheet pile enclosure should be removed prior to solidification, excavation or dredging to limit contamination of the TCRA armor cap material. The enclosed area could be sectioned with silt curtains to further limit the potential for contamination of the TCRA armor cap material. Additionally, a work plan should be in place to minimize equipment tracking between capped (or clean) and exposed contaminated areas. Periodic equipment cleaning could be employed to prevent contamination of otherwise clean, reusable cap materials.

In submerged areas, installation of sheet pile walls prior to cap removal would provide a barrier to contain resuspension from cap removal activities and reduce off site transport. If dewatering is possible, working in the dry would significantly reduce contaminant transport from resuspension and release. Though not as effective as sheet pile, silt curtains could also be used to reduce transport of resuspended contaminated sediments. Problems with silt curtains were noted during the TCRA cap construction, yet despite requiring a great deal of maintenance, the silt curtains appeared to be effective (Anchor QEA 2012). Resuspended sediment contained within the sheet pile or silt curtain enclosure may subsequently settle out within the contained area, which could contaminate remaining un-removed cap material. (See Sheet Pile and Silt Curtain Installation/Removal.)

Resuspension and Release from Exposed Uncapped Sediments

Removal of the existing cap (Alternatives 4N, 5N, 5aN) will also expose the contaminated sediments for a period of time until they are either stabilized, removed, or either covered or capped. There is potential for contaminants to be released into overlying water during exposure. Exposed upland soils can also be transported by rainfall runoff and dust. Also, resuspension of the contaminated material is possible during storm and flood events, which could allow transport to the surrounding area. The risk of flood occurrence depends on the season and duration of the construction. For alternatives 4N and 5aN, the area in which the cap will be removed will be enclosed within sheet pile. However, the FS suggests the likelihood of the sheet pile being overtopped and resulting in inundation of the construction footprint is approximately 38 percent for alternative 4N, and 40 percent for alternative 5aN. Alternatives 5N and 6N, using silt curtains, are also subject to inundation, with a likelihood of 30 percent and 36 percent, respectively (Anchor QEA 2014).

Potential practices that could minimize contaminant resuspension and release from exposed sediment include the use of silt curtains, or sheet piles. The FS report suggests limited effectiveness of the sheet pile due to gaps during construction, necessary openings to balance water pressures, and river-induced scour (Anchor QEA 2014). However, use of sheet piles in shallow water such as along the berms of the Western Cell may be able to operate in the dry. In deeper areas the remediation operations would need to proceed in the wet, use of sheet piles for controlling resuspension releases and contaminant releases would be much more effective than silt curtains even if water exchanges were allowed to balance water pressures. Exchanges would occur near the surface with sheet piles but near the bottom for silt curtains, resulting in about one third of the releases observed using silt curtains. Additionally, armoring around the outside of the sheet pile wall could control river-induced scour. For resuspended sediment that is contained within a sheet pile (4N, 5aN) or a turbidity curtain (5N, 6N), flocculants may be added to encourage settling of contaminated particles, but mixing and higher suspended solids concentrations would be needed to be particularly effective. Also, activated carbon may be added to sorb dissolved contaminants; however, activated carbon would need to be added regularly because the carbon will settle out of suspension, limiting its effectiveness. Neither application has been routinely performed and are not recommended due to the low suspended solids concentration and low dissolved contaminant concentration. As both silt curtains and sheet piles may leak, additional practices may be needed to manage contaminants released outside the contained area. Monitoring is recommended to determine the need for such controls.

For upland areas, water spraying should be employed as needed to control dust. Also, exposed sediment is subject to resuspension during rainfall runoff or tidal inundation. Silt fencing or hay bales may be used to minimize release of contaminated sediment-laden runoff. Also, during TCRA Armor Cap construction, a temporary water control berm was constructed to minimize potential for tidal water to inundate the Western Cell during stabilization activities. The berm was constructed with a crest elevation of approximately 2.5 feet NAVD 88, using CCRB and 6 mm thick polyethylene sheeting (Anchor QEA 2012, p. 39). Potentially, the surface area exposed at a given time could be reduced by staging the construction activities, working within subareas, and using sacrificial covers which would support fill, bedding or filter requirements for the final disposition.

Solidification/Stabilization

Alternative 4N proposes S/S performed using large-diameter augers or conventional excavators, similar to those used for S/S in the Western Cell during the TCRA. Submerged areas would be isolated from surface water with sheet pile and mostly dewatered prior to S/S. The FS assumes a sheet pile enclosure with a top elevation 2 feet above typical mean higher high water (mhhw). The sheet pile would be removed following completion of S/S; then, the Permanent Cap would be constructed over the S/S footprint. None of the other alternatives include S/S activities (Anchor QEA 2014). S/S activities will potentially result in resuspension, release, and residuals as the uncapped contaminated material is mixed with Portland cement. Mixing of the sediment will loosen it, making it temporarily more subject to resuspension and erosion. However, the S/S treatment will increase resistance to erosion as it cures over a period of about ten days. In upland areas, runoff controls should be in place to capture suspended sediment from rainfall. The FS suggests that the submerged areas be enclosed with sheet piles and dewatered. If not dewatered, sheet pile enclosures would also help retain resuspended solids, and released contaminants. The FS suggests ineffectiveness of sheet pile barriers due to gaps that occur during installation, openings to balance water pressures, and river-current-induced scour. If properly installed, shallow sheet pile barriers should be able for the most part to be installed without gaps, and any gaps could be sealed with fine-grained backfill. If water pressures are significant, a cofferdam may be needed. If S/S is performed in the wet, the degree to which resuspension occurs will depend on the equipment used to mix the sediment and cement.

S/S activities will involve transport across the site to maneuver mixing equipment and deliver Portland cement. To minimize contaminant spreading, decontamination of trucks and equipment (and workers) may be needed upon exiting the site. A water truck may be needed to suppress dust from both the contaminated sediment and Portland cement.
Post S/S monitoring will be needed to determine the extent to which S/S is effective for stabilizing contaminants. Residual contamination is addressed by the planned Permanent Cap, MNR, and ICs. Residuals may be further managed by addition of activated carbon prior to capping.

Sheet Pile Installation and Removal

For Alternatives 4N, 5aN, and potentially 5N and 6N, a sheet pile wall has been suggested as a means to dewater submerged areas and/or manage resuspended contaminated sediment. However, there are also risks associated with both installation and removal of the sheet pile itself. The FS suggests that sheet pile would be driven through the existing TCRA Cap. Although this approach allows coverage of the contaminated sediments during construction, it is not recommended because of the difficulties associated with driving sheet pile through the large armor rock, and achieving a tight seal between joints. Instead, it is recommended that a portion of the rock armor be removed from the sheet pile footprint, and the geotextile or geomembrane cut and peeled back to avoid damage or shifting during sheet pile installation. Activities associated with driving the sheet pile will disturb the exposed sediment causing some limited resuspension, considering that the sediment has been consolidated under the armor cap and geotextile. Additionally, the impact should be relatively small due to the small footprint required for the sheet pile.

Additional resuspension and release is likely to occur during removal of the sheet pile allowing recontamination of the cap or release of contaminants off site. The sheet pile will likely be driven through the entire depth of the contaminated sediment to achieve stability. Upon removal, sediment that adheres to the sheet pile will be subject to resuspension in the water column. Sheet pile should be removed carefully to minimize resuspension. The cap in the area from which the sheet pile was removed will need to be restored.

During the course of construction activities suspended sediments will accumulate within the enclosed area; however, considering the brackish nature of the site water flocculation and settling will maintain relatively low concentrations of total suspended solids, probably a concentration of less than 250 *mg/L*, within the enclosure. Upon removal of the sheet pile, this sediment laden water may be released allowing transport of contaminants offsite. At a minimum, it is suggested to allow time for particulates to settle after construction activities cease prior to sheet pile removal, the vast majority of the suspended solids should settle within a day. Flocculants may also be used to promote settling and create dense, strong flocs that would settle in minutes. Furthermore, dispersal of activated carbon may be used to adsorb dissolved contaminants. Once deposited on the bottom, the carbon would continue to treat contaminants on the surface.

Silt Curtain Installation and Removal

The FS recommends a silt curtain be installed for Alternatives 5N and 6N. Installation of silt curtain should not cause significant resuspension of contaminated sediment. As with sheet pile, suspended contaminated sediment and dissolved contaminants that builds up behind the silt curtain is subject to release during curtain removal; however, this quantity would be expected to be quite small considering the exchange of water that will occur at the site. Silt curtains do very little to control releases at the bottom of the water column. Consequently, use of flocculants to promote settling and/or activated carbon to adsorb dissolved contaminants would not provide much benefit immediately prior to silt curtain removal. Silt curtains should be removed by pulling both the top and bottom lines, or by furling the curtain and removing with a boat.

As noted in the TCRA Final Removal Action Completion Report (Anchor QEA 2012), issues were experienced with the use of a turbidity curtain during the TCRA implementation. The turbidity curtain was subject to river currents and tidal fluctuations, and frequently shifted position. Repositioning and management of the curtain was needed on a regular basis. The strain resulted in detachment from the anchors, and tearing of the floating boom from the submerged skirt. It was noted that in some situations, the curtains can cause more resuspension than if the curtain were not there. Despite the problems, the silt curtain was considered effective. Sheet pile barriers such as proposed for Alternatives 4N and 5aN should also be considered.

The location of the proposed silt curtains was not specified. Some distance should be maintained between the silt curtain and the work area to allow for shifting of the curtain due to tidal fluctuation. Silt curtains may also increase turbidity and scour along the bottom due to movement along the bottom as well as increased current velocities underneath the curtain; however, this would not be a concern if the silt curtain were placed over the TCRA cap.

Site Dewatering

Site dewatering is suggested in the FS for Alternatives 4N, maybe 5N, and possibly in the Western Cell for 5aN and 6N. Site dewatering in submerged areas would require isolation with sheet pile (which has been addressed), berms, cofferdam, or removable dams (geotubes). Upland excavation that occurs below the groundwater table may also require dewatering. Dewatering effluent would need to be treated or shipped to a licensed facility.

Perimeter Berm Installation and Removal

To manage water quality during construction, Alternative 5aN includes an earthen berm in shallow water (depths up to approximately 3 feet), extending to an elevation at least 2 feet above mhhw, but limited to a total height of 4 to 5 feet above the existing mudline. In greater water depths, the berm would transition into a sheet pile barrier. It is assumed that the existing TCRA cap would be removed from the berm area prior to berm construction, thus exposing the geotextile or underlying contaminated soils/sediments. Conventional earth-moving equipment would likely be used to construct the berm. Berm construction activities could disturb the underlying sediments, resulting in resuspension. It appears sediments in the berm vicinity have concentrations less than the PCL, yielding limited potential for significant loss of contaminant mass.

Presumably, the containment berm will be removed after excavation and backfilling has been completed within the enclosed area. Care should be taken during removal minimized disturbance of the backfilled area. Alternatively, the berm could be left in place to protect the site from barge strikes under high water conditions.

Removal of Contaminated Soil/Sediment/Sludge

Alternatives 5N, 5aN and 6N involve removal of varying amounts of contaminated sediment. Alternative 5N would remove soil and sediment with concentrations exceeding 13,000 *ng/kg* $TEQ_{DF,M}$ (52,000 cy). Alternative 5aN would remove soil and sediment exceeding the PCL where the water depth is 10 feet or less, and soils exceeding 13,000 *ng/kg* $TEQ_{DF,M}$ at any depth (137,600 cy total). For Alternative 6N, all soil/sediment exceeding the PCL would be removed (200,100 cy). Water-side removal may occur via dredging, although the dredge type is not specified in the FS. The FS also refers to the possibility of dewatering the work area and using land-based earth-moving equipment, particularly in the Western Cell and perhaps shallow portions of the Eastern Cell. Upland excavation would be accomplished with conventional earthwork equipment (excavators, dozers, loaders, etc.). For upland excavation below the groundwater table, ditches, sumps, wellpoint systems or deep wells are discussed in the FS for water management. Dewatering effluent may need to be treated or shipped to a licensed facility (See Site Dewatering).

Land-based removal will involve disturbance of contaminated sediments with earthwork equipment. Risks include equipment tracking contamination off site, transport of disturbed sediment via dust or rainfall runoff, as well as residual contamination that is left in place. Water spraying may need to be employed to control dust, and silt fence or hay bales to prevent transport of runoff particulates. A work plan is needed to sequence excavation in order to minimize cross contamination of clean areas. Periodic equipment cleaning, such as prior to leaving the site may also be used to avoid spreading contamination.

Upon excavation, the material would likely be transported to an area where it is stockpiled prior to dewatering. Areas used to stockpile contaminated materials should also be managed to control dust and runoff, such as covering stockpiled materials, and the use of silt fence barriers. There are also risks associated with spills during transport to the disposal facility and releases from the landfill itself, which are not addressed here. Depending on the results of monitoring, a cleanup pass may be used to remove the top layer of soil with residual contamination.

For dredging activities, management strategies are needed to control resuspension, contaminant release, and residual contamination. Engineered barrier controls (sheet pile and earthen berm for Alternative 5aN, turbidity curtain for Alternatives 5N and 6N) are included in the FS, and would be appropriate for containment of resuspension. Although, the FS assumes a certain degree of leakage of these barriers, careful installment and management will optimize their efficiency.

Controls are needed for contaminated residuals that are left in place. For Alternatives 5N, 5aN and 6N, the FS calls for covering the excavated areas with backfill. Alternative 5N would be further covered with a permanent rock armor cap. Therefore, the dredge cut should be designed to leave a slope no greater than 1V:5H to permit placement of a stable cap or backfill. Monitoring post-dredging should be done to determine the need for controls to manage residuals left in place. A cleanup dredging pass may be useful to remove some of the residuals. A layer of carbon placed prior to backfilling, or blended with the backfill material would protect against contaminant releases from residuals (in both upland and submerged areas). Activated carbon has been shown to sequester dioxins and furans and reduce bioavailability (Chai *et al.* 2012, USEPA 2013). Carbon (or other amendments) may be delivered using engineered amendments such as AquaGate+™, which may both increase cohesion to prevent erosion, as well as adsorb contaminants. MNR is also planned, as natural deposition is predicted to occur. Institutional controls are also planned for long-term management of contaminants left on site.

Permanent Cap Construction

Alternatives 3N, 4N, 5N and 5aN include different variations of construction of a Permanent Cap. Each of the alternatives includes addition of armor rock and rubble mound protection to the existing Armor Cap to flatten the slopes and improve stability. A protective perimeter barrier consisting of a submerged rock berm would also be constructed to protect the cap from vessel traffic. Alternatives 3N and 5aN involve placement of armor rock over top of the existing cap and construction of the rock berm.

For Alternative 3N, there is little risk associated with resuspension of contaminated sediments during Permanent Cap construction, as the existing TCRA cap will be in place and intact. With Alternative 5aN, in the area adjacent to that planned for Permanent Cap construction, the existing cap will have been removed, and contaminated sediment excavated greater than the PCL), and backfilled with 6 inches clean sediment. Assuming the Permanent Cap will be constructed after placement of backfill, care should be taken to avoid disturbing the backfill. It is unclear whether the Permanent Cap area will be inside or outside the sheet pile and berm enclosure used to control resuspension during excavation, but presumably it would be constructed with the sheet pile wall and berm in place to control potential releases during cap placement.

In addition to the rock berm and placement of rock over the existing cap, Alternatives 4N and 5N also include construction of the permanent cap over areas of contaminated sediment where the existing TCRA cap was removed. Replacing cap that was removed is referred to as armored cap restoration and discussed below.

Restoration of Armor Cap

For Alternatives 4N and 5N the existing TCRA cap will be removed in areas to allow S/S (4N) or removal (5N) of material with TEQ > 13,000 *ng/kg*. After S/S or excavation, the Armored Cap will be replaced, which will include replacement of the armor rock layer, geomembrane and geotextile. Geomembrane or geotextile and armor rock should be placed carefully to minimize resuspension. It was noted in the TCRA Final Removal Action Completion Report (Anchor QEA 2012), that site monitoring of turbidity resulting from tugboat and barge movement around the TCRA Site during water-side placement activities showed no exceedances that would trigger additional BMPs. However, resuspension could be greater for Alternative 5N due to the presence of residuals and the loss of sediment strength from recent disturbance induced by the removal operation.

Plans for Alternative 4N include a sheet pile wall which will retain resuspended material. Presumably the sheet pile will remain in place until after the armor cap is restored. Alternative 5N may incorporate use of silt curtain rather than sheet pile walls for containment, which will provide some retention of resuspended solids. For Alternative 4N, the replacement will occur on top of stabilized soil/sediment which should improve cohesion and reduce resuspension. The Western Cell area is primarily upland, whereas the area in the Eastern Cell is submerged, although sheet pile containment is planned, with possible dewatering. Assuming the site is not dewatered, concentrations of resuspended contaminated sediment may have built up during S/S activities. Settlement of the resuspended solids should be allowed (either waiting a period of time, or enhancing settling by flocculant addition) prior to cap placement to avoid contaminating the clean cap. The cap placement should be sequenced so as to minimize equipment contact with the contaminated soils/sediments.

Addition of Residuals Cover/Backfill

Alternatives 5N, 5aN, and 6N would include backfilling the areas that are excavated with 6-inch thick cover. The backfilled areas in Alternative 5N would subsequently be covered with an armored cap. Natural deposition is further expected to cover the site; however, deposition rates are low in most areas, particularly shallow areas. For Alternative 5N, soils/ sediments exceeding 13,000 *ng/kg* $TEQ_{DF,M}$ would be removed prior to backfilling. For Alternatives 5aN and 6N, the soils/sediment exceeding the PCL would be removed, thus backfilling would occur over top relatively clean soil/sediment, with the exception of residuals. Backfill should be place in such a manner as to minimize disturbance of the residuals and underlying material. This includes sequencing the activity such as to minimize equipment tracking between backfilled and exposed areas.

Treatment/Dewatering Excavated Sediment

Landfills have been tentatively identified for disposal of materials from the site. Sediment dewatering by amendment prior to transporting for disposal is suggested for Alternatives 5N, 5aN and 6N in order to reduce potential mobility of contaminants during transportation and at the disposal facility. An off-site facility with water access has been suggested for processing dredged sediment prior to shipment. The facility would need the capacity to stockpile excavated material, treated material, and armor rock, as well as space for treatment. Institutional controls such as fencing and warning signs would also be needed at the off-site facility. Material stockpiles (both untreated and treated) would need to be managed to control runoff using covers for the stockpiles and silt fencing.

Dust controls may also be needed. Requirements for shipping hazardous materials would be followed, including packaging in appropriate containers and proper labeling. The FS notes that water generated from sediment dewatering would need to be treated on-site for discharge, or collected and transported off-site for disposal, depending on water quality.

Summary of BMPs

Several alternatives have been presented in the FS for remediation of the San Jacinto River Waste Pits Superfund Site. BMPs have been examined for the remediation activities planned for each of the alternatives.

1. Alternative 1N (no further action) and Alternative 2N (implementation of MNR and ICs) will not disturb the existing TCRA Armor and would not generate resuspension, residuals or release that would require BMPs outside the planned monitoring and maintenance.

2. Alternative 3N includes addition of armor stone to flatten slopes of the TCRA cap, as well as construction of a submerged perimeter berm to protect the Permanent Cap. As the TCRA cap will remain in place providing protection from the underlying sediments, generation of resuspension or releases is unlikely, and therefore does not require BMPs beyond the planned MNR and ICs.

3. Alternative 4N requires partial removal of the TCRA cap, S/S of the underlying sediments, restoration of the armored cap and implementation of MNR and ICs. The slopes of the remaining cap would be flattened and a perimeter berm installed to protect the Permanent Cap. A number of BMPs are recommended to manage resuspension from Alternative 4N activities. Installation of sheet pile walls is planned. As noted previously, better seals between joints may be achieved if the existing armor cap is removed from the sheet pile footprint prior to installation. The sheet pile should be in place to capture resuspension during removal of the existing TCRA cap, S/S, and restoration of the armored cap. If dewatering is conducted, the effluent may need to be treated or shipped to a licensed facility. Controls such as silt fence are needed to manage runoff from upland areas of the site. Application of water may be needed to control dust. The removed cap material should be handled to avoid spreading contamination or recontaminating the

site. Removed geotextile and geomembrane and contaminated armor stone should be disposed in appropriate containers for transport to landfill. As discussed in the FS, direct loading into trucks for transport to the disposal facility may eliminate the need for stockpiles. Periodic equipment cleaning and decontamination of trucks prior to leaving the site may reduce tracking contaminants off site. A plan to sequence cap removal, S/S and cap restoration activities is needed to minimize equipment tracking between clean and contaminated areas. This may include segmenting the site into subareas. Upon completion of S/S, monitoring should be conducted to determine residual contamination. Residual contamination is addressed to some extent by the planned Permanent Cap, MNR and ICs. Activated carbon may be dispersed in the water column or placed on the stabilized surface prior to capping as needed to further manage resuspension or releases in the water column or surface residuals. Flocculant may also be used to limit releases of resuspended solids during removal of the sheet pile.

4. Alternative 5N requires partial removal of the TCRA cap, and excavation of the underlying sediments, followed by restoration of the armored cap, enhancement of the remaining cap, perimeter berm installation, MNR and ICs. Rather than sheet pile walls, silt curtain is suggested in the FS to manage resuspended material from Alternative 5N activities. As experienced in the TCRA cap construction (Anchor QEA 2012), silt curtains can be problematic and will need to be managed throughout the duration of the construction activities. Sheet pile walls would provide much better control of contaminant releases, residuals and resuspension for these highly contaminated materials. As with Alternative 4N, flocculants or activated carbon may be needed to treat resuspended solids or dissolved contaminants trapped by the sheet pile wall prior to its removal, but would not provide much benefit if a silt curtain were used for resuspension control. For upland activities, runoff controls (silt fence and/or hay bales) and dust control are needed. As used in the TCRA activities, a temporary water control berm may be installed to reduce inundation of the upland area by tidal water. A work plan is needed to determine optimal sequence for working in different areas of the site to minimize cross contamination, as well as decontamination of equipment prior to

exiting the site. Staging the construction, may also reduce the surface area exposed at a given time, reducing the risk of contaminant releases during flood events. Residual contamination may be addressed by the use of a cleanup pass of either the dredge or land-based equipment. Prior to cap restoration, the area will be backfilled prior to removal of the resuspension BMP. If post-excavation monitoring indicates the need for additional residual management, activated carbon could be placed to provide sequestration of contaminants.

5. Alternative 5aN includes more extensive removal of the TCRA cap and excavation of underlying sediments which would be subsequently backfilled. Armor stone would be added to flatten the remaining existing cap slope, and the perimeter berm would be constructed along with MNR and ICs. Alternative 5aN includes the use of a perimeter berm in shallow areas which would transition to sheet pile walls in deeper water. The berm and sheet pile would serve to contain resuspended sediments during construction activities. As with Alternatives 4N and 5N, cross contamination should be minimized through work sequencing and decontamination of equipment. Removed cap material should be properly contained and shipped to a landfill, although clean armor rock may be reused. Other BMPs for upland areas include the use of silt fence to control runoff and water spraying for dust control. Water control berms could also be used to minimize tidal inundation of upland areas. Resuspended solids trapped behind the sheet pile/berm could be managed by allowing it to settle, or by addition of flocculant to promote settling. Similarly, dissolved contaminants could be treated by addition of activated carbon. Activated carbon may also be used to treat residual contamination left on the surface of the excavated area prior to backfill. A cleanup pass may also be useful to remove residual contamination from the surface. A residual cover/backfill should be placed carefully to avoid disturbing the underlying soil/sediment before removal of sheet pile walls or silt curtains. An off-site facility will likely be used to stockpile materials and treat excavated sediment prior to transportation to a landfill. The off-site location will also require dust and runoff controls as well as institutional controls. Water

from dewatering would need to be treated on-site for discharge or collected and transported off-site for disposal.

6. Alternative 6N involves complete removal of the TCRA cap and excavation of all soils and sediments exceeding the PCL, including the area near the Upland Sand Separation Area. The areas would be subsequently backfilled, and ICs and MNR implanted. A permanent cap is not included in this alternative. To manage resuspension, a silt curtain is planned, although sheet pile was mentioned as a possibility. Sheet pile would likely be more effective for controlling resuspension. Resuspended solids trapped behind the silt curtain should be allowed to settle prior to curtain removal. Residual contamination may also be managed by addition of activated carbon to the surface either before backfilling or as a component of the backfill material. The residual cover/backfill should be placed carefully to avoid disturbing the underlying soil/sediment before removal of sheet pile walls or silt curtains. Silt fence is recommended to manage upland runoff, and water spraying for dust control at both the upland portion of the SJRWP site, as well as at the off-site staging area.

Development of New Full Removal Alternative to Minimize Sediment Resuspension and Residuals during Dredging/Removal

Alternative 6N involves complete removal of the TCRA cap and excavation of all soils and sediments exceeding the PCL, including the area near the Upland Sand Separation Area. The areas would be subsequently backfilled, and ICs and MNR employed. A permanent cap is not included in this alternative. To manage resuspension, a silt curtain is planned, although sheet pile was mentioned as a possibility. Sheet pile would likely be more effective for controlling resuspension. Additionally, virtually all releases by resuspension and erosion of residuals could be eliminated by excavation in the dry. Evaluation of a new full removal Alternative 6N* incorporating these BMPs to the extent practicable is presented below and compared with Alternative 6N as proposed in the Feasibility Study.

Description and Implementation of New Full Removal Alternative

The proposed full removal alternative is an enhancement of Alternative 6N using enhanced BMPs to control contaminant releases during and following implementation. The alternative consists of full removal of materials exceeding the PCL. All material above the PCL located beneath the Armored Cap or at depth in an area to the west would be removed to the extent practicable. This would involve removal of approximately 200,000 cy of material as well as the existing Armored Cap within the footprint of the Eastern and Western Cells, inside the original berms, and in the northwestern area. The dredged area would then be covered with a layer of clean fill. Armored cap would be left in place where the sediment contaminant concentration is below the PCL. These areas include the area west of the western berm and north of the Eastern Cell, including a deeper area ranging in elevation from -4 to -10 ft NAV88.

Implementation of the alternative includes the following operations and components and could be performed in stages (one cell or area at a time):

Western and Eastern Cells:

1. Removal of armored cap from the footprint of the berms.

2. Construct or raise berms to desired elevation (e.g., the 10-yr flood stage) to enclose cell and prevent transport of resuspended contaminated sediment. Due to construction limitations, the eastern and northern berm of the Eastern Cell would be built where the surface sediment elevation is no lower than about -3 ft NAV88 and would connect from the northern end of the central berm to the eastern end of the southern berm. Enclosure of only shallow water areas (elevations above about -3 ft NAVD88) with a sheet pile wall and berm will reduce releases nearly as well as enclosing the entire TCRA cap area since the high sediment $TEQ_{DF,M}$ concentrations are nearly all in these shallow areas.

3. Install sheet pile wall within berm to strengthen and seal berm to aid dewatering; enhance berm as needed to accommodate design flood pressure loading on wall; use joint sealants to reduce potential leakage rates; and establish top elevation to provide protection from larger floods (e.g., 25-yr or 50-yr floods). The design elevation should balance the safe

design loading with the design flood stage and wave heights as well as the impacts of overtopping the wall.

4. Armor external side of berm with removed armor cap material to control erosion.

5. Dewater cell to the extent practicable and treat water as needed to control releases.

6. Remove armored cap and geotextile within cell in the dry to the extent practicable.

7. Remove contaminated sediment in the dry to the extent practicable. The removed material will be dewatered or solidified for disposal in an off-site facility. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. Some operations, such as water treatment, could be barge mounted.

8. Cover the dredged surface with two layers of clean fill to limit intermixing of residuals with fill.

9. Remove sheet pile walls. Flatten berm and cut slopes to promote stability.

Northwestern Area:

1. Install silt curtains in deeper waters above the armored cap outside the footprint of the area to be dredged, connecting to existing or newly constructed berms and enclosing the area.

2. Construct berms or install sheet pile wall in shallow water areas to limit the flow through the area and control contaminant releases.

3. Remove armored cap and geotextile in the wet.

4. Remove contaminated sediment in the wet to the target depth. Verify that the contaminated sediment inventory had been removed except for the generated residuals. Remove residuals in a cleanup if practicable. The removed material will be dewatered or solidified for disposal in an off-site facility.

5. Cover the dredged surface with multiple layers of clean fill to limit intermixing of residuals with fill.

6. Remove sheet pile walls. Flatten berm and cut slopes to promote stability. Remove silt curtains.

Resuspension and Residuals Estimates Cell/Area Wide

In order to develop a new full removal alternative, 6N*, the impoundment area was divided into sections developed during the TCRA cap installation. The area was divided into a Western Cell, Eastern Cell and a Northwestern Area with each having different site conditions including contaminant concentrations and permanent cap cover. The recommended approach to achieve complete removal would be by dredging and excavating incrementally and completing activities in such a way that releases are reduced by best management practices such as berm construction and utilizing sheet pile walls.

Western Cell

The Western Cell, which typically sits above the water surface and is temporarily submerged during storm events, is by all accounts a stable surface that has been protected by the installation of a geomembrane, geotextile and rock riprap. The Western Cell is also protected by berms along the east and west sides of the cell. This cell may be excavated in the dry by constructing a berm on the north side of the cell and installing a sheet pile wall through the berms to raise the effective height of the berms and provide protection from storm flows, tidal fluctuations, waves and up to 10-year flood events. Installing the sheet pile walls at the top of the berms would provide more support for the wall, facilitate sealing joints between the sheet piles above the berm, and reduce the potential leakage through the wall and berms since the wall would not be exposed to the water column except during very high flow conditions. Excavation and backfilling in the dry will eliminate potential resuspension and residuals releases.

Eastern Cell

The Eastern Cell is open on the north and east sides with a berm on the western and southern boundaries. This cell was repaired as a part of the original TCRA remediation and has an armored cap in place that consists of both recycled concrete and natural rock with geotextile. To minimize releases it is advised that the Eastern Cell be divided into two sections: shallow water with depths no greater than about 4 ft and deep water that encompasses the northwest section of the Eastern cell and has depths from 10-15 ft. By dividing the cell into two sections, releases can be minimized and incremental releases can be better estimated for the cell. It should also be noted that an area of roughly 2.5 acres of the Eastern cell is not included in this analysis as the sediment concentrations are well below the PCL as stated in the Feasibility Study.

Shallow Water. The shallow water portion of the Eastern Cell is the largest section to be removed, as shown in Table 12-1. The surface area is approximately 5.7 acres and 46,000 c.y. of sediment are to be dredged from the area assuming an average dredge depth of 5 feet. Since this area is located in shallow water, it can easily be confined with a sheet pile wall to reduce the releases from dredging to just the releases to the water column and not the residuals. Sheet pile should be installed along the north and east sides, tying in to the existing berms on the south and west sides of the area as well as the former berm on the east side. If the deep water section of the Eastern Cell were confined with its sheet pile wall prior to dredging the shallow water section of the Eastern Cell, a silt curtain could be substituted for the sheet pile wall along the northern boundary of this shallow water section due to potential construction issues from the soft fill conditions. With the installation of the sheet pile wall, the releases predicted in this section will be the result of the removal of the TCRA cap including geotextile and rock rip rap, suspended material during the installation and removal of the sheet pile wall, and an assumed loss of all material suspended during dredging operations.

Deep Water. The deep water portion of the Eastern Cell is a small section along the northern edge of the cell and connecting to the Northwestern Area. This section has a deeper channel running through it where the depths average 10 feet and are 15 feet in the deepest portion. Smaller than the shallow water area, this section can be dredged with either a turbidity curtain or a sheet pile wall to control the sediment releases while allowing interchange of water to reduce the net force on the controls. Due to its small size of 1.8 acres, the area will be easy to confine with either method.

Table 12-1. Cell and Area Parameters

Parameter	Western Cell	Northwestern Area	East Cell: Shallow Water	East Cell: Deep Water
Surface Area (acres)	4.1	1.7	5.7	1.8
Volume Dredged (cy)	66,700	19,496	46,074	14,222
Average Surface Sediment Concentration (ng/kg)	6471	7799	6048	5127
Weighted Average Contaminant Concentration (ng/kg)	15,806	3095	2394	2023

The existing TCRA permanent cap in this area consists of geotextile and natural stone armoring. Some releases will occur during the removal of the cap, but they will be minimal compared to potential releases from dredging and generated residuals. The sheet pile wall should be installed slightly outside the limits of the section and outside of the deep channel.

This will allow for more stable conditions with the sheet pile wall. The wall should also be designed that it does allow for tidal interchange. The wall should be installed in a U-shape with the deepest portion left open allowing flow into and out of the containment. In combination with the wall, a turbidity curtain should be used to help contain some of the suspended materials. For the purposes of this analysis, it was assumed that the wall completely enclosed the area but through the interchange a worst-case scenario of all resuspended material during dredging activities was lost. It was assumed that the dredging residuals would not be subject to erosion due to the control of bottom currents by the wall. It was further assumed that the any disturbed residual material would settle before the sheet pile wall was removed. Other releases include the minor loss of sediment during the construction and removal of the sheet pile wall.

If only a turbidity curtain were used to confine the area, then releases will be considerably greater due to potential erosion and transport of a portion of the dredging residuals. All resuspended material from TCRA removal and dredging activities will be lost below the turbidity curtain. It was also assumed that 20% of the generated residuals will lost below the turbidity curtain. Analyses of both control methods were completed to provide a comparison of the releases of both methods.

Northwestern Area

The Northwestern Area is a steeply sloped, deep water extension of the Western Cell, which was originally separated by a berm. The area is a relatively small section of 1.7 acres. The TCRA armored cap is composed of varying thicknesses of recycled concrete with a blended granular filter instead of a geotextile. The average depth in this section is 15 feet, which makes it somewhat impractical to confine with a sheet pile wall. To construct a wall or cofferdam that provides protection from flood flows, the sheet piles would have to be driven into the sediment as much as 40 feet. With a sheet pile wall, removal would need to be performed in the wet, but removal could be performed in the dry with a cofferdam. Building a cofferdam to enclose this area could require several years to construct and thousands of truckloads of materials and would be expected to cost about five times as much as a sheet pile wall. The most practical method of controlling resuspended material would be the use of a turbidity curtain. For this analysis, it was assumed that all resuspended material would be lost through the turbidity curtain including releases from the removal of the armoring, dredging activities and 20% of the generated residuals that would be lost through the bottom due to currents. If a sheet pile wall were used, much of the resuspended material would be expected to be released, while none of the generated residuals would be eroded and transported. If a cofferdam were used, only minor releases of sediment during the construction and removal of the cofferdam would occur if removal is performed in the dry.

<u>Sheet Pile Wall</u>

A sheet pile wall is recommended for both portions of the Eastern Cell as a means to control sediment releases during remedial actions; however, both sections of the Eastern Cell will be dredged in the wet and will both experience some releases due to the construction and removal of the sheet pile wall. Incorporation of a berm into sheet pile wall design would provide increased stability for the wall. The berm material could be used as fill or cover material for the site after dredging is completed.

Assumptions

The basic assumptions used in this analysis are the same as used in the resuspension calculations used in Task 11. These assumptions can be found in Table 12-2. It is assumed that the contaminant concentration of the surrounding sediment in the deep water portions will be 1,000 ng/kg while the average surficial concentration will be roughly 6,000 ng/kg in the shallow water sections based on information provided in the Feasibility Study. The sheet pile wall will be required to be driven through the soft clay layer and into the sand layer as suggested in Task 11. The sheet pile wall in both sections of the Eastern Cell will be constructed outside of the limits of the deep water and in water with an average depth of no more than 5 ft, allowing for a more stable wall. Tidal water exchange is also allowed to preserve stability. Sediment properties and sheet pile wall properties were assumed to be the same as those listed in Task 11 in Table 11-1.

Equations

The methods used for determining the resuspended sediments can be found in Table 12-2 and are the recommended methods presented in *Resuspension Factor Approach for Estimating Dredging-related Sediment Resuspension* (Hayes *et al*., 2007) and referenced in the *Technical Guidelines for Environmental Dredging of Contaminated Sediments* (Palermo *et al*., 2008).

Results

The results from the sheet pile wall releases analysis can be found in Table 12-3. The results present both a mass of suspended solids and contaminant lost as well as a daily loss rate. The releases for the shallow water are considerably more due to the larger amount of sheet pile being installed and removed as well as the fact that the sheet pile wall is running through the highest surface contaminant concentrations along the northern boundary of the shallow water area.

Table 12-2. Equations Used for Resuspension Calculations during Sheet Pile Construction and Removal

Parameter	Equation
Mass Disturbed (kg)	$m = t * A * \rho_t$
Contaminant Release @ Assumed Sediment Conc. (ng)	$m_{cr} = m * c$
Volume of Sediment to Stick to Both Sides of Sheet Pile (ft^3 sediment / ft^2 wall)	$Vs = \Delta s * Aw * 2$
Mass of Sediment / ft^2 of Wall (kg/ft^2 wall)	$m_w = Vs * \rho_b$
Mass (kg)	$m_r = m_w * L_w * D_s$
Contaminant Release (ng)	$m_{cr} = m_r * c$

TCRA Cap Removal

The process of removing the TCRA is completed by first removing the rock riprap and then removing the geotextile. This process results in some amount of material disturbed and material sticking to the surface of the geotextile and washed as it pulled through the water column. The amount of resuspended sediment was estimated for all three areas. The shallow water area could be removed in the dry once the sheet pile wall is installed, but for the purposes of this analysis was included as a worst case.

Assumptions

As previously stated in Task 11, the process of removing the geotextile from the surface will act similar to that of a bucket dredge with sediment stuck to the fabric that will wash off as it is pulled through the water column. Assumptions for the removal of the TCRA cap can be found in Table 12-4. The surface area of each section was estimated and the sediment characteristics were assumed to be the same as assumed during the sheet pile wall construction and removal. Sediment was assumed to be slightly to moderately sticky with an adjusted thickness of 3.375 mm adhering to the geotextile. An average surface concentration was estimated

Table 12-3. Resuspended Sediments During Sheet Pile Construction and Removal in Eastern Cell

Parameter	Construction		Removal	
	Shallow Water	Deep Water	Shallow Water	Deep Water
Mass Disturbed (kg)	2470	1810	5450	4000
Solids Loss Rate (kg/day)	33	33	73	73
Contaminant Release @ assumed Sed. Conc. (mg)	14.8	1.81	32.7	4.00
Rate of Contaminant Release (mg/day)	0.198	0.033	0.436	0.073

for each area incrementally based on information provided in the Feasibility Study. It was also assumed that during removal 50% of the sediment would wash from the geotextile and all sediment suspended would be lost.

Equations

The methods used for determining the resuspended sediments can be found in Table 12-5 and are the recommended methods presented in *Resuspension Factor Approach for Estimating Dredging-related Sediment Resuspension* (Hayes *et al.*, 2007) and referenced in *Technical Guidelines for Environmental Dredging of Contaminated Sediments* (Palermo *et al.*, 2008). These methods are the same as were used to determine resuspended sediments during sheet pile wall construction and removal.

Results

Results from the incremental analysis of sediment resuspended during the TCRA cap removal can be found in Table 12-6. The average surface sediment concentration was estimated using data provided in the Feasibility Study and was averaged across the footprint for each alternative. The largest quantity of sediment and contaminant to be lost comes from the shallow water portion of the Eastern Cell which also has the largest surface area to be disturbed. Combined, it is estimated that 31 metric tons of sediment will be resuspended during the removal process and only 0.2 grams of contaminant will be released during this process.

Table 12-4. TCRA Cap Removal Assumptions

Parameter	Value	Parameter	Value
NW Area (acres)	1.7	**Characteristic sediment thickness Δs_c (mm)**	4.5
East Cell: Shallow Water (acres)	5.7	**Adjusted sediment thickness Δs (mm)**	3.375
East Cell: Deep Water (acres)	1.8	**Sediment resuspended during ascent through water column (%)**	50
Sediment Stickiness	Slightly --> Moderate	**Surface Soil Density (kg/m³)**	500

Table 12-5. Equations Used to Estimate Sediment Resuspension During Geotextile Removal

Geotextile Removal Equations	
Mass Resuspended (kg)	$m_r = \Delta s * A * \rho * \%R$
Contaminant Release (ng)	$m_{cr} = m_r * C$

Dredging

Dredging can be an effective way to remove large quantities of sediments, but this method can lead to exposure, releases and lasting effects if proper planning is not completed and best management practices are not used. Dredging is being considered for all areas, but releases should only be expected when removal is completed in the wet as in the Northwestern Area and the Eastern Cell. Excavation of the Western Cell will be performed in the dry and will have no releases during the removal process.

Table 12-6. Incremental Analysis of Sediment Resuspended During Geotextile Removal

Parameter	NW Area	Eastern Cell: Shallow Water	Eastern Cell: Deep Water
Area Disturbed (m^2)	6,880	23,067	7,284
Average Surface Sediment Concentration (ng/kg)	7,799	6,048	5,127
Sediment Mass Resuspended (metric tons)	6	19	6
Contaminant Mass Resuspended (g)	0.045	0.118	0.032

Assumptions

Many of the assumptions stated in Task 11 for dredging resuspension are applicable to the analysis of the Northwestern Area and Eastern Cell. A mechanical clamshell dredge is recommended as the best method of material removal for areas to be dredged in the wet, while an excavator is recommended to be used in a land side operation or shallow water. The Northwestern Area is assumed to utilize a turbidity curtain as a means of controlling releases while the deep water section of the Eastern Cell is analyzed with both the use of a turbidity curtain and a sheet pile wall to illustrate the effectiveness of the alternative BMPs and present the best method of removal.

For this analysis, the clamshell bucket was assumed to fit the description of the characteristic clamshell bucket as described in Hayes *et al.* (2007) and the resuspension factor method was used to determine the possible resuspension for the site conditions. Sediment was assumed to be slightly to moderately sticky with an average thickness of 4.5 mm stuck to the bucket. The assumption of an average dredge depth of 10 feet plus a 1 foot over-dredge is applied in this analysis; however, the average water depth is assumed to be 15 feet in both sections. All assumptions made in the determination of the Resuspension Factor can be found in Table 12-7.
A weighted average sediment concentration was calculated based on the results of the grab samples and sediment cores as presented in the Feasibility Study Figure 2-4. The sediment concentrations for each area

were averaged across the area specific footprint. Assumptions for the weighted average sediment concentration and dredge area can be found in Table 12-8.

Equations

Methods used to determine the resuspension factor and the resuspended sediment mass were completed using techniques described in Hayes *et al.* (2007) for the determination of the resuspension factor based on characteristic properties. The equations and constants used to determine the resuspension factor can be found in Table 12-9 and the equations used to determine the sediment and contaminant mass resuspended can be found in Table 12-10.

Results

The determination of the Resuspension Factor for each scenario can be found in Table 12-11. While it may be possible to excavate the shallow water section of the Eastern Cell in the dry if a berm were constructed, the estimated resuspension was calculated for dredging in the wet for comparison. The parameters used in this method were determined by making assumptions on dredging characteristics as described above. With each area having a different average water depth, they each have a slightly different Resuspension Factor. The Northwest Area has the greatest factor of 0.84 percent since it has the deepest water.

An estimation of the resuspension possible during mechanical dredging can be found in Table 12-12. An incremental analysis of each respective footprint was used to estimate the potential resuspension of fine sediments for the dredging activities of each of the areas. The total mass of sediment removed was calculated assuming an average density throughout the sediment of 950 kg/m^3. As the method of determining mass rate of sediment release accounts for only the fine sediments (f_{74}), as seen in Table 12-10, the bulk sediment concentration was adjusted to reflect the fine sediments that are resuspended during dredging activities. The bulk sediment concentration was estimated incrementally based on sediment core data provided in the Feasibility Study and was then adjusted based on the volume of fines in the sediment.

Table 12-7. Dredging Resuspension Assumptions

Property	Value	Property	Value
Bucket Volume, Vb (m^3)	7.65	**Characteristic Descent Velocity, Ǔd (m/s)**	1.2
Equivalent Diameter (m)	2.45	**Descent Velocity, Ud (m/s)**	1
Equivalent Surface Area (m^2)	7.24	**Characteristic Pre-dredge Water Depth, hc (m)**	8.3
Average Dredge Depth (ft)	NW Area: 6	**Pre-dredge Water Depth, h (m)**	NW Area: 4.5
	Eastern Cell: 4		Eastern Cell Deep: 3
Sediment Removal Thickness (m)	1.2		Eastern Cell Shallow: 1.5
Over dredging Depth (ft)	1	**Characteristic Ascent Velocity, Ǔa (m/s)**	1.6
fsed	2	**Ascent Velocity, Ua (m/s)**	1.2
Characteristic Sediment Thickness Δs_c (mm)	4.5	**f74 (%)**	NW Area: 60
Adjusted Sediment Thickness Δs (mm)	3.375		Eastern Cell: 75
In Situ Solids Concentration, Cs (kg/m^3)	950	**Dredge Rate , Ṽs (m^3/hr)**	25.5

Table 12-8. Mechanical Dredging Incremental Analysis Assumptions

Parameter	Northwestern Area	Eastern Cell: Deep Water	Eastern Cell: Shallow Water
Volume Dredged (c.y.)	19,496	14,222	46,074
Total Dry Sediment mass Dredged assuming 950 kg/m³ (kg)	1.42E+07	1.03E+07	3.35E+07
Dry Mass of Fine Sediments (kg)	8.50E+06	7.75E+06	2.51E+07
Days Required	24	18	58
Average Bulk Sediment Concentration (ng/kg)	3,095	2,023	2,394

Table 12-9. Dredging Resuspension Equations

Parameter	Equation	Parameter	Equation
Characteristic Resuspension Factor, Rc (%)	$Rc = r_1+r_2+r_3+r_4$	**Resuspension Factor, R'c (%)**	$R'c = r'_1+r'_2+r'_3+r'_4$
r'_1	$r'_1 = faa*fdv*ftd*fsed*r_1$	**r'_3**	$r'_3 = [(fla*wla+fbw*wbw+fea*web)*fta+fsw*wsw]*fsed*r_3$
faa	faa = 1.025*(π/Vb)^(1/3)	**fbw**	fbw = 1.35*(π/Vb)^(1/3)
fdv	fdv = (Ud/Ǔd)^2	**fsw**	fsw = (Ua/Ǔa)^2
ftd	ftd = (h*Ǔd)/(hc*Ud)	**fta**	fta = (h*Ǔa)/(hc*Ua)
r'_2	$r'_2 = fbv*fec*fsed*r_2$	**r'_4**	$r'_4 = fso*fsed*r_4$
fbv	fbv = (Ud/Ǔd)^2		

Table 12-10. Sediment Loss Equations

Parameter	Equation
Mass rate of sediment release, g, (g/s)	**g = Rc*(f_{74}/100)*(($\tilde{V}$s*Cs)/360)**
Mass of sediment released, m (kg)	**m = g(kg/day) * days required**

Residuals

Residuals are the result of sediment that falls back or is dislodged, sloughed or left during dredging activities. Many different factors affect the amount of residuals and there is currently no commonly accepted method to accurately predict the post-dredging residuals. Palermo *et al.* (2008) recommends in the *Technical Guidelines for Environmental Dredging of Contaminated Sediments* to assume that the residual contaminant concentration be equal to the depth-averaged contaminant concentration of the sediment removed in the last pass, which would include residuals from the previous pass. This method is further detailed in Palermo *et al.* (2008) and was used in this analysis as was used in the residuals analysis in Task 11.

Assumptions

All forms of dredging result in some amount of residuals, typically averaging between 5 and 9% lost for strongly hydrophobic contaminants (Patmont, 2006) with this percent varying based on type of equipment, sediment characteristics, and number of dredge lifts. A worst-case scenario of 9% residuals was selected due to the soft materials and tendency for mechanical clamshell dredges to lose more sediment creating more residuals. The dredge plan was also assumed based on the weighted average contaminant concentration in the respective area. For the Northwestern Area the sediment profile was determined to only require an average dredge depth of 6 feet plus a 1 foot of overdredging, which would adequately remove sediments to the cleanup level. For the deep water section of the Eastern Cell, only an average dredge depth of 4 feet plus 1 foot of overdredging is needed. It was assumed that the residuals layer would be less dense than the underlying material and would have a density of 500 kg/m^3. All assumptions can be found in Table 12-13 and a suggested dredge plan found in Table 12-14.

Table 12-11. Resuspension Factor for Clamshell Bucket

Characteristic Resuspension Factor, R (%)	Northwestern Area	Deep Water Eastern Cell	Shallow Water Eastern Cell
Loss during descent , r1	0.01	0.01	0.01
Loss during bucket impact, r2	0.09	0.09	0.09
Loss during ascent , r3	0.15	0.15	0.15
Loss during slewing , r4	0.25	0.25	0.25
r'1 = faa*fdv*ftd*fsed*r1			
faa	0.753	0.753	0.753
fdv	0.694	0.694	0.694
ftd	0.661	0.441	0.220
r'1	0.007	0.005	0.002
r'2 = fbv*fec*fsed*r2			
fbv	0.694	0.694	0.694
fec	1	1	1
r'2	0.125	0.125	0.125
r'3 = [(fla*wla+fbw*wbw+fea*web)*fta+fsw*wsw]*fsed*r3			
wla	0.2	0.2	0.2
fla	1	1	1
wbw	0.05	0.05	0.05
fbw	1	1	1
web	0.65	0.65	0.65
fea (assume)	1	1	1
wsw	0.1	0.1	0.1
fsw	0.563	0.563	0.563
fta	0.734	0.490	0.245
r'3	0.215	0.149	0.083
r'4 = fso*fsed*r4			
fso (assume)	1	1	1
r'4	0.5	0.5	0.5
Rc	0.847	0.779	0.710

Table 12-12. Incremental Analysis of Total Resuspended Sediments during Mechanical Dredging

Parameter	Northwestern Area	Eastern Cell: Shallow Water	Eastern Cell: Deep Water
Volume Dredged (c.y.)	19,496	46,074	14,222
Total Dry Sediment Mass Dredged assuming 950 kg/m³ (metric tons)	14,160	33,465	10,330
Dry Mass of Fine Sediments Dredged (metric tons)	8,496	25,098	7,747
Days Required	24	58	18
Average Bulk Sediment Concentration (ng/kg)	3,095	2,394	2,023
Fine Sediment Concentration (ng/kg)	5,158	3,192	2,697
Fine Sediment Release Rate (kg/day)	2,953	3,095	3,394
Dry Mass of Fine Sediments Resuspended (metric tons)	72	178	60
Contaminant Mass Resuspended (mg)	371	569	163
Contaminant Release Rate (mg/day)	15	9.9	9.2

Table 12-13. Assumptions Made for Residuals Estimate

Parameter	Value
Assessment	Worst-case Scenario for Potential Residuals
Residuals Left (%)	9
Assumed Residuals Density, ρ (kg/m³)	500

Equations

The following method used to determine the residuals was presented in Palermo *et al.* (2008) and is broken down by each dredge layer as shown in Table 12-15. The resultant is the determination of the mass, contaminant concentration and thickness of residuals layer.

Table 12-14. Recommended Dredge Plan for NW Area and Eastern Cell

Lift	Cut, D (ft.)	Density, ρ (kg/m³)	Average Concentration, C (ng/kg)
Northwestern Area			
1	0.2	500	7,799
	1.8	950	7,799
2	2	950	2,661
3	2	950	517
	1	950	159
Eastern Cell: Shallow Water			
1	0.2	500	6,049
	1.8	950	6,049
2	2	950	85
	1	950	51
Eastern Cell: Deep Water			
1	0.2	500	5127
	1.8	950	5127
2	2	950	34
	1	950	86

Results

The potential residuals were determined using methods presented in the USACE Technical Guidelines for *Environmental Dredging of Contaminated Sediments* (2008). The results of this analysis can be found in Tables 12-16, 12-17, and 12-18. Table 12-16 presents a step-by-step analysis of each area footprint resulting in sediment mass and contaminant mass per surface area as well as a final residual concentration and residual layer thickness. Using these results, as well as the estimated surface areas of each section, the sediment and contaminant mass could be determined as seen in Table 12-17. This table presents the total potential residuals that are generated during mechanical dredging for each section. Based on data provided in the Feasibility Study, dredging completed in the Eastern Cell would not be as deep as in the Northwestern Area and therefore would only require two dredging passes including the over dredging to ensure that all contaminated material was removed. The Northwestern Area, which is located with deep water and higher sediment concentration, will result in a higher residual concentration.

Table 12-15. Method of Residuals Estimation

1st Production Pass - Composite	
Mass, M_{1c} (kg-ft/m³)	$M_{1c} = (D_{1S} * \rho_{1S}) + (D_{1B} *$
Contaminant Mass, CM_1 (ng-ft/m³)	$CM_1 = C_1 * M_1$
1st Production Pass – Residuals Layer	
M_{1R} (kg-ft/m³)	$M_{1R} = \%R * M_1$
CM_{1R} (ng-ft/m³)	$CM_{1R} = \%R * CM_1$
Residual Contaminant Concentration, CC_{1R} (ng/kg)	$CC_{1R} = CM_{1R}/M_{1R}$
2nd Production Pass - Sediment	
M_2 (kg-ft/m³)	$M_2 = D_2 * \rho_2$
CM_2 (ng-ft/m³)	$CM_2 = C_2 * M_2$
2nd Production Pass - Composite	
M_{2c} (kg-ft/m³)	$M_{2c} = M_2 + M_{1R}$
CM_{2c} (ng-ft/m³)	$CM_{2c} = CM_2 + CM_{1R}$
2nd Production Pass - Residuals	
M_{2R} (kg-ft/m³)	$M_{2R} = \%R * M_{2c}$
CM_{2R} (ng-ft/m³)	$CM_{2R} = \%R * C_{2c}$
CC_{2R} (ng/kg)	$CC_{2R} = CM_{2R}/M_{2R}$
Final Production Pass - Sediment	
M_F (kg-ft/m³)	$M_F = D_F * P_F$
CM_F (ng-ft/m³)	$CM_F = C_F * M_F$
Final Production Pass - Over Dredging	
M_{OD} (kg-ft/m³)	$M_{OD} = D_{OD} * \rho_{OD}$
CM_{OD} (ng-ft/m³)	$CM_{OD} = C_{OD} * M_{OD}$
Final Production Pass - Composite	
M_{Fc} (kg-ft/m³)	$M_{Fc} = M_{2R} + M_F + M_{OD}$
CM_{Fc} (ng-ft/m³)	$CM_{Fc} = CM_{2R} + CM_F +$
Final Production Pass - Residuals	
M_{FR} (kg-ft/m³)	$M_{FR} = \%R * M_{Fc}$
CM_{FR} (ng-ft/m³)	$CM_{FR} = \%R * C_{Fc}$
CC_{FR} (ng/kg)	$CC_{FR} = CM_{FR}/M_{FR}$
Residual Thickness, T_R (ft)	$T_R = M_{FR}/\rho_R$

Table 12-16. Incremental Analysis of Potential Residuals

Parameter	Northwestern Area	Eastern Cell: Shallow Water	Eastern Cell: Deep Water
1st Production Pass -Top Layer			
Residual Mass, M_{1T} (kg-ft/m3)	100	100	100
Residual Contaminant Mass, CM_{1T}	7.80E+05	6.05E+05	5.13E+05
1st Production Pass - Underlying Layer			
M_{1U} (kg-ft/m3)	1,710	1,710	1,710
CM_{1U} (ng-ft/m3)	1.33E+07	1.03E+07	8.77E+06
1st Production Pass - Composite			
M_{1C} (kg-ft/m3)	1,810	1,810	1,810
CM_{1C} (ng-ft/m3)	1.41E+07	1.09E+07	9.28E+06
1st Production Pass - Residuals Layer			
M_{1R} (kg-ft/m3)	162	162	162
CM_{1R} (ng-ft/m3)	1.27E+06	9.85E+05	8.35E+05
Residual Contaminant Concentration, CC_{1R}	7,799	6,049	5,127
2nd Production Pass - Sediment			
M_2 (kg-ft/m3)	1,900		
CM_2 (ng-ft/m3)	5.06E+06		
2nd Production Pass - Composite			
M_{2c} (kg-ft/m3)	2,063		
CM_{2c} (ng-f./m3)	6.33E+06		
2nd Production Pass -Residuals			
M_{2R} (kg-ft/m3)	186		
CM_{2R} (ng-ft/m3)	569,359		
CC_{2R} (ng/kg)	3,067		
Final Production Pass - Sediment			
M_F (kg-ft/m3)	1,900	1,900	1,900
CM_F (ng-ft/m3)	9.82E+05	1.61E+05	6.47E+04
Final Production Pass – Over Dredging			
M_{OD} (kg-ft/m3)	950	950	950
CM_{OD} (ng-ft/m3)	1.51E+05	4.87E+04	8.19E+04
Final Production Pass - Composite			
M_{Fc} (kg-ft/m3)	3,036	3,013	3,013
CM_{Fc} (ng-ft/m3)	1.70E+06	1.20E+06	1.52E+05
Final Production Pass -Residuals			
M_{FR} (kg-ft/m3)	273	271	271
CM_{FR} (ng-ft/m3)	1.53E+05	1.08E+05	1.37E+04
CC_{FR} (ng/kg)	561	397	50
Residual Thickness, T_R (ft)	0.546	0.542	0.542

Table 12-17. Incremental Analysis of Residuals

Parameter	Northwestern Area	Eastern Cell: Shallow Water	Eastern Cell: Deep Water
Sediment Residual Mass (metric tons)	573	1,907	602
Contaminant Residual Mass (mg)	321	756	30
Contaminant Concentration (ng/kg)	561	397	50

Table 12-18 presents the estimated amount of residuals lost with the use of a turbidity curtain. It was assumed that the Shallow Water section of the Eastern Cell would not have a loss of residuals due to the sheet pile wall, but is included in this analysis for a comparison of best management practices. It is assumed that based on prior knowledge that roughly 20% of the fine-grained remaining residuals would be lost below the turbidity curtain due to currents.

Table 12-18. Potential Incremental Releases from Erosion of Residuals with Silt Curtain during Dredging

Parameter	Northwestern Area	Eastern Cell: Shallow Water	Eastern Cell: Deep Water
Sediment Residual Mass (metric tons)	261	611	193
Contaminant Residual Mass (mg)	836	1,537	377
Contaminant Concentration (ng/kg)	3,205	2,518	1,956

Conclusions

This assessment on a sectional basis shows that there is sediment loss, but if completed using best management practices then releases can be considerably lessened. It is recommended that whenever possible, activities should be completed in the dry such as the shallow water portion of the Eastern Cell. By constructing a berm and sheet pile wall structure, the area can be completely dewatered and all activities can be completed in the dry. Releases in the deep water section of the Eastern Cell can be greatly minimized if a sheet pile wall is utilized and does not allow residual releases. There will also be limited exposure to the water before the permanent cap is placed over the residual layers if a sheet pile wall is used. If the conditions do not allow for the use of a sheet pile wall and only a turbidity curtain may be used, then releases are increased significantly as shown in the summary Table 12-19. These areas where a silt curtain is used will have greater releases and long term effects.

A summary of the sectional releases and the total releases can be found in Table 12-19. This table shows the comparison of the total mass of sediment and contaminants removed by dredging to the total mass of sediments and contaminants lost with the two methods of containment. The mass of sediment removed by dredging was calculated by assuming an average sediment density of 950 kg/m^3 and by using the averaged sediment contaminant concentrations.

This assessment presents the possible outcomes of the new full removal Alternative 6N* on a section and area basis with very specific assumptions and site conditions with the enhanced containment BMPs that could decreases the releases from about 3.3% of the contaminant mass based on dredging in the wet using silt curtains as the BMP in all areas to about 0.4% by a combination of excavation of shallow water areas in the dry, dredging deep water areas in the wet within a sheet pile and berm containment, or within a silt curtain enclosure. Nearly 89% of the contaminant mass is located in shallow water areas. If these shallow water areas are excavated in the dry as opposed to dredging in the wet as proposed in Alternative 6N, the predicted releases would be reduced by 88% as compared to Alternative 6N using silt curtains as the BMP or by 50% as compared to Alternative 6N using sheet pile walls as the BMP based on the predictions presented in Tables 11-21 and 12-19. The actual sediment releases and residuals will vary depending on the actual circumstances of remedial activity. Over 80% of the reduction in releases comes from excavating the Western Cell in the dry. Use of sheet pile walls that would be difficult to construct in deep water areas instead of silt curtains would provide only an additional 8% reduction of the overall releases predicted for Alternative 6N using silt curtains as the BMP as compared to an 88% reduction provided by excavation of shallow water areas in the dry.

Additionally, if sheet pile walls are used in the Northwestern Area while dredging in the wet and allowing water levels to equilibrate inside and outside the wall, then the predicted short-term contaminant releases are predicted to decrease by 0.14% of the contaminant removed. The minimum predicted short-term contaminant releases are 0.20% if shallow water areas are removed in the dry and deep water areas are enclosed in sheet pile walls while dredged in the wet. If sediments from the entire site are removed in the dry, the contaminants releases would be limited to releases from construction of the containment structures and fugitive dust losses which would amount to about 0.1% of the contaminants removed.

Table 12-19. Summary of Short-Term Sediment and Contaminant Release Estimates

Areas	BMP	Total mass of dry solids removed (metric tons)	Total mass of dry solids released (metric tons)	Sediment released (%)	Total mass of contaminant removed (g)	Total mass of contaminant released (g)	Percentage of contaminant released (%)
Northwestern Area[1, 2]	Silt Curtain	14,200	340	2.39	44	1.25	2.86
Western Cell	Sheet Pile Wall (Dry)	87,000	50	0.06	440	0.43	0.10
Eastern Cell: Shallow Water	Sheet Pile Wall (Dry)	33,500	19	0.06	80	0.12	0.15
Eastern Cell: Deep Water	Silt Curtain	10,300	260	2.51	21	0.57	2.73
	Sheet Pile Wall (Wet)		72	0.70		0.20	0.96
Total	Silt Curtains in Deep Water	145,000	670	0.46	590	2.37	0.40
	Sheet Pile Walls throughout Eastern Cell [3]		480	0.33		2.0	0.34[3]

1 If a sheet pile wall were able to be constructed and removal were performed in the wet, the releases would be reduced by about 65%.

2 If a cofferdam were able to be constructed and removal were performed in the dry, the releases would be reduced by about 95%.

3 If a sheet pile wall were used in all deep water areas and removal were performed in the wet, the total releases would be reduced by about 40% to an overall contaminant release rate of 0.2%.

Task 13

Statement

Assess the validity of statements made in the Feasibility Study that remedial alternative 4N with removal, solidification, and placing wastes again beneath the TCRA cap has great uncertainty as to implementation and that such management of the waste will result in significant releases.

Methodology

The feasibility of the solidification alternative will be reviewed for reliability, implementability, and constructability as well as short-term effectiveness.

Solidification

Western Cell

The Western Cell of the area north of I-10 has had action taken in it to deal with the contaminated soil in the short term. A portion of the Western Cell used solidification/stabilization in the top 3 feet of the soil. Once the S/S was complete a geomembrane and geotextiles were used to cover the area and armor rock was then placed on top.

The FS states that for the Western Cell, the maximum depth of S/S would be approximately 10-feet below the current base of the armored cap. Since a portion of the area to be solidified already has a 3-foot layer of solidified material with a geomembrane and geotextiles on top and covered with armor rock, the need for solidification to a depth of 10 feet below the armor cap in that area is questionable. If groundwater were migrating into the material below the solidified cap and moving material from underneath the cap, then solidification would be necessary; however, there is not a regional or local groundwater gradient to drive groundwater flow through the waste fill. Since dioxins have low water solubility and mainly bind to soil particles, there is no need to disturb the area for deeper mixing of S/S reagents.

The removal of the armor cap, geomembrane and geotextiles could cause problems with allowing contaminated material to be exposed to atmospheric variables that could cause the material to move. However,

this would be unlikely in the portion of the area that has already had the upper 3 feet solidified, which should be a stable mass of material.
The FS states that the geomembrane would be removed and disposed of as contaminated debris and the armor rock cap would be removed and washed for reuse or disposed in an upland facility. Once the materials are removed then either excavators or augers would be used for the S/S of the material. The use of augers in this situation would be a tedious task that would take a long time to accomplish. The use of excavators would be a more preferred method that would be quicker to accomplish the S/S of the material. The use of excavators would create problems by generating dust that could carry contaminants off the site. It is suggested that water be sprayed on the area during the process to reduce the generation of dust at the site.

Since the surficial material in the Western Cell is not submerged, there are many ways where S/S could be applied. The main problem is the presence of the geomembrane and the armor cap. It is a labor intensive effort to remove these materials so that S/S can be applied to the area for the treatment. It would probably prove best to remove smaller sections at a time rather than remove the entire armor cap and geomembrane at one time. With smaller sections removed, such as 0.25 acres, the material could be excavated to the desired depth and then placed back in lifts that are sufficient for mixing, 12 to 16 inches. Once the material is placed back, the recommended amount of Portland cement could be added to the material along with water; standard equipment such as tractors and discs could be used to mix the materials. After mixing the materials, the mixture would be compacted and the next layer would be added and the process repeated until the area has been refilled. Performing the cap removal and solidification in small sections would greatly reduce the sediment exposure and risk of releases from overtopping events.

The FS estimates that 0.85% of the solidified material will be lost during removal and treatment, although presumably only for the area to be excavated in the wet located in the Eastern Cell or Northwestern Area. This loss value is appropriate for solidification in the wet when water exchange is allowed to equalize the water level inside and outside the sheet pile wall. However, this value would be inappropriate for removal in the dry; very little loss should occur when solidifying in the dry. The releases for the Western Cell for excavation and solidification in the dry are unclear in the FS.

The FS expresses concern with the risks of storm and floods overtopping the Western Cell from as small as a 3-yr event. If this is the case, the sheet pile wall should be placed within the existing berm of the Western Cell, on the outer edge of the crest, which is generally dry. The joints could be sealed in the dry to below the TCRA cap, greatly reducing the potential for leakage. The top of the wall could also be placed several feet higher (at least 9 ft NAVD88) since the wall would be supported to an elevation of at least 4 ft NAVD88. This will greatly reduce the risk of overtopping in the Western Cell. Additionally, the removed armor stone could be used to support the wall. Consequently, the short-term effectiveness of Alternative 4N is significantly under predicted, unless releases are predicted only from solidification operations in the wet.

The FS also predicts an elevated contaminant concentration in the cap placed after solidification based on the perceived potential for mixing during cap placement (apparently in the wet). The FS assumes the contaminant concentration in the armor cap will equal 5% of the contaminated sediment concentration. The FS is not clear as to how this is applied in the F&T modeling. If cap placement is performed in the dry, there is little potential for mixing. This is particularly true for the existing cap design that calls for a geotextile, geomembrane, a second geotextile and armor stone. Examination of the existing TCRA cap did not find any mixing of the contaminated sediment with the armor cap. Therefore, the estimated surface cap contamination concentration is too high even in the wet. If residuals are present after solidification, a thin sand bedding layer could be placed prior to placing the armored cap and geosynthetics to secure the residuals from contaminating the armor cap. Consequently, the long-term effectiveness of Alternative 4N is significantly under predicted and should be comparable to Alternative 3N.

Eastern Cell

The Eastern Cell located north of I-10 is submerged and has water depths of up to 10 feet. The FS proposes to install a sheet pile wall around the Eastern Cell in order to isolate the area from adjacent water. In order for the sheet pile wall to be effective, the armored cap and geotextile would first have to be removed where the wall is to be constructed. This would be approximately a 10-foot-wide section of armored cap and geotextile. By doing this, the sheet pile wall could be constructed so that the area could be sealed off from adjacent waters. If the armored cap and geotextile are not removed, then there is no way to seal the sheet pile wall. Also, the sheet pile could not be driven through the armored cap and problems would arise with pushing the geotextile into the sediments.

Sheet pile walls are not structurally sound for 10 feet of pressure head. Reinforcements would have to be used to stabilize the wall so that the water pressure exerted on the outside of the wall would not cause failure of the wall. Another method that would work better would be the use of caissons but this would cause the cost to increase. The use of a wall to separate the treatment area from adjacent waters is a good thought but at these depths it is not feasible to do this in order to dewater the area. Even if dewatering could be done, the removal of the armored cap and geotextile would be a challenge and the mixing and setting of the material with Portland cement would be a long process.

For the *in situ* treatment of sediments other means could be applied in order to stabilize the sediments. Hollow stem augers have been demonstrated as one technique to stabilize contaminated sediments *in situ*. This system uses three augers, 3-foot in diameter, to drive into the sediment. The middle auger turns opposite of the other 2 augers to aid in the mixing of the sediment. Slurried Portland cement, or other pozzolanic reagents, is pumped into the augers both while they are going down in the sediments and while being withdrawn from the sediments to ensure complete mixing. The armored cap and geotextile would have to be removed in order for the augers to work and this would cause disturbance of the sediments beneath the geotextile. The sheet pile wall could still be installed in order to prevent loss of sediment resuspended during the removal of the cap and geotextile and during the mixing of the sediments with the Portland cement.

Any type of treatment for the stabilization of the sediments below the geotextile will disturb the sediment and will cause some resuspension of the material in the water column. A major factor that will suspend sediment will be the removal of the geotextile and the overlying armored cap, particularly if removed jointly. It is highly unlikely that the armored cap could be removed in a separate process without severely disturbing the sediment surface unless performed by divers, which would be very time-consuming and expensive.

Since the contaminants of concern are not extremely water soluble, the contaminants will be bound on the sediment. If the sediment is isolated and undisturbed, then the contaminants should not move in the system appreciably. The average current speed at the site is generally between 0.1 and 0.2 ft/sec for a tidal cycle; peak current speeds during a tidal cycle are generally less than 0.4 ft/sec. These currents would not erode the sediments if appropriate BMPs are used. Peak flooding event currents produce velocities in excess of 1 m/sec, which would be sufficient to erode sediment disturbed from cap/geotextile removal and solidification operations prior to amendment addition and compaction. Following solidification and armored capping, the solidified sediment should be sufficiently protected by the modified (flattened and thickened) cap to resist erosion during major storm events. Monitoring of the cap will have to be performed after these events to determine damage and what is needed to be repaired.

Removal

The FS provides numerous statements on the short- and long-term effectiveness of removal, particularly dredging in the wet rather than excavation in the dry. The statements are supported by past experiences; however, the formulation of the alternatives and the application of BMPs lack consistency. As an example, it appears that removal in the Western Cell is performed in the dry with landside operations in Alternatives 5N and 5aN, while its removal is performed in the wet in Alternative 6N. Similarly, removal in Alternative 5N is performed with a sheet pile wall to control releases while in Alternative 5aN removal within the footprint of Alternative 5N within the Eastern Cell is performed with a silt curtain, allowing greater releases from an area with very high contaminant concentrations. Ideally, removal in the Western Cell would be performed in the same manner in all of the alternatives so that one can understand the costs and benefits of expanding the footprint of remediation or removal. Consequently, the performance of the alternatives as predicted in the fate and transport modeling tends to distort the incremental impacts of expanding the comprehensiveness of the removal alternatives.

A comparison of short-term effectiveness of Alternative 4N and 5N illustrates differences in BMPs or fate and transport modeling assumptions. The FS states:

> *"The modeling presented in Appendix A demonstrates short-term water column impacts associated with Alternative 4N. Specifically, over the TCRA Site footprint, this alternative is estimated to increase the annual average water column concentration of TCDD by a factor of 10 in year 1 compared to existing conditions.*
>
> *The modeling presented in Appendix A demonstrates short-term water column impacts associated with Alternative 5N. Specifically, over the TCRA Site footprint, this alternative is estimated to increase the annual average water column concentration of TCDD by a factor of about 50 in year 1 compared to existing conditions."*

Since both alternatives are addressing the same area and mass of sediment and similarly disturbing the sediments, one would expect the similar releases and impacts on the water column. In both alternatives the sediment would or could be removed in the same manner, in 4N to add solidification reagents and in 5N for disposal. In fact, one would expect additional releases in 4N from placing the treated sediment back in place; yet, the impact of 4N on the water column is only 20% of the impact of 5N. The cause for these differences is not presented in the FS, but it appears that they reflect differences in the BMPs used, particularly in the Eastern Cell. The 50-fold increase is reflective of the use of silt curtains and removal in the wet. Existing conditions are reflective of Alternative 3N.

Containment Alternatives

BMPs

The FS states:

> *"Operational and engineering controls (rigid and flexible barriers) would be used to the extent practicable to mitigate these potential releases; however, case studies have shown that engineering controls used to control impacts from dredging such as sheetpiles may have limited effectiveness, are subject to leakage, accumulate*

resuspended sediments at the base of the walls which is impossible to completely capture, and have other technical limitations (USACE 2008b; Anchor Environmental 2005; Anchor QEA and Arcadis 2010). Further, use of rigid barriers can result in unintended consequences, such as concentration of dissolved-phase chemicals, localized scour adjacent to the barrier, and/or the spread of contaminants during structure removal (Ecology 1995; Konechne et al. 2010; Anchor QEA and Arcadis 2010).

Flexible barriers such as turbidity curtains will suffer from suspended sediment losses because these types of barriers are not truly water-tight (USACE 2008a; USACE 2008b; Francingues and Palermo 2006; Anchor Environmental 2005; Anchor QEA and Arcadis 2010). Proper design and installation of engineered barriers would be critical for minimizing the issues described above."

While sheet pile walls may have limited effectiveness, are subject to leakage, and accumulate resuspended sediments at the base of the walls, these walls are much more effective than silt curtains. Leakage through shallow walls can be controlled by covering the walls with plastic sheeting, adding sealants and incorporating the walls within shallow berms, which would allow excavation in the dry. Placing the walls in shallow areas would allow the walls to be taller, limiting their potential overtopping. In deeper waters, sheet pile walls limit flow through the site and can restrict flow to the surface, limiting erosion of residuals, while silt curtains direct flow along the bottom of the water column, promoting the transport of resuspended sediment and allowing erosion of residuals. Accumulated resuspended sediments at the base of the walls can be readily capped or covered in place, if not removed by a suction dredge.

The FS additionally provides the following statements regarding the use of sheet pile walls:

"The use of a sheetpile barrier does little to enhance the short-term effectiveness of this alternative because of documented effectiveness issues with engineered barriers discussed in Section 4.1, including:

> • *Incomplete isolation due to gaps in sheetpiles that may occur during installation*
>
> • *The need to provide openings in the sheetpile to balance water pressures on both sides of the pile*
>
> • *The potential for river-current-induced scour adjacent to the sheetpile"*

The three bullets listed above do not provide significant issues in shallow wall installations, such as a wall built at the crest of the outside face of the Western Cell berm, which is normally above the waterline. Gaps between sheet piles could be readily sealed, and there would not be a need to balance water pressures on both sides of the wall. Additionally, the base of the wall is already armored, which would limit the scour potential. For removal operations performed in the wet within sheet pile enclosures with openings to equalize water pressures on both sides of the wall, the sheet pile will virtually prevent erosion of the residuals, reducing releases by at least 70 percent and greatly increasing short-term effectiveness relative to silt curtains.

The FS further poses the following concerns for the use of sheet pile walls:

> *"In addition to these documented issues with sheetpile barriers, the use of sheetpiles increases the risk of recontamination and resuspension of soil/sediments during sheetpile installation and removal (Ecology 1995), and potential cross-contamination associated with driving sheetpiling through impacted materials into non-impacted material."*

The area and mass of contamination impacted by the sheet piles leading to potential recontamination and resuspension of contaminated sediment during installation and removal are equivalent to a very small fraction of the potential reduction in releases achieved by their use over that of other BMPs such as silt curtains. Cross-contamination associated with driving sheet piling through impacted materials into non-impacted material does not pose additional risk because there would not be any exposure to the underlying materials, besides being of limited mass.

Releases and Residuals

The FS assumes the following releases from removal:

> *"A 3-inch layer of dredge residuals was assumed to be generated above the deeper undredged sediments; 15 dioxin/furan concentrations in the residual layer were assumed to be equal to sediment concentrations in the deepest samples above the specified dredge depths, which were considered representative of the last dredge pass (Patmont and Palermo 2007; Bridges et al. 2010). In other words, because Alternatives 5aN and 6N include removal of sediments exceeding the PCL (220 ng/kg TEQ), the residual layer concentration was defined based on sampling data collected immediately above the 220 ng/kg TEQ depth horizon (which in many cases was greater than 220 ng/kg TEQ). As with the deep concentrations, the residual layer concentrations were defined as a single average concentration over the footprint of each dredge area.*
>
> *The top 6 inches of the simulated bed sediment in each dredge area was assumed to consist of a residual cover (e.g., sand); dioxin/furan concentrations in this cover material were assumed to be 5 percent of the dredge residual concentrations (due to mixing when the cover is placed). This value was specified based on experience from other dredging projects (e.g., Alcoa 2006; Anchor Environmental 2007)."*

If a 3-inch layer of dredge residuals having a concentration of the last dredge pass are presumed, then a clean-up pass should be included in the dredge plan to reduce the future exposure. Additionally, if mixing at a rate of 5 percent of the residuals concentration is expected in the 6-inch residual cover when residual concentrations may be quite high without over-dredging or a clean-up pass, then a 12-inch residuals cover should be placed in two 6-inch lifts so that the bioactive zone would be clean following remediation and would yield less diffusive flux than the existing TCRA cap without a geomembrane.

Task 14

Statement

Provide a model evaluation of the full removal Alternative 6N identified in the Feasibility Study as well any new alternative(s) developed under Task 12 (Identify and evaluate techniques …) above. Include modeling of sediment resuspension and residuals.

Methodology

Modeling was performed of the full removal Alternative 6N included representing the post-dredged elevations in the northern impoundments and a 1 cm layer of dredging sediment residuals on the surface of the newly exposed sediment bed in the Eastern Cell and Northwestern Area. The modeling did not simulate the relatively short period between dredging and cover placement.

Findings

The model was run for a one month period during which there were no releases of water from Lake Houston into the upper SJR in order to simulate the full range of tidal conditions over a lunar month. This simulated a low energy simulation in the SLR estuary, which was chosen to result in the minimum amount of area that would be exposed to the eroded and subsequently transported contaminated residuals (*i.e.*, the best case scenario).

The sediment bed below the residuals was assumed to be consolidated, and the critical shear stress for erosion was set at 1.0 Pa as found in the SedFlume study. No resuspension of that sediment occurred during the one month low-energy simulation. Using an estimated critical shear stress for erosion of 0.1 Pa for the residuals, approximately 25 percent of the total residual mass in the identified area was eroded and transported out of the Site. The eroded sediment residuals (represented as bed aggregates in the model) were transported in both the upstream direction during flood tides and downstream direction during ebb tides, though the majority of the eroded residuals were transported downstream. The area of the estuary in which the eroded sediment residuals were eventually deposited stretched halfway between Lynchburg and Morgan's Point in the downstream direction. This was determined by representing the dredged residuals as a different sediment size class, which allowed percentages of that sediment class (above 1 percent) in the surface sediment bed layer to be the marker for locating where the residuals eventually deposited. In the upstream direction, the sediment residuals were present up to the area in proximity to the northern end of Grennel Slough.

Alternative 6N would set back the natural recovery of the site back to existing conditions by up to two decades considering the time required for design, construction and assimilation of the releases into the sediment bed below the bioactive zone. The setback for Alternative 6N if only silt curtains are used as the resuspension BMP may increase a measurable area of the sediment in the immediate vicinity of the cap area to a concentration exceeding the PCL. The new Alternative 6N* with enhanced BMPs, despite its much smaller short-term releases, would still set back the natural recovery of the site back to existing conditions by up to a decade considering the time required for design, construction and assimilation of the releases into the sediment bed below the bioactive zone. However, the setback for Alternative 6N* may not increase a sizeable area of the sediment outside the cap area to a concentration exceeding the PCL. These short-term releases that are incorporated into the surrounding sediment bed would subsequently be available for redistribution during erosion events from high flows or storm events.

In conclusion, the full remove alternative would result in a significant, albeit short-term increase in the exposures of the estuary to contamination due to the erosion and subsequent transport of the sediment residuals that would be present at the end of the dredging operations in the Northern Impoundments. The identified zone of this increased exposure, even during the simulated normal conditions is fairly far-reaching.

Task 15

Statement

Evaluate floodplain management and impact considerations of construction, considering Alternatives 3N, 5aN, 6N, and any new alternative(s) developed under Task 12, in the floodplain and floodwaters pathway and how that would impact flood control, water flow issues and obstructions in navigable waters. This includes impact on changes to potential flooding and any offsets that are needed due to displacement of water caused by construction in the floodway (height or overall footprint) including effects at the current temporary TCRA cap and any potential future remedial measures.

Findings

This task was accomplished using the calibrated LTFATE model described in Task 2. As described, the LTFATE model domain included the 100-year floodplain, so it was an appropriate tool to use to perform this evaluation. The strategy used with LTFATE was to block off the grid cells that represent the Northern Impoundments (even those representing the Western Cell). The LTFATE grid in proximity to the Site is shown in Figure 3-2. The grid with the blocked cells was used to evaluate the maximum impact that construction of any of the listed Alternatives would have on potential flooding in proximity to the Site. The one month normal weather period that was simulated in Task 14 was used as the simulation period for this task as well. Both the original (*i.e.*, base) model and the model with the blocked grid cells (subsequently referred to as the construction model) were run for this one month simulation. The blocked grid cells in the construction model did not cause any of the grid cells along the shoreline in the portion of the SJR estuary where the Site is located to flood (*i.e.*, become wet). The average difference between the base and construction models predicted water surface elevations in the 120 closest grid cells that surround the Site over the one month simulation was less than 1 cm. Considering the small ratio of the surface area of the Northern Impoundments to the surface area of the embayment where the impoundments are located, this result was not unexpected.

As stated above, the LTFATE model was used to perform the floodplain impacts evaluation. Often times the HEC-RAS model, which a onedimensional (1D) hydraulic model, is used to perform these evaluations. Since HEC-RAS is a 1D, it is severe limitations in representing complex water bodies such as the SJR estuary. In fact, at this time it would not be appropriate to use HEC-RAS to represent an estuary such as the SJR estuary, whereas it is appropriate to do using a multi-dimensional hydrodynamic model. The uncertainties associated with the use of HEC-RAS to perform the impact evaluation would be at a minimum one order of magnitude higher than those associated with the use of a 2D hydrodynamic model such as LTFATE.

In conclusion, the construction of any of the proposed Alternatives is not expected to cause any flooding in the vicinity of the SJR Waste Pits Site, and therefore should not require the implementation of any flood control measures during the construction of any of the Alternatives under consideration by the EPA Site team.

Task 16

Statement

Project the long-term (500 years) effects of the capping alternative (3N) compared to the full removal alternative (6N) on water quality.

Predictions

To project and compare the long-term effects of the existing capping alternative (3N) versus the full removal alternative (6N), the contaminated sediment-water interaction model, the RECOVERY model was used to predict the contaminant flux and release into the overlying water and to analyze the interactions of a contaminant over 500 years in the sediment profile and bioactive zone. Using RECOVERY, a total flux of contaminant over time and a peak flux were determined to assess the performance of each of the alternatives. The mixed layer (bioactive zone) sediment concentrations were then used to estimate the total bioaccumulation potential of catfish, crabs and clams which were stated as the three species of concern in the RI.

RECOVERY Modeling

RECOVERY is a screening-level model used to assess the long-term impact of contaminated sediments on surface waters. The model couples contaminated interaction between the water column and the bottom sediment, as well as between the contaminated and clean bottom sediments. The analysis is intended primarily for organic contaminants with the assumption that the water column is well mixed. The processes that are incorporated in the model include sorption, decay, volatilization, burial, resuspension, settling, bioturbation, and pore-water diffusion. The solution couples contaminant mass balance in the water column and in the mixed sediment layer along with diffusion and bioturbation in the deep sediment layers.

As shown in Figure 16-1, the system is idealized as a well-mixed surface water layer underlain by a vertically stratified sediment column. The sediment is assumed to be well-mixed horizontally but segmented vertically into a well-mixed surface layer and deep sediment. The latter, in turn, is segmented into layers with varying thicknesses, porosities, and contaminant concentrations underlain by an uncontaminated region. This configuration is helpful for capping scenarios such as this where contamination occurred over a long time, therefore appearing layered. The mixed surface layer is needed because an unconsolidated layer is often observed at the surface of sediment due to a number of processes including bioturbation and mechanical mixing.

Figure 16-1 depicts a basic model simulation including a mixed surface layer, a clean cap underlain by contaminated sediments and a clean deep sediments layer. Figure 16-2 represents the conditions of cap mixed with dredge residuals or surface sediments during cap or backfill placement. Once the cap has been placed, the results are a mixed layer, a new clean cap followed by the contaminated cap, the underlying contaminated sediments, and finally the deep clean sediments.

RECOVERY Scenarios

To compare the full removal alternative (6N) to the current TCRA cap (3N) following remediation activities, the alternatives were broken down incrementally based on the conditions of the individual removal alternative footprints as described in Tasks 11 and 12. This resulted in multiple runs being completed for both alternatives 6N and 3N based on the conditions of the 5N, 5aN, and 6N footprints following remediation. These results were also compared to the background conditions outside of the TCRA cap area with a scenario of surrounding conditions without additional releases from removal activities.

Figure 16-1. Initial Clean Cap Scenario

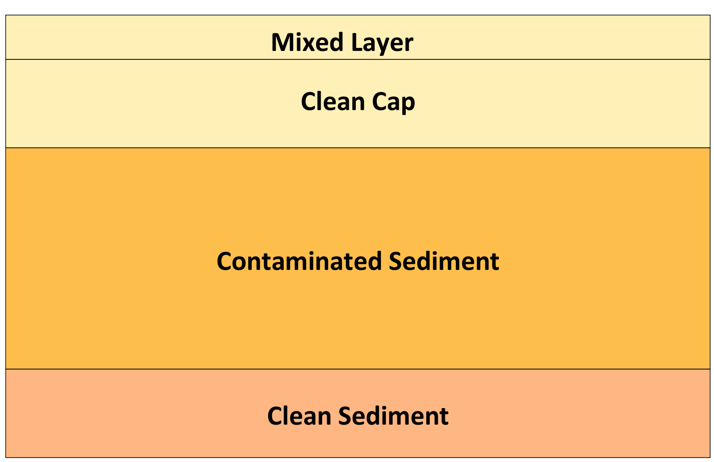
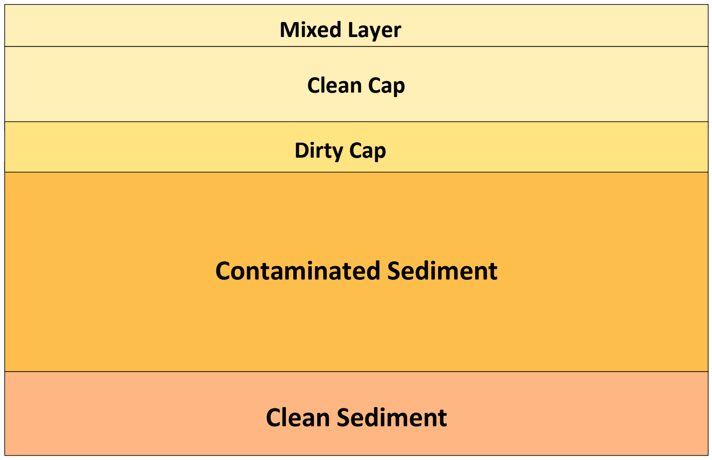


Figure 16-2. Remediated Cap Scenario



RECOVERY Assumptions

Assumptions what were made to complete the RECOVERY model runs are listed in Table 16-1. The contaminant selected for the model runs was 2,3,7,8-Tetrachlorodibenzodioxin (TCDD), which is present in the TCRA cap area and is noted in the Feasibility Study. The octanol-water partitioning coefficient was identified in the RECOVERY model as being 5.25E+06 and was adopted for use in this evaluation. The water suspended solids content and fraction organic carbon were assumed based on knowledge of the site and data from the Remedial Investigation and Feasibility Study. The residence time was estimated using velocity data provided in the Feasibility Study and was used in the calculation of the flow through the system. The surface area of both the water body and the sediment profile was estimated to be an arbitrary 1000 square meters, which would not affect the results of the model and could be scaled for any size surface area, with an assumed water depth of 1.5 m across all scenarios. The sediment profile depth was assumed to be 1 m for all scenarios and a constant specific gravity of 2.65 was used for all materials.

Based on information provided in the Feasibility Study, it was determined that the TCRA site is primarily a depositional site with very little erosion potential. As such, a low resuspension velocity was assumed along with a low burial velocity. These values were used to estimate the settling velocity as stated below, which is representative of clays and very fine silts.

Table 16-1. RECOVERY Model Assumptions

Parameter	**Assumption**
Contaminant	2,3,7,8 TCDD Dioxin
Partitioning Coefficient, K_{ow}	5.25E+06
Suspended Solids Concentration in Water	20
Fraction of Organic Carbon in Solids (%)	0.1
Residence Time (years)	0.0001
Calculated Flow Through (m^3/yr)	1.13E+07
Surface Area of Simulation (m^2)	1000
Water Depth (m)	1.5
Sediment Profile Depth (m)	1
Specific Gravity	2.65
Wind Speed (m/sec)	2
Resuspension Velocity (m/yr)	0.001
Burial Velocity (m/yr)	0.004
Calculated Settling Velocity (m/yr)	271

Surrounding Conditions

The details of the Surrounding Conditions scenario can be found in Table 16-2. This scenario was assumed to be outside of the TCRA region but within the Preliminary Site Perimeter and reflects the unremediated, impacted area (about 700 acres) that could be potentially affected by releases from the TCRA area or could affect the TCRA area in the future. The scenario was considered a simple two layer system having a 10-cm mixed layer that was slightly more organic than the underlying sediment. All sediment, including the mixed layer, was assumed to have an initial TCDD contaminant concentration of 10 ng/kg.

Table 16-2. Surrounding Conditions

Layer	Layer Depth (cm)	Porosity	TOC (%)	Concentration (ng/kg)
Mixed	10	0.7	4	10
Sediment	98	0.6	3	10

3N

Alternative 3N was divided into two TCRA cap regions, the Eastern Cell and Northwestern Area, as described in the Feasibility Study. The areas are very different in composition as the Eastern Cell has a geotextile and rock riprap protection while the Northwestern Area has only an aggregate filter and recycled concrete as a permanent cap. The 3N alternative was further divided based on the footprint of each of the removal alternatives, 5N, 5aN, and 6N, and an incremental analysis of the entire TCRA cap area. Porosities were assumed based on site conditions and the fraction of organic carbon (TOC %) was assumed based on data provided in the Feasibility Study. Sediment TCDD concentrations were assumed based on the average sediment concentrations determined in Task 11 for each footprint.

Table 16-3 describes the scenarios for the Eastern Cell of the TCRA cap. In this area, there is a geotextile along with a rock riprap permanent cap. For the purposes of this analysis, and due to restrictions in the RECOVERY model, the rock riprap layer could not be accurately modeled due to the absence of organic matter in the riprap and the potential rapid exchange of water within the interstices of the riprap with the water column. Therefore, the riprap was not included in any of the model runs. It was also assumed that for this area the geotextile, while not modeled, does keep the mixed layer clean and not exposed to the contaminated sediment. This resulted in a sediment profile with a 2-cm clean mixed layer and the remaining sediment having a constant contaminant concentration. TOC values varied for each removal footprints based on assumptions made in Task 11.

Table 16-4 represents the model runs completed for the Northwestern Area. The Northwestern Area is different from the Eastern Cell in that it does not have any form of geotextile to protect from sediment resuspension. Instead, there is a blended aggregate filter layer covered by recycled concrete as the permanent cap. For these model runs the concrete was not included as a layer and the aggregate was assumed to be very coarse sand with low organic content. The sediment profile was assumed to consist of a 2-cm mixed layer followed by a 12-cm aggregate layer, an 8-cm layer in which the aggregate was mixed with the contaminated sediment, and lastly the remaining 78 cm of completely contaminated sediment. The bottom contaminated sediment concentration was assumed based on calculations made in Task 11, and it was assumed that the mixed aggregate/sediment layer was approximately 15% of the contaminant concentration of the surficial sediment.

Table 16-3. Alternative 3N Eastern Cell Components

Layer	Thick-ness (cm)	Poro-sity	TOC (%)			Concentration (ng/kg)		
			5N Foot-print	5aN Incre-ment	6N Incre-ment	5N Foot-print	5aN Incre-ment	6N Incre-ment
Mixed	2	0.4	0.5	0.5	0.5	0	0	0
Sediment	98	0.6	12	6	5	13,000	5,800	4,030

Table 16-4. Alternative 3N Northwestern Area Components

Layer	Thick-ness (cm)	Poro-sity	TOC (%)			Concentration (ng/kg)		
			5N Foot-print	5aN Incre-ment	6N Incre-ment	5N Foot-print	5aN Incre-ment	6N Incre-ment
Mixed	2	0.4	0.5	0.5	0.5	0	0	0
Aggregate	12	0.2	0.5	0.5	0.5	1	1	1
Mixed Cap/ Sediment	8	0.4	3	3	3	1,950	870	605
Sediment	78	0.6	12	6	5	13,000	5,800	4,030

6N

The full removal alternative (6N) was divided into multiple scenarios; first, by the method of backfill placement and secondly by the footprint of each removal alternative. By specifying three methods of backfill placement, a comparison can be made between them and a best method of placement plan can be developed and utilized if the full removal alternative is selected. The three methods include a dump placement, raining of the material, and a recommended best practice method of placing the material in two layers.

The first method of placement is considered the least desirable. Dumping of the material from a barge or excavator leads to a great deal of suspension and mixing, and there is no acceptable way to ensure that the material is spread evenly over the surface and is the proper thickness. As such, the sediment profile is assumed to look similar to that in Table 16-5. Here the profile is divided into a 10-cm mixed layer, a small 5-cm sand layer, followed by the residual layer that remains following dredging, and lastly the deep sediment that has a concentration below the cleanup level. The residual thickness and concentration, as determined in Task 11, are considerably high, and when the backfill is dumped there is significant mixing that results in the sand and mixed layers having a concentration approximately 5% of the residuals concentration. The porosity and TOC were assumed based on data provided in the Feasibility Study. As previously stated, the rock riprap which would be used to reinforce the cap is not included in the model runs.

Table 16-6 represents the sediment profiles if the backfill material is placed by raining the material. This method is preferred to dumping since there is more control in the distribution of the material and layer thickness, as well as reduced mixing limited to a thin layer between the clean material and the residuals and less potential for resuspension. The top 10 cm of the mixed layer is left clean while the concentration that was previously mixed over 15 cm in the dump placement scenarios is now mixed with a smaller layer of 5 cm of sand. While this increases the concentration in the sand layer to 15% of the residuals contaminant concentration, there is now a clean barrier between the contaminant and the water column. Below the sand is the estimated 3 cm residuals layer followed by the remaining deep sediments that are below the cleanup level of contamination.

Lastly, a best practice method for placement is recommended as described in Table 16-7. This method involves carefully placing the sand material in two equal layers which considerably reduces mixing with the contaminated material and suspension. This results in the top 6 inches of material, including the mixed layer, remaining clean and increasing the barrier between the contaminated residuals and the water column. As seen in the profile, there is an assumed 10-cm mixed layer, with the next 5 cm below the mixed layer remaining clean, followed by 15 cm of sand having mixed with the residuals to yield a contaminant concentration of 5% of the residuals layer. Below the sand are the 3-cm residuals layer and the remaining deep sediments.

Table 16-5. 6N Scenario 1 - Dump Placement of Backfill

Layer	Layer Depth (cm)	Poro-sity	TOC (%)	Concentration (ng/kg)		
				5N Footprint	5aN Increment	6N Increment
Mixed	10	0.5	1	416	136	98.5
Sand	5	0.4	0.5	416	136	98.5
Residuals	3	0.6	3	8,320	2,720	1,970
Deep Sediment	82	0.6	3	200	200	200

Table 16-6. 6N Scenario 2 - Raining Placement of Backfill

Layer	Layer Depth (cm)	Poro-sity	TOC (%)	Concentration (ng/kg)		
				5N Footprint	5aN Increment	6N Increment
Mixed	10	0.5	1	0	0	0
Sand	5	0.4	0.5	1,248	408	295
Residuals	3	0.6	3	8,320	2,720	1,970
Deep Sediment	82	0.6	3	200	200	200

Table 16-7. 6N Scenario 3 - Best Practice Placement of Backfill in Two Layers

Layer	Layer Depth (cm)	Poro-sity	TOC (%)	Concentration (ng/kg)		
				5N Footprint	5aN Increment	6N Increment
Mixed	10	0.5	1	0	0	0
Sand	5	0.4	0.5	0	0	0
	15	0.4	0.5	416	136	98.5
Residuals	3	0.6	3	8,320	2,720	1,970
Deep Sediment	67	0.6	3	200	200	200

Results

Data from the multiple RECOVERY model runs were analyzed to determine the peak total flux of contaminant over the model period (500 years). These data are useful in determining how well the site is performing and how much contaminant is potentially lost into the water column over time.

Peak contaminant releases and dissolved contaminant concentrations driving the risks from contaminant exposures are shown in Tables 16-8 and 16-9. The peak contaminant flux given in Table 16-8 and the total contaminant releases during the simulation period given in Table 16-10 are low for all scenarios compared with the unremediated area within the Preliminary Site Perimeter. In a comparison between the two areas of the 3N alternative, there is more flux occurring in the Eastern Cell than in the Northwestern Area. This is due to the absence of a sand and gravel filter in the Eastern Cell and presence of a sand and gravel filter in the Northwestern Area. The blended filter restricts water exchange and decreases the contaminant concentration gradient that drives the diffusive contaminant flux. Comparing the three backfill placement methods of the 6N alternative, the best practice method of placing the material over two layers is far superior and has considerably less flux than the other two placement methods. The flux from this method is also significantly less than that experienced if the current cap remains in place. The dump backfill placement method with potential mixing throughout the fill yields contaminant fluxes greater than that occurring in the surrounding unremediated area.

Table 16-8. Peak Contaminant Flux Rate

Scenario	Time to Peak (years)	Peak Contaminant Flux (µg/m²-yr)
Surrounding Conditions	0.047	8.34E-04
3N Eastern Cell 5N Footprint	3.45	6.09E-05
3N Eastern Cell 5aN – 5N Increment	3.46	5.43E-05
3N Eastern Cell 6N - 5aN Increment	3.46	4.53E-05
3N NW Area 3N - 5N Footprint	3.46	7.50E-09
3N NW Area 5aN – 5N Increment	3.46	7.50E-09
3N NW Area 6N – 5aN Increment	3.46	7.50E-09
6N Dump Placement - 5N Footprint	0.048	5.75E-02
6N Dump Placement - 5aN Increment	0.049	1.88E-02
6N Dump Placement - 6N Increment	0.048	1.36E-02
6N Rain Placement - 5N Footprint	6.31	1.76E-05
6N Rain Placement - 5aN Increment	6.33	5.75E-06
6N Rain Placement - 6N Increment	6.32	4.17E-06
6N Best Placement - 5N Footprint	22.3	4.24E-21
6N Best Placement - 5aN Increment	22.2	1.39E-21
6N Best Placement - 6N Increment	22.2	1.00E-21

Table 16-9. Peak Dissolved Contaminant Concentrations

Scenario	Cover Placement Method	BAZ ng/L	Water ng/L
Surroundings		3.20E-04	4E-08
3N		2.00E-05	7E-09
6N	Dump	4.40E-03	2E-06
6N	Rain	1.35E-06	5E-10
6N	Best	3.25E-22	1 E-25

Table 16-10. Total Contaminant Release over 500-yr Simulation Period

Scenario	Total Release over 500 years (mg)
Surrounding Conditions	28,900
Eastern Cell 3N - 5N Footprint	2.18
Eastern Cell 3N - 5aN Increment	8.11
Eastern Cell 3N - 6N Increment	0.0
NW Area 3N - 5N Footprint	0.0
NW Area 3N - 5aN Increment	2.54E-04
NW Area 3N - 6N Increment	2.54E-04
6N Dump Placement - 5N Footprint	10,200
6N Dump Placement - 5aN Increment	7,160
6N Dump Placement - 6N Increment	2,960
6N Rain Placement - 5N Footprint	4.06
6N Rain Placement - 5aN Increment	2.84
6N Rain Placement - 6N Increment	1.17
6N Best Practice Placement - 5N Footprint	1.22E-15
6N Best Practice Placement - 5aN Increment	8.49E-16
6N Best Practice Placement - 6N Increment	3.51E-16

Task 17

Statement

Assess the potential impacts to fish, shellfish, and crabs from sediment resuspension as a result of dredging in the near term and for the long term.

BSAF and Total Bioaccumulation Potential

Bioaccumulation is the uptake chemicals by an organism through routes of exposure including ingestion and inhalation. The amount of bioaccumulation depends on the bioavailability of a chemical contaminant as well sediment concentrations, and the specific organism. Other factors affecting the bioaccumulation include the total organic carbon (TOC) present in the sediment in which low TOC tends to result greater bioaccumulation while higher TOC contents result in lower bioaccumulation. Benthic organisms that dwell or ingest fine grained material, which itself is associated with higher contaminant concentrations, are more likely to be exposed to these higher concentrations of contaminants and resulting in a higher potential for bioaccumulation. Dredging and any other activities which disturb and resuspend sediments create conditions that allow for higher bioaccumulation potential and cause higher concentrations of contaminants in the water column creating a new pathway for organisms to ingest the contaminants.

In order to determine the concentration at which an organism exposed to contaminated sediments may become contaminated the biota-sediment accumulation factor (BSAF) in combination with the lipids content of an organism, the TOC and the sediment concentration of the specified area are used to estimate a Total Bioaccumulation Potential or TBP. The TBP is a useful tool in estimating the affect contaminated sediment may have on the food chain starting with the sediments that organisms such as blue crab, catfish and clams ingest. The following section estimates the TBP of the listed organisms in the TCRA cap area ingesting only organisms in equilibrium with the remediation areas.

Assumptions

Assumptions for the determination of the TBP can be found in Table 17-1. The lipid content for each species was assumed based on literature from the Texas Department of Health Services as well as from the report "Assessing Bioaccumulation in Aquatic Organisms Exposed to Contaminated Sediments" by Clarke and McFarland (1991). The BSAF value chosen for each species was assumed from data provided in Appendix B of the RI report. However, the analysis for these BSAF values did not follow standard practice which would define BSAF as the lipid normalized tissue concentration relative to an organic carbon normalized sediment concentration. As such, the BSAF values needed to be adjusted by the ratio of sediment TOC content to tissue lipid content. The mean surficial sediment TOC content is about 5% but may be as high as 12%. The BSAF values using normalized concentrations would be as much as 10 to 15 times higher than the reported values in Appendix B of the RI report. Baylor University computed BSAFs from measured tissue concentrations and sediment concentrations from San Jacinto River samples. The mean values for TCDD are reported in Table 17-1. The Baylor University values (TEHI BSAF Report 8/31/2012) are somewhat higher than the values reported in Appendix B of the RI but in the range of other reported values, some of which are about 4 times higher. Nevertheless, the values are suitable for comparing alternatives using TBP as a screening exercise. These values along with %TOC for the mixed layer and the peak and average mixed layer sediment concentrations for the 500 years simulated in Task 16 for each scenario were used in the calculation of the TBP.

Table 17-1. Assumptions for TBP Calculation

Parameter	Blue Crab	Catfish	Clam
Lipid Content (%)	0.8	6.2	2.2
BSAF	0.022	0.044	0.070

TBP

The total bioaccumulation potential is used to determine the contaminant concentration at which a specific species may become exposed to the contaminant through ingestion of sediment as its only source of contamination. The TBP presented here considers only the consumption of contaminated sediments and does not take into account the consumption of previously contaminated organisms.

For this analysis, the peak and average sediment concentrations for the mixed layer over the 500-yr simulation period were used in the calculation of the peak and an average TBP over time. This provides a worst-case scenario with the peak value and a more likely to occur average sediment concentration in which organisms may be exposed to the contaminant. Results from both analyses may be found below in Tables 17-2 and 17-

From the results, the catfish have the highest potential for bioaccumulation, which should be expected as it has the highest lipids content. Clarke *et al.* (1991) notes that in general, the higher the total lipids content of an organism, the greater its capacity for bioaccumulation. The clam and blue crab have lower potential for bioaccumulation, with the clam's being slightly higher. In a case-by-case comparison, the dump placement of backfill in the 6N alternative creates the highest potential for bioaccumulation due the likelihood of resuspending material and mixing of the backfill with the contaminated residuals. As expected, the best practice placement of backfill in the full removal alternative resulted in the lowest potential of bioaccumulation for all species. It is considerably lower than the potential for all other backfill methods, including the TBP of the current TCRA cap of the 3N alternative.

Conclusions

Both capping as performed in Alternative 3N and removal as performed in Alternative 6N are very effective; however, dredging is only particularly effective if backfill is placed without disturbing the residual. Backfilling must be performed by raining or placement in two layers. Post-remediation contaminant releases from the remediation area will be much smaller than the releases from the rest of the area within the Preliminary Site Perimeter.

Table 17-2. Peak Total Bioaccumulation Potential

RECOVERY Scenario		TOC (%)	Peak Mixed Layer TCDD Concentration (ng/kg)	Peak Blue Crab TBP (ppq)	Peak Catfish TBP (ppq)	Peak Clam TBP (ppq)
Surrounding Conditions		4	10.	44.0	682	385
3N Eastern Cell	5N Footprint	0.5	0.369	13.0	202	113
	5aN Increment	0.5	0.329	11.6	179	101
	6N Increment	0.5	0.275	9.6	150	84.5
3N Northwestern Area	5N Footprint	0.5	4.55E-05	1.60E-03	2.50E-02	1.40E-02
	5aN Increment	0.5	4.55E-05	1.60E-03	2.50E-02	1.40E-02
	6N Increment	0.5	4.55E-05	1.60E-03	2.50E-02	1.40E-02
6N Dump Placement	5N Footprint	1	416	7,319	114,000	64,200
	5aN Increment	1	136	2,390	37,100	21,000
	6N Increment	1	98.5	1,735	26,900	15,200
6N Raining Placement	5N Footprint	1	0.127	2.22	34.6	19.6
	5aN Increment	1	0.042	0.740	11.34	6.37
	6N Increment	1	0.030	0.529	8.20	4.63
6N Best Practice Placement	5N Footprint	1	3.06E-17	5.39E-16	8.34E-15	4.71E-15
	5aN Increment	1	1.00E-17	1.76E-16	2.73E-15	1.54E-15
	6N Increment	1	7.25E-17	1.28E-16	1.98E-15	1.12E-15

Table 17-3. Average Total Bioaccumulation Potential

RECOVERY Scenario		TOC (%)	Average Mixed Layer TCDD Conc. (ng/kg)	Average Blue Crab TBP (ppq)	Average Catfish TBP (ppq)	Average Clam TBP (ppq)
Surrounding Conditions		4	0.489	2.137	33.4	14.0
3N Eastern Cell	5N Footprint	0.5	7.44E-03	0.254	4.05	2.32
	5aN Increment	0.5	6.63E-03	0.233	3.61	2.03
	6N Increment	0.5	5.53E-03	0.190	3.02	1.69
3N Northwestern Area	5N Footprint	0.5	9.17E-07	3.24E-05	5.00E-04	2.82E-04
	5aN Increment	0.5	9.17E-07	3.24E-05	5.00E-04	2.82E-04
	6N Increment	0.5	9.17E-07	3.24E-05	5.00E-04	2.82E-04
6N Dump Placement	5N Footprint	1	20.3	358	5534	3128
	5aN Increment	1	6.65	117	1814	1023
	6N Increment	1	4.81	84.6	1312	739
6N Raining Placement	5N Footprint	1	8.09E-03	0.148	2.21	1.26
	5aN Increment	1	2.64E-03	0.042	0.721	0.386
	6N Increment	1	1.92E-03	0.042	0.525	0.290
6N Best Practice Placement	5N Footprint	1	2.40E-18	4.23E-17	6.55E-16	3.70E-16
	5aN Increment	1	7.87E-19	1.39E-17	2.15E-16	1.21E-16
	6N Increment	1	5.69E-19	1.00E-17	1.55E-16	8.79E-17

Task 18

Statement

Assess the potential for release of material from the waste pits caused by a storm occurring during a removal/dredging operation; identify and evaluate measures for mitigating/reducing any such releases.

Findings

The modeling performed in Task 14 clearly demonstrated that sediment residuals are predicted to be eroded from the areas that would be dredged in the Eastern Cell and Northwestern Area even during non-storm, *i.e.*, normal, conditions under routine high flow conditions. If a storm, *e.g.*, tropical storm or high flows under flood conditions in the SJR, occurred during the actual removal/dredging operation, the likelihood of extremely significant releases of contaminated sediment occurring is very high. There is the potential to erode exposed sediments as well as residuals without a resuspension BMP or if a silt curtain is used as the resuspension BMP. A silt curtain would not be able to withstand the forces of high flow or waves and therefore the bottom shear stresses would not be controlled. The mass of sediment residuals that would erode from the locations where removal and/or dredging operations had been performed would be significantly greater (at least several times greater depending on the magnitude of the hydrodynamic event) than that found from the modeling performed in Task 14 or predictions of releases presented in Tasks 11 and 12. Likewise, the portion of the estuary that would be exposed to the released contaminated sediments during a storm event would most likely be significantly larger than the zone of exposure identified in Task 14. It would probably even include significant portions of the floodplain since the latter would be inundated to some extent during any storm with a return period greater than approximately 2 years.

The only BMPs that would be capable of preventing most of the contaminated sediment releases would be a substantial containment structures to isolate the removal operations, residuals and exposed sediment. The containment structures could consist of berms and sheet pile walls or caissons to an elevation of about +9 NAVD88. If performing excavation of the sediments in the dry, the top of the berms would preferably be no lower than +4 NAVD88.

Without complete isolation by containment structures (*i.e.*, where water exchange is permitted to equilibrate the water surface elevation on both sides of the containment structure) or when the containment elevation is less than about +5 NAVD88, erosion of recently formed dredging residuals by the bottom shear stresses resulting from flow through the gaps and over the walls, depending on the magnitude of the flooding, would be expected; however, very limited erosion of exposed sediment would be expected. Recently formed residuals could contain up to about 1% of the contaminant mass. In these circumstances, it would be advisable to perform the removals in small sections at a time such that the armor stone and geotextile within the small section would be removed, and then the sediment removed and a thin layer of sacrificial fill placed before advancing to the next section and repeating the process. Under these removal operations, it would also be advisable to limit or restrict removal activities to a period when there is a lower probability of tropical storms and flooding conditions.

Task 19

Statement

Estimate the rate of natural attenuation in sediment concentrations / residuals and recommend a monitoring program to evaluate the progress. Discuss the uncertainty regarding the rate of natural attenuation.

Findings

Based on the modeling performed in Tasks 2, 3, 4, and 14, the estimated range of net sedimentation rates (NSR) at the site is 1.3 cm/yr ± 0.8 cm/yr. This NSR is the average value over the entire cap, and it is important to keep in mind that the NSR was calculated by averaging the instances of both erosion and deposition in each grid cell over the simulated time period. The latter included long periods of fair (*i.e.*, normal) weather, as well as high energy events including storms and floods. The positive value, i.e., 1.3 cm/yr, indicates that there was, averaged over the cap, more deposition than erosion, albeit a small net site-averaged quantity per year. Nevertheless, even this relatively low average NSR on the cap is predicted to maintain the cap's effectiveness, and will contribute to the rate of natural attenuation in the contaminated sediment concentrations found from the 500-year simulations performed using RECOVERY (as described in Task 16). The average NSR of 1.3 cm/yr is based on the modeling performed in previous tasks, as well as the analysis performed by AQ (Anchor QEA 2012). The uncertainty in the long-term NSR of ± 0.8 cm/yr is based on the sensitivity analysis performed in Task 4, and is in the same range as that given by AQ (Anchor QEA 2012).

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Appendix A

Description of LTFATE Modeling System

LTFATE is a multi-dimensional modeling system maintained by ERDC (Hayter *et al*. 2012). The hydrodynamic module in LTFATE is the Environmental Fluid Dynamics Code (EFDC) surface water modeling system (Hamrick 2007a; 2007b; and 2007c). EFDC is a public domain, three-dimensional finite difference model that contains dynamically linked hydrodynamic and sediment transport modules. Brief descriptions of these two modules are described below.

Hydrodynamic module in LTFATE

EFDC can simulate barotropic and baroclinic flow in a water body due to astronomical tides, wind, density gradients, and river inflow. It solves the three-dimensional (3D), vertically hydrostatic, free surface, turbulence averaged equations of motion. EFDC is extremely versatile, and can be used for 1D, 2D-laterally averaged (*2DV*), 2D-vertically averaged (2DH), or 3D simulations of rivers, lakes, reservoirs, estuaries, coastal seas, and wetlands.

For realistic representation of horizontal boundaries, the governing equations in EFDC are formulated such that the horizontal coordinates, x and y, are curvilinear. To provide uniform resolution in the vertical direction, the sigma (stretching) transformation is used. The equations of motion and transport solved in EFDC are turbulence-averaged, because prior to averaging, although they represent a closed set of instantaneous velocities and concentrations, they cannot be solved for turbulent flows. A statistical approach is applied, where the instantaneous values are decomposed into mean and fluctuating values to enable the solution. Additional terms that represent turbulence are introduced to the equations for the mean flow. Turbulent equations of motion are formulated to utilize the Boussinesq approximation for variable density. The Boussinesq approximation accounts for variations in density only in the gravity term. This assumption simplifies the governing equations significantly, but may introduce large errors when density gradients are large.

The resulting governing equations, presented in Appendix B, include parameterized, Reynolds-averaged stress and flux terms that account for the turbulent diffusion of momentum, heat and salt. The turbulence parameterization in EFDC is based on the Mellor and Yamada (1982) level 2.5 turbulence closure scheme, as modified by Galperin *et al*. (1988), that relates turbulent correlation terms to the mean state variables. The EFDC model also solves several transport and transformation equations for different dissolved and suspended constituents, including suspended sediments, toxic contaminants, and water quality state variables. Detailed descriptions of the model formulation and numerical solution technique used in EFDC are provided by Hamrick (2007b). Additional capabilities of EFDC include: 1) simulation of wetting and drying of flood plains, mud flats, and tidal marshes; 2) integrated, near-field mixing zone model; 3) simulation of hydraulic control structures such as dams and culverts; and 4) simulation of wave boundary layers and wave-induced mean currents. A more detailed description of EFDC is given in Appendix B.

Sediment transport module

The sediment transport model in LTFATE is a modified version of the SEDZLJ mixed sediment transport model (Jones and Lick 2001; James *et al*. 2010) that a) includes a three-dimensional representation of the sediment bed, and b) can simulate winnowing and armoring of the surficial layer of the sediment bed. SEDZLJ is dynamically linked to LTFATE in that the hydrodynamics and sediment transport modules are both run during each model time step. This enables simulated changes in morphology to be instantly fed-back to the hydrodynamic model. A more detailed description of SEDZLJ is given in Appendix C.

One of the first steps in performing sediment transport modeling is to use grain size distribution data from sediment samples collected at different locations throughout the model domain to determine how many discrete sediment size classes are needed to adequately represent the full range of sediment sizes. Typically, three to eight size classes are used. For example, AQ used four sediment size classes in their sediment transport model of the SJR. One size class was used to represent sediment in the cohesive sediment size range, 5 μm, and three size classes were used to represent the noncohesive sediment size range, 140, 510 and 3,500 μm.

Appendix B

Description of LTFATE Hydrodynamic Module

EFDC is a public domain, 3D finite difference model that contains dynamically linked hydrodynamic and sediment transport modules. EFDC can simulate barotropic and baroclinic flow in a water body due to astronomical tides, wind, density gradients, and river inflow. It solves the 3D vertically hydrostatic, free surface, turbulence averaged equations of motion. EFDC can be used for 1D, 2D-laterally averaged (*2DV*), 2D-vertically averaged (2DH), or 3D simulations of rivers, lakes, reservoirs, estuaries, coastal seas, and wetlands.

EFDC solves the 3D Reynolds-averaged equations of continuity (Equation B-1), linear momentum (Equations B-2 and B-3), hydrostatic pressure (Equation B-4), equation of state (Equation B-5) and transport equations for salinity and temperature (Equations B-6 and B-7) written for curvilinear-orthogonal horizontal coordinates and a sigma (stretching) vertical coordinate. These are given by Hamrick (2007b) and repeated below:

$$\frac{\partial(m\varepsilon)}{\partial t} + \frac{\partial(m_y Hu)}{\partial x} + \frac{\partial(m_x Hv)}{\partial y} + \frac{\partial(mw)}{\partial z} = 0 \qquad \text{(B-1)}$$

$$\frac{\partial(mHu)}{\partial t} + \frac{\partial(m_y Huu)}{\partial x} + \frac{\partial(m_x Hvu)}{\partial y} + \frac{\partial(mwu)}{\partial z} - \left(mf + v\frac{\partial(m_y)}{\partial x} - u\frac{\partial m_x}{\partial y}\right)Hv = m_y H\frac{\partial(g\varepsilon + p)}{\partial x} - m_y\left(\frac{\partial H}{\partial x} - z\frac{\partial H}{\partial x}\right)\frac{\partial p}{\partial z} + \frac{\partial\left(mH^{-1}A_v\frac{\partial u}{\partial z}\right)}{\partial z} + Q_u \qquad \text{(B-2)}$$

$$\frac{\partial(mHv)}{\partial t}+\frac{\partial(m_yHuv)}{\partial x}+\frac{\partial(m_xHvv)}{\partial y}+\frac{\partial(mwv)}{\partial z}+$$

$$(mf+v\frac{\partial(m_y)}{\partial x}+u\frac{\partial m_x}{\partial y})Hu=m_xH\frac{\partial(g\varepsilon+p)}{\partial y}- \qquad \text{(B-3)}$$

$$m_x(\frac{\partial H}{\partial y}-z\frac{\partial H}{\partial y})\frac{\partial p}{\partial z}+\frac{\partial(mH^{-1}A_v\frac{\partial v}{\partial z})}{\partial z}+Q_v$$

$$\frac{\partial p}{\partial z}=\frac{gH(\rho-\rho_o)}{\rho_o}=gHb \qquad \text{(B-4)}$$

$$\rho=\rho\left(\rho,S,T\right) \qquad \text{(B-5)}$$

$$\frac{\partial(mHS)}{\partial t}+\frac{\partial(m_yHuS)}{\partial x}+\frac{\partial(m_xHvS)}{\partial y}+\frac{\partial(mwS)}{\partial z}=\frac{\partial(\frac{mA_b}{H}\frac{\partial S}{\partial z})}{\partial z}+Q_s \qquad \text{(B-6)}$$

$$\frac{\partial(mHT)}{\partial t}+\frac{\partial(m_yHuT)}{\partial x}+\frac{\partial(m_xHvT)}{\partial y}+\frac{\partial(mwT)}{\partial z}=\frac{\partial(\frac{mA_b}{H}\frac{\partial T}{\partial z})}{\partial z}+Q_T \qquad \text{(B-7)}$$

where u and v are the mean horizontal velocity components in (x,y) coordinates; m_x and m_y are the square roots of the diagonal components of the metric tensor, and $m= m_x m_y$ is the Jacobian or square root of the metric tensor determinant; p is the pressure in excess of the reference pressure, $\frac{\rho_o gH(1-z)}{\rho_o}$, where ρ_o is the reference density; f is the Coriolis parameter for latitudinal variation; A_v is the vertical turbulent viscosity; and A_b is the vertical turbulent diffusivity. The buoyancy b in Equation B-4 is the normalized deviation of density from the reference value. Equation B-5 is the equation of state that calculates water density, ρ, as functions of p, salinity, S, and temperature, T.

The sigma (stretching) transformation and mapping of the vertical coordinate is given as:

$$z=\frac{(z^*+h)}{(\xi+h)} \qquad \text{(B-8)}$$

where z^* is the physical vertical coordinate, and h and ξ are the depth below and the displacement about the undisturbed physical vertical coordinate origin, $z^* = 0$, respectively, and $H=h+\xi$ is the total depth. The vertical velocity in z coordinates, w, is related to the physical vertical velocity w^* by:

$$w = w^* - z\left(\frac{\partial \xi}{\partial t} + \frac{u}{m_x}\frac{\partial \xi}{\partial x} + \frac{v}{m_y}\frac{\partial \xi}{\partial y}\right) + (1-z)\left(\frac{u}{m_x}\frac{\partial h}{\partial x} + \frac{v}{m_y}\frac{\partial h}{\partial y}\right) \qquad \text{(B-9)}$$

The solutions of Equations B-2, B-3, B-6 and B-7 require the values for the vertical turbulent viscosity and diffusivity and the source and sink terms. The vertical eddy viscosity and diffusivity, A_v and A_b, are parameterized according to the level 2.5 (second-order) turbulence closure model of Mellor and Yamada (1982), as modified by Galperin *et al*. (1988), in which the vertical eddy viscosities are calculated based on the turbulent kinetic energy and the turbulent macroscale equations. The Mellor and Yamada level 2.5 (MY2.5) turbulence closure model is derived by starting from the Reynolds stress and turbulent heat flux equations under the assumption of a nearly isotropic environment, where the Reynolds stress is generated due to the exchange of momentum in the turbulent mixing process. To make the turbulence equations closed, all empirical constants are obtained by assuming that turbulent heat production is primarily balanced by turbulent dissipation.

The vertical turbulent viscosity and diffusivity are related to the turbulent intensity, q^2, turbulent length scale, l and a Richardson number R_q as follows:

$$A_v = \Phi_v ql = 0.4(1+36R_q)^{-1}(1+6R_q)^{-1}(1+8R_q)ql \qquad \text{(B-10)}$$

$$A_b = \Phi_b ql = 0.5(1+36R_q)^{-1}ql \qquad \text{(B-11)}$$

where A_v and A_b are stability functions that account for reduced and enhanced vertical mixing or transport in stable and unstable vertical, density-stratified environments, respectively, and the local Richardson number is given as:

$$R_q = \frac{gH\frac{\partial b}{\partial z}}{q^2}\frac{l^2}{H^2} \tag{B-12}$$

A critical Richardson number, R_q = 0.20, was found at which turbulence and mixing cease to exist (Mellor and Yamada 1982). Galperin *et al.* (1988) introduced a length scale limitation in the MY scheme by imposing an upper limit for the mixing length to account for the limitation of the vertical turbulent excursions in stably stratified flows. They also modified and introduced stability functions that account for reduced or enhanced vertical mixing for different stratification regimes.

The turbulence intensity (q^2) and the turbulence length scale (l) are computed using the following two transport equations:

$$\frac{\partial(mHq^2)}{\partial t} + \frac{\partial(m_y Huq^2)}{\partial x} + \frac{\partial(m_x Hvq^2)}{\partial y} + \frac{\partial(mwq^2)}{\partial z} = \frac{\partial(\frac{mA_q \frac{\partial q^2}{\partial z}}{H})}{\partial z} + Q_q \tag{B-13}$$
$$+2\frac{mA_v}{H}((\frac{\partial^2 u}{\partial z^2}) + (\frac{\partial^2 v}{\partial z^2})) + 2mgA_b\frac{\partial b}{\partial z} - 2mH(\frac{q^3}{(B_1 l)})$$

$$\frac{\partial(mHq^2 l)}{\partial t} + \frac{\partial(m_y Huq^2 l)}{\partial x} + \frac{\partial(m_x Hvq^2 l)}{\partial y} + \frac{\partial(mwq^2 l)}{\partial z} =$$
$$\frac{\partial(\frac{mA_q \frac{\partial q^2 l}{\partial z}}{H})}{\partial z} + Q_l + 2\frac{mE_1 lA_v}{H}((\frac{\partial^2 u}{\partial z^2}) + (\frac{\partial^2 v}{\partial z^2})) + mgE_1E_3lA_b\frac{\partial b}{\partial z} \tag{B-14}$$
$$-H(\frac{q^3}{(B_1)})(1 + E_2(\kappa L)^{-2} l^2)$$

The above two equations include a wall proximity function, $W = 1 + E_2 l(\kappa L)^{-2}$, that assures a positive value of diffusion coefficient $L^{-1} = (H)^{-1}(z^{-1} + (1-z)^{-1})$). κ, B_1, E_1, E_2, and E_3 are empirical constants with values 0.4, 16.6, 1.8, 1.33, and 0.25, respectively. All terms with *Q's* (Q_u, Q_v, Q_q, Q_l, Q_s, Q_T) are sub-grid scale sink-source terms that are modeled as sub-grid scale horizontal diffusion. The vertical diffusivity, A_q, is in general taken to be equal to the vertical turbulent viscosity, A_v (Hamrick 2007b).

The vertical boundary conditions for the solutions of the momentum equations are based on the specification of the kinematic shear stresses. At the bottom, the bed shear stresses are computed using the near bed velocity components (u_1,v_1) as:

$$(\tau_{bx},\tau_{by}) = c_b\sqrt{u_1^2+v_1^2}(u_1,v_1) \tag{B-15}$$

where the bottom drag coefficient $c_b = (\frac{\kappa}{\ln(\Delta_1/2z_o)})^2$, where κ is the von Karman constant, Δ_1 is the dimensionless thickness of the bottom layer, $z_o = z_o^*/H$ is the dimensionless roughness height, and z_o^* is roughness height in meters. At the surface layer, the shear stresses are computed using the u, v components of the wind velocity (u_w,v_w) above the water surface (usually measured at 10 m above the surface) and are given as:

$$(\tau_{sx},\tau_{sy}) = c_s\sqrt{u_w^2+v_w^2}(u_w,v_w) \tag{B-16}$$

where $c_s = 0.001\frac{\rho_a}{\rho_w}(0.8+0.065\sqrt{u_w{}^2+v_w^2})$ and ρ_a and ρ_w are the air and water densities, respectively. Zero flux vertical boundary conditions are used for the transport equations.

Numerically, EFDC is second-order accurate both in space and time. A staggered grid or C-grid provides the framework for the second-order accurate spatial finite differencing used to solve the equations of motion. Integration over time involves an internal-external mode splitting procedure separating the internal shear, or baroclinic mode, from the external free surface gravity wave, or barotropic mode. In the external mode, the model uses a semi-implicit scheme that allows the use of relatively large time steps. The internal equations are solved at the same time step as the external equations, and are implicit with respect to vertical diffusion. Details of the finite difference numerical schemes used in the EFDC model are given in Hamrick (2007b), and will not be presented in this report.

The generic transport equation solved in EFDC for a dissolved (*e.g.*, chemical contaminant) or suspended (*e.g.*, sediment) constituent having a mass per unit volume concentration C, is

$$\frac{\partial m_x m_y HC}{\partial t}+\frac{\partial m_y HuC}{\partial_x}+\frac{\partial m_x HvC}{\partial y}+\frac{\partial m_x m_y wC}{\partial z}-\frac{\partial m_x m_y w_{sc} C}{\partial z}= \frac{\partial}{\partial_x}\left(\frac{m_y}{m_x}HK_H\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial_y}\left(\frac{m_x}{m_y}HK_H\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial_z}\left(m_x m_y\frac{K_v}{H}\frac{\partial C}{\partial z}\right)+Q_c \quad \text{(B-17)}$$

where K_V and K_H are the vertical and horizontal turbulent diffusion coefficients, respectively; w_{sc} is a positive settling velocity when C represents the mass concentration of suspended sediment; and Q_c represents external sources or sinks and reactive internal sources or sinks. For sediment, $C = S_i$, where S_i represents the concentration of the *ith* sediment class. So, Eq. B-17, which is the 3D advective-dispersive transport equation, is solved for each of the sediment size classes that the grain size distribution at the site is divided into. In this case, Q_{ci} = source/sink term for the *ith* sediment size class that accounts for erosion/deposition. The equation used to calculate Q_{ci} is the following:

$$S_i = E_{sus,i} - D_{sus,i} \quad \text{(B-18)}$$

where $E_{sus,i}$ = sediment erosion rate for the *ith* sediment size class that is eroded and entrained into suspension, and $D_{sus,i}$ = sediment deposition rate for the *ith* sediment size class. Expressions for $D_{sus,i}$ and $E_{sus,i}$ are given later in this chapter.

The solution procedure for Eq. B-17 is the same as that for the salinity and heat transport equations, which use a high-order upwind difference solution scheme for the advection terms (Hamrick 2007b). Although the advection scheme is designed to minimize numerical diffusion, a small amount of horizontal diffusion remains inherent in the numerical scheme. As such, the horizontal diffusion terms in Equation B-17 are omitted by setting K_H equal to zero.

Appendix C

Description of LTFATE Sediment Transport Module

The sediment transport model in LTFATE is a modified version of the SEDZLJ mixed sediment transport model (Jones and Lick 2001; James *et al*. 2010) that includes a 3D representation of the sediment bed, and can simulate winnowing and armoring of the surficial layer of the sediment bed. SEDZLJ is dynamically linked to LTFATE in that the hydrodynamic and sediment transport modules are both run during each model time step.

Suspended Load Transport of Sediment

LTFATE solves Equation B-17 for the transport of each of the sediment classes to determine the suspension concentration for each size class in every water column layer in each grid cell. Included in this equation is the settling velocity, w_{sc}, for each sediment size class. The settling velocities for noncohesive sediments are calculated in SEDZLJ using the following equation (Cheng 1997):

$$W_s = \frac{\mu}{d}\left(\sqrt{25+1.2d_*^2}-5\right)^{\frac{3}{2}} \quad \text{(C-1)}$$

where μ = dynamic viscosity of water; d = sediment diameter; and d_* = non-dimensional particle diameter given by:

$$d_* = d\left[\left(\rho_s/\rho_w - 1\right)g/\nu^2\right]^{1/3} \quad \text{(C-2)}$$

where ρ_w = water density, ρ_s = sediment particle density, g = acceleration due to gravity, and ν = kinematic fluid viscosity. Cheng's formula is based on measured settling speeds of real sediments. As a result it produces slower settling speeds than those given by Stokes' Law because real sediments have irregular shapes and thus a greater hydrodynamic resistance than perfect spheres as assumed in Stokes' law.

For the cohesive sediment size classes, the settling velocities are set equal to the mean settling velocities of flocs and eroded bed aggregates determined from an empirical formulation that is a function of the concentration of suspended sediment.

The erosion and deposition of each of the sediment size classes, *i.e.*, the source/sink term in the 3D transport equation (Equation C-17), and the subsequent change in the composition and thickness of the sediment bed in each grid cell are calculated by SEDZLJ at each time step.

Description of SEDZLJ

The sediment bed model in LTFATE is the SEDZLJ sediment transport model (Jones and Lick 2001). SEDZLJ is dynamically linked to EFDC in LTFATE. SEDZLJ is an advanced sediment bed model that represents the dynamic processes of erosion, bedload transport, bed sorting, armoring, consolidation of fine-grain sediment dominated sediment beds, settling of flocculated cohesive sediment, settling of individual noncohesive sediment particles, and deposition. An active layer formulation is used to describe sediment bed interactions during simultaneous erosion and deposition. The active layer facilitates coarsening during the bed armoring process.

Figure C-1 shows the simulated sediment transport processes in SEDZLJ. In this figure, U = near bed flow velocity, δ_{bl} = thickness of layer in which bedload occurs, U_{bl} = average bedload transport velocity, D_{bl} = sediment deposition rate for the sediment being transported as bedload E_{bl} = sediment erosion rate for the sediment being transported as bedload, E_{sus} = sediment erosion rate for the sediment that is eroded and entrained into suspension, and D_{sus} = sediment deposition rate for suspended sediment. Specific capabilities of SEDZLJ are listed below.

- Whereas a hydrodynamic model is calibrated to account for the total bed shear stress, which is the sum of the form drag due to bed forms and other large-scale physical features and the skin friction (also called the surface friction), the correct component of the bed shear stress to

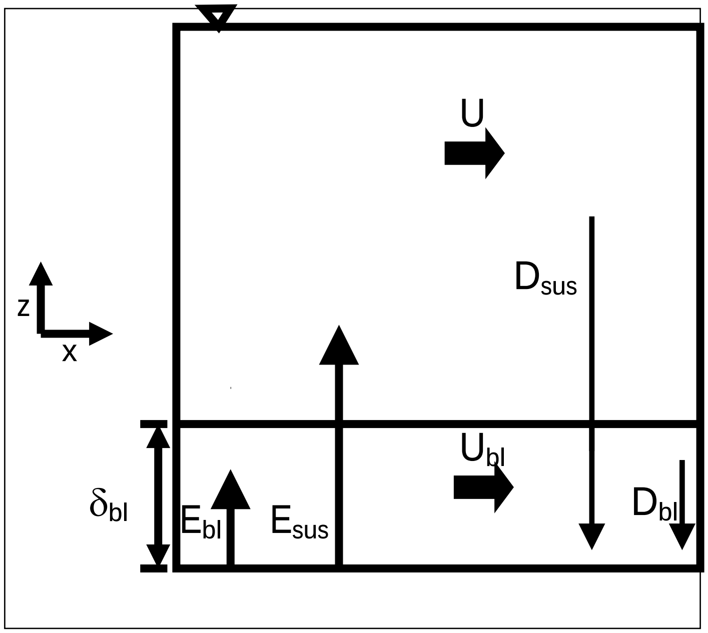


Figure C-1. Sediment transport processes simulated in SEDZLJ.

use in predicting sediment resuspension and deposition is the skin friction. The skin friction is calculated in SEDZLJ as a function of the near-bed current velocity and the effective bed roughness. The latter is specified in SEDZLJ as a linear function of the mean particle diameter in the active layer.

Multiple size classes of both fine-grain (*i.e.*, cohesive) and noncohesive sediments can be represented in the sediment bed. As stated previously, this capability is necessary to simulate coarsening and subsequent armoring of the surficial sediment bed surface during high flow events.

- To correctly represent the processes of erosion and deposition, the sediment bed in SEDZLJ can be divided into multiple layers, some of which are used to represent the existing sediment bed and others that are used to represent new bed layers that form due to deposition during model simulations. Figure C-2 shows a schematic diagram of this multiple bed layer structure. The graph on the right hand side of this figure shows the variation in the measured gross erosion rate (in units of *cm/s*) with depth into the sediment bed as a function of the applied skin friction. A SEDFLUME study is normally used to measure these erosion rates.

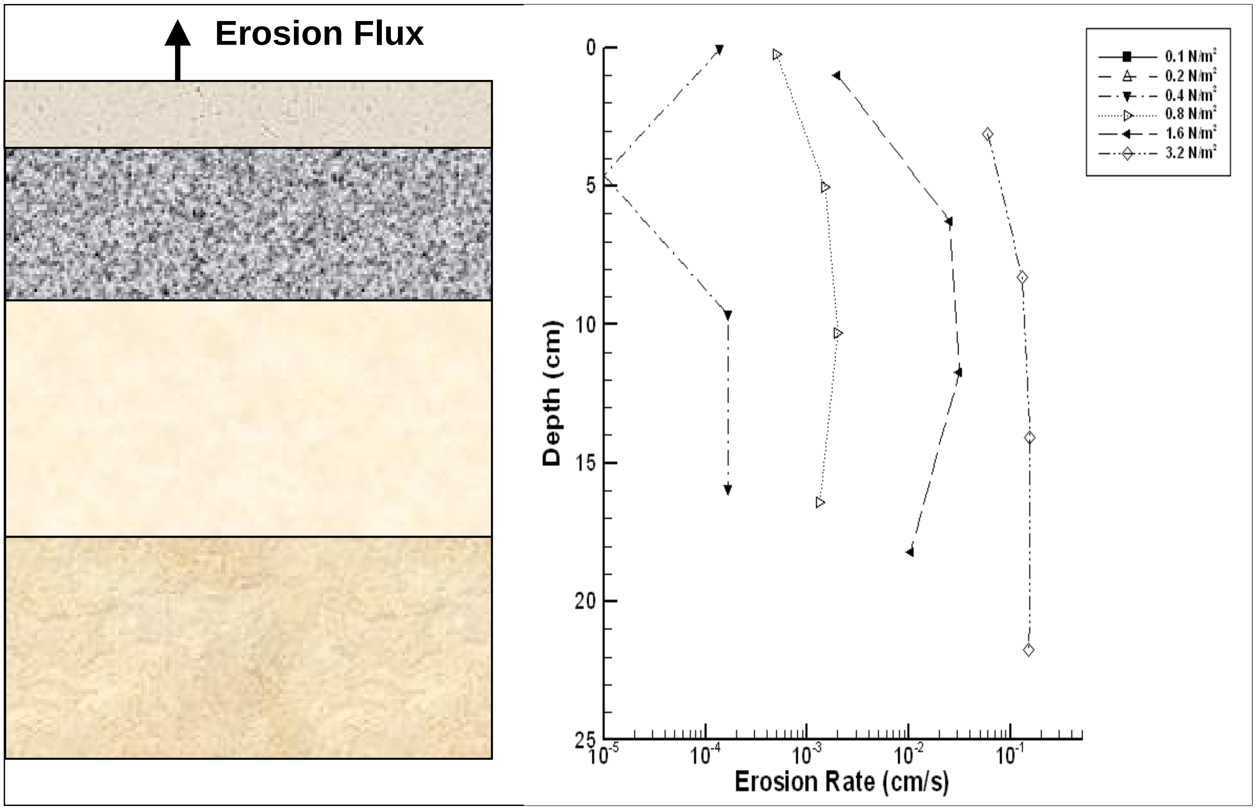


Figure C-2. Multi-bed layer model used in SEDZLJ.

- Erosion from both cohesive and non-cohesive beds is affected by bed armoring, which is a process that limits the amount of bed erosion that occurs during a high-flow event. Bed armoring occurs in a bed that contains a range of particle sizes (*e.g.*, clay, silt, sand). During a high-flow event when erosion is occurring, finer particles (*i.e.*, clay and silt, and fine sand) tend to be eroded at a faster rate than coarser particles (*i.e.*, medium to coarse sand). The differences in erosion rates of the various sediment particle sizes creates a thin layer at the surface of the sediment bed, referred to as the active layer, that is depleted of finer particles and enriched with coarser particles. This depletion-enrichment process can lead to bed armoring, where the active layer is primarily composed of coarse particles that have limited mobility. The multiple bed model in SEDZLJ accounts for the exchange of sediment through and the change in composition of this active layer. The thickness of the active layer is normally calculated as a time varying function of the mean sediment particle diameter in the active layer, the critical shear stress for resuspension corresponding to the mean particle diameter, and the bed shear stress. Figure C-3 shows a schematic of the active layer at the top of the multi-bed layer model used in SEDZLJ.

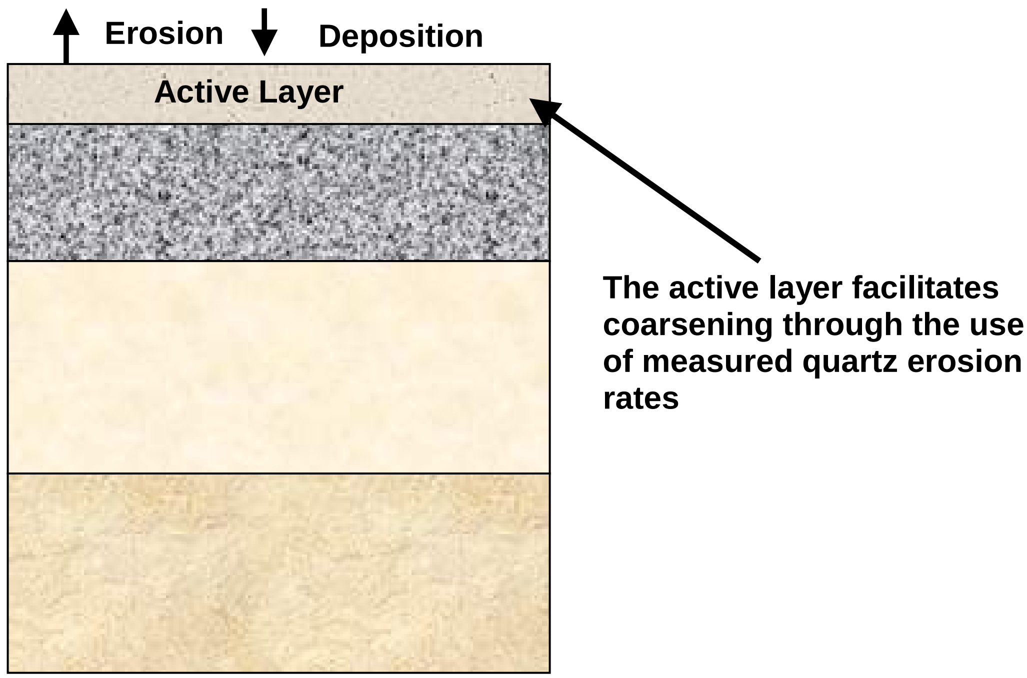


Figure C-3. Schematic of Active Layer used in SEDZLJ.

- SEDZLJ was designed to use the results obtained with SEDFLUME, which is a straight, closed conduit rectangular cross-section flume in which detailed measurements of critical shear stress of erosion and erosion rate as a function of sediment depth are made using sediment cores dominated by cohesive sediment collected at the site to be modeled (McNeil *et al*. 1996). However, when SEDFLUME results are not available, it is possible to use a combination of values for these parameters available from literature and/or the results of SEDFLUME tests performed at other similar sites. In this case, a detailed sensitivity analysis should be performed to assist in quantifying the uncertainty that results from the use of these non-site specific erosion parameters.

- SEDZLJ can simulate overburden-induced consolidation of cohesive sediments. An algorithm that simulates the process of primary consolidation, which is caused by the expulsion of pore water from the sediment, of a fine-grained, *i.e.*, cohesive, dominated sediment bed is included in SEDZLJ. The consolidation algorithm in SEDZLJ accounts for the following changes in two important bed parameters: 1) increase in bed bulk density with time due to the expulsion of pore water, and 2) increase in the bed shear strength (also referred to as the critical shear stress for resuspension) with time. The latter parameter is the minimum value of the bed shear stress at which measurable resuspension of cohesive sediment occurs. As such, the process of consolidation typically results in reduced erosion for a given excess bed shear stress (defined as the difference between the bed shear stress and the critical shear stress for erosion) due to the increase in the bed shear strength. In addition, the increase in bulk density needs to be represented to accurately account for the mass of sediment (per unit bed area) that resuspends when the bed surface is subjected to a flow-induced excess bed shear stress.

Models that represent primary consolidation range from empirical equations that approximate the increases in bed bulk density and critical shear stress for resuspension due to porewater expulsion (Sanford 2008) to finite difference models that solve the non-linear finite strain consolidation equation that governs primary consolidation in saturated porous media (*e.g.*, Arega and Hayter 2008). An empirical-based consolidation algorithm is included in SEDZLJ.

- SEDZLJ contains a morphologic algorithm that, when enabled by the model user, will adjust the bed elevation to account for erosion and deposition of sediment.

Bedload Transport of Noncohesive Sediment

The approach used by Van Rijn (1984) to simulate bedload transport is used in SEDZLJ. The 2D mass balance equation for the concentration of sediment moving as bedload is given by:

$$\frac{\partial(\delta_{bl}C_b)}{\partial t} = \frac{\partial q_{b,x}}{\partial x} + \frac{\partial q_{b,y}}{\partial y} + Q_b \qquad \text{(C-3)}$$

where δ_{bl} = bedload thickness; C_b = bedload concentration; $q_{b,x}$ and $q_{b,y}$ = x- and y-components of the bedload sediment flux, respectively; and Q_b =

sediment flux from the bed. Van Rijn (1984) gives the following equation for the thickness of the layer in which bedload is occurring:

$$\delta_{bl} = 0.3 d d_*^{0.7} (\Delta\tau)^{0.5} \tag{C-4}$$

where $\Delta\tau = \tau_b - \tau_{ce}$; τ_b = bed shear stress, and τ_{ce} = critical shear stress for erosion.

The bedload fluxes in the *x*- and *y*-directions are given by:

$$q_{b,x} = \delta_{bl} u_{b,x} C_b$$

$$q_{b,y} = \delta_{bl} u_{b,y} C_b$$

where $u_{b,x}$ and $u_{b,y}$ = *x*- and *y*-components of the bedload velocity, u_b, which van Rijn (1984) gave as

$$u_b = 1.5 \tau_*^{0.6} \left[\left(\frac{\rho_s}{\rho_w} - 1 \right) g d \right]^{0.5} \tag{C-5}$$

with the dimensionless parameter τ_* given as

$$\tau_* = \frac{\tau_b - \tau_{ce}}{\tau_{ce}} \tag{C-6}$$

The *x*- and *y*-components of u_b are calculated as the vector projections of the LTFATE Cartesian velocity components *u* and *v*.

The sediment flux from the bed due to bedload, Q_{bl}, is equal to

$$Q_b = E_{bl} - D_{bl} \tag{C-7}$$

Deposition of Sediment

In contrast to previous conceptual models, deposition of suspended noncohesive sediment and cohesive flocs is now believed to occur continually, and not just when the bed shear stress is less than a so-called critical shear stress of deposition (Mehta 2014). The rate of deposition of the *ith* sediment size class, $D_{sus,i}$ is given by:

$$D_{sus,i} = -\frac{W_{s,i} C_i}{d} \tag{C-8}$$

where $W_{s,i}$ is given by Eq. C-1 for noncohesive sediment and by the empirical formulation used for the settling velocities of suspended flocs and bed aggregates, and d = thickness of the bottom water column layer in a three-dimensional model. Because of their high settling velocities, noncohesive sediments deposit relatively quickly (in comparison to the deposition of cohesive sediments) under all flows. Due to the settling velocities of flocs being a lot slower than those of noncohesive sediment, the deposition rate of flocs are usually several orders of magnitude smaller.

Deposited cohesive sediments usually form a thin surface layer that is often called a fluff or benthic nepheloid layer that is often less than 1 cm in thickness. The fluff layer typically forms in estuaries and coastal waters via deposition of suspended flocs during the decelerating phase of tidal flows, in particular immediately before slack water (Krone 1972; and Hayter and Mehta 1986). The fluff layer is usually easily resuspended by the accelerating currents following slack water in tidal bodies of water.

The rate of deposition of the *ith* noncohesive sediment class moving as bedload is given by (James *et al*. 2010):

$$D_{bl,i} = -P_{bl,i} W_{s,i} C_{bl,i} \tag{C-9}$$

where $C_{bl,i}$ = mass concentration of the *ith* noncohesive sediment class being transported as bedload, and $P_{bl,i}$ = probability of deposition from bedload transport. The latter parameter is given by:

$$P_{bl,i} = \frac{E_{bl,i}}{W_{s,i} C_{bl,i}^{eq}} \tag{C-10}$$

where

$$C_{bl,i}^{eq} = \frac{0.18 C_o \tau_b}{d_*} \tag{C-11}$$

which is the steady-state sediment concentration in bedload that results from a dynamic equilibrium between erosion and deposition, d_* is given by Eq. C-2, and C_o = 0.65.

Erosion of Sediment

Erosion of a cohesive sediment bed occurs whenever the current and wave-induced bed shear stress is great enough to break the electrochemical interparticle bonds (Partheniades 1965; Paaswell 1973). When this happens, erosion takes place by the removal of individual sediment particles or bed aggregates. This type of erosion is time dependent and is defined as surface erosion or resuspension. In contrast, another type of erosion occurs more or less instantaneously by the removal of relatively large pieces of the bed. This process is referred to as mass erosion, and occurs when the bed shear stress exceeds the bed bulk strength along some deep-seated plane that is typically much greater than the bed shear strength of the surficial sediment.

The erosion rate of cohesive sediments, E, is given experimentally by:

$$\begin{aligned} E &= 0; & (\tau < \tau_{cr}) \\ E &= A\tau^{n}; & (\tau_{cr} < \tau < \tau_{m}) \\ E &= A\tau_{m}^{n}; & (\tau > \tau_{m}) \end{aligned} \qquad \text{(C-12)}$$

where the exponent, coefficient, critical shear stress for erosion, and maximum shear stress (above which E is not a function of τ) n, A, and τ_{cr}, respectively, are determined from a SEDFLUME study. The erosion rates of the noncohesive sediment size classes were determined as a function of the difference between the bed shear stress and the critical shear stress for erosion using the results obtained by Roberts *et al.* (1998) who measured the erosion rates of quartz particles in a SEDFLUME.

The erosion rate of the *ith* noncohesive sediment size class that is transported as bedload, $E_{bl,i}$, is calculated by the following equation in which it is assumed there is dynamic equilibrium between erosion and deposition:

$$E_{bl,i} = P_{bl,i} W_{s,i} C_{bl,i} \qquad \text{(C-13)}$$

Appendix D

Description of LTFATE Propwash Module

The propwash module added to LTFATE simulates the near-bed flow field behind a moving vessel, specifically the velocity within the ship's propeller jet, and calculates the resulting bed shear stresses. The latter are vectorially added to the current and wave induced bed shear stresses and used to calculate the rates of sediment erosion. This module is described in this Appendix.

Data Requirements

The data needed to fully utilize the propwash module consists of the history of vessel movements in the SJR, especially near the Site, the types (e.g., tugboats, tankers, container ships), sizes, and drafts of the vessels; the diameter, applied horsepower, depths of the propeller shafts, and number of propellers on each of the vessels; the vessel speeds and paths, and the times when the vessels pass close to the Site. This would be an enormous database, but it was not available to EPA. A greatly simplified and idealized representation of such a database was constructed for use with the propwash module. Following the description of the propwash module in the next section, the methodology of incorporating it into the sediment transport simulations performed with LTFATE is described.

Description of Propwash Module

The approach described by Lam *et al.* (2011) was used to predict the time-averaged axial, rotational and radial components of the velocity field within a vessel's propeller jet. The axial component of the propeller's velocity jet contributes the most to the near bed velocity that induces the shear stress that acts on the surface of the sediment bed. The following equations given by Lam *et al.* are used to calculate the efflux velocity. Equation D-1 gives the basic equation for calculating the efflux velocity (V_e), which is the maximum velocity at the propeller's face.

$$V_e = E_o n D (C_t)^{\frac{1}{2}} \tag{D-1}$$

where E_o = efflux coefficient, n = rotation speed of the propeller (rps), D = propeller diameter (m), and C_t = propeller thrust coefficient. The latter is calculated using the area $A = \pi D^2/4$. The efflux coefficient is given by

$$E_o = \left(\frac{D}{D_h}\right)^{-0.403} C_t^{-1.79} BAR^{0.744} \tag{D-2}$$

where BAR = ratio of projected area of all propeller blades to the propeller disc area.

Another parameter that is needed is the distance, R_{mo}, from the rotation axis to the location where the axial velocity is maximum, at which the maximum thrust occurs. Hamill *et al.* (2004) found the following expression for this distance.

$$R_{mo} = 0.7(R - R_h) \tag{D-3}$$

where R = propeller radius, and R_h = radius of the propeller hub.

Using the values of R_{mo} and V_e, the maximum velocity and its location at different longitudinal distances can be predicted as follows for the zone of established flow. The following equation by Hashmi (1993) can be used to calculate the decay of the maximum velocity for a submerged jet, given by the ratio V_{max}/V_e, at a distance x from the initial efflux plane.

$$\frac{V_{max}}{V_e} = 0.638e^{(-0.097(x/D))} \tag{D-4}$$

Using the value of V_{max} at a given longitudinal distance x, the lateral velocity distribution ($V_{x,r}$) in the zone for established flow can be determined using the following equation.

$$\frac{V_{x,r}}{V_{max}} = e^{(-22.2(r/x)^2)} \tag{D-5}$$

where r = the lateral distance from the longitudinal axis.

Application of the Propwash Module

Equation D-5 was used to calculate $V_{x,r}$ for a tugboat at the position just above the bed surface using estimates for the parameters defined above. The tugboat used in the model simulations was assumed to have the same physical characteristics as that given by Ziegler *et al*. (2014), these being D = 1.8 m, depth of propeller shaft = 2.7 m, number of propellers = 2, maximum horsepower = 6,000, and the power applied was 50 percent.

The assumed path of a tugboat, that being parallel to the eastern side of the cap and approximately 30 m from the eastern cap edge, defined the direction of $V_{x,r}$, and this velocity was vectorially added to the current- and wave-induced near bottom flow velocity in the specified grid cells. The grid cells were defined to be those along the path of the tugboat and that fell within the distance 8D from the instantaneous location of the tugboat. It was assumed that the tugboat did not cross the cap due to the relatively shallow water over the inundated portion of the cap.

The total near bottom flow velocity was used to calculate the bed shear stress in the SEDZLJ sediment bed model, and subsequently used to calculate the erosion rate of the surficial sediment bed layer. During the month-long model simulation in which the propwash module was activated, it was assumed that a single tugboat moved along the specified path, alternating in directions six times over the duration of a tidal cycle. A few centimeters of scour occurred during each passage of the tugboat, with the depth of scour decreasing throughout the model simulation due to increasing bed shear strength with depth into the sediment bed. This resulted in a net scour of more than 70 cm in most of the grid cells along the chosen path.

Appendix E

Wave Modeling during Hurricane Ike

Purpose

The purpose of the numerical wave modeling is to estimate storm waves during Hurricane Ike at the northern Galveston Bay and Port of Houston.

Wave Model

Wave modeling was conducted using CMS-Wave, a steady-state two-dimensional spectral wave model (Lin *et al*. 2008; Lin *et al*. 2011a, 2011b) capable of simulating wind waves in the open coast or in a bay or estuarine system. CMS-Wave is part of an integrated Coastal Modeling System (Demirbilek and Rosati 2011) developed at CHL to assist in coastal region project applications.

CMS-Wave can be used either in half-plane or full-plane mode for wind wave generation and transformation. It is based on the wave-action balance equation that includes wave propagation, refraction, shoaling, diffraction, reflection, breaking, and dissipation. The half-plane mode is the default and CMS-Wave can run more efficiently in this mode as waves are transformed primarily from the seaward boundary toward shore.

In the present study, CMS-Wave full-plane mode was used to simulate storm wave conditions during Hurricane Ike at the northern Galveston Bay and Port of Houston. The CMS-Wave uses the Surface-water Modeling System, SMS (Demirbilek *et al*. 2007; Zundel 2006) interface for grid generation, model setup, and post-processing.

Model Domain, Bathymetry, and Forcing

Bathymetry Data

Bay bathymetry data available for the wave modeling included LiDAR (http://shoals.sam.usace.army.mil) and periodic channel surveys conducted by the USACE Galveston District. The offshore bathymetry data were obtained from the US Coastal Relief Model by National Geophysical Data Center, NGDC (http://www.ngdc.noaa.gov/mgg/coastal/crm.html). The upland topography was downloaded from NOAA Gridded Global Topography Database (http://www.ngdc.noaa.gov/mgg/topo/topo.html). The digital coastlines are available from GEOphysical DAta System GEODAS (https://www.ngdc.noaa.gov/mgg/geodas/geodas.html).

Model Grid

The CMS model domain covers the Galveston Bay system with navigation channels connecting GIWW, Port of Houston, and Gulf of Mexico. It includes the Houston-Galveston Ship Channel, Galveston Entrance Channel between the east end of Galveston Island and the west end of Bolivar Peninsula, San Luis Pass between the west end of Galveston Island and the east end of Follets Island, and Rollover Pass, a small man-made cut located at the lower east end of East Bay. Figure E-1 shows the Galveston Bay system included in the present wave modeling area.

The CMS model grid extends approximately 60 mi (95 km) alongshore and 54 mi (86 km) cross-shore with the southern offshore boundary reaching to the 60-ft (18-m) isobaths, referenced to Mean Sea Level (MSL). Figure E-2 shows the model domain consisting of 1166 × 1406 cells with variable cell spacing of 130 ft (40 m) along the Houston-Galveston Ship Channel and 660 ft (200 m) at the corners of offshore boundary.

Forcing Conditions

Wind and water level data used to force the wave model are available from three NOAA coastal stations (http://tidesandcurrents.noaa.gov): Sta 8771013 at Eagle Point (29° 28' 54” N, 94° 55' 0” W), Sta 8770613 at Morgans Point (29° 40' 54” N, 94° 59' 6” W), and Sta 8771341 at Galveston Bay entrance north jetty (29° 21' 24” N, 94° 43' 30” W). Directional wave spectra measured from NDBC Buoy 42035 (29° 13' 54” N, 94° 24' 46” W)

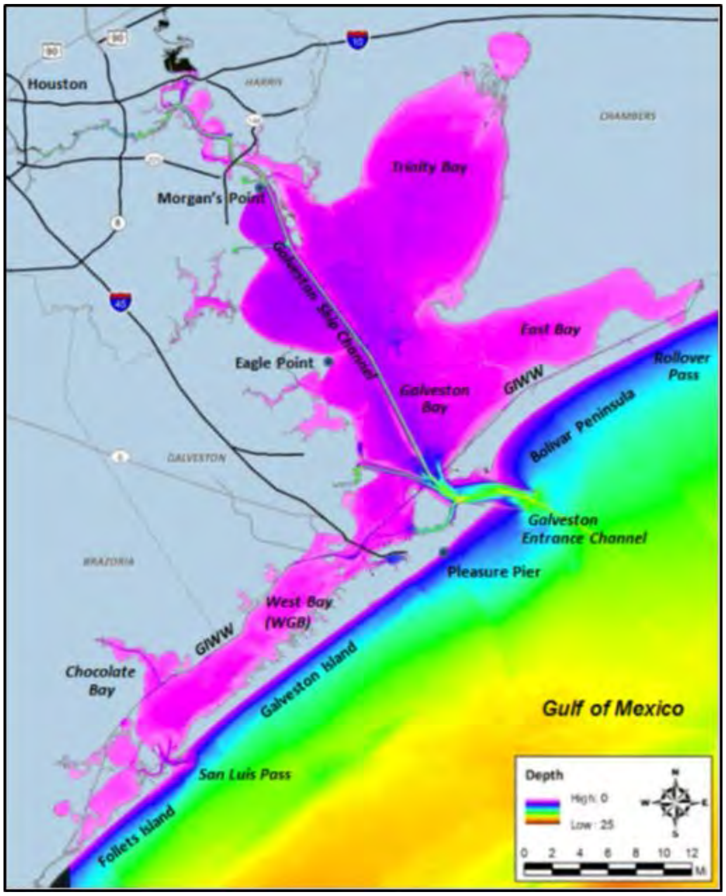


Figure E-1. Location map of Galveston Bay system

offshore Galveston Bay Entrance (Figure E-2) are use as incident waves along the wave model Gulf boundary. Buoy 42035 also collects surface wind data. Figures E-3 shows the hourly wind and wave data measured from NOAA Stations 8771013, 8770613, 8771341, and NDBC Buoy 42035 in September 2008. Strong winds with large waves observed around 13th September are corresponding to Hurricane Ike during landfall near the Galveston Bay entrance.

Figure E-4 shows the water level data collected at three NOAA coastal stations in September 2008. High water levels occurred on the 13th September corresponding to the storm surge during Hurricane Ike.

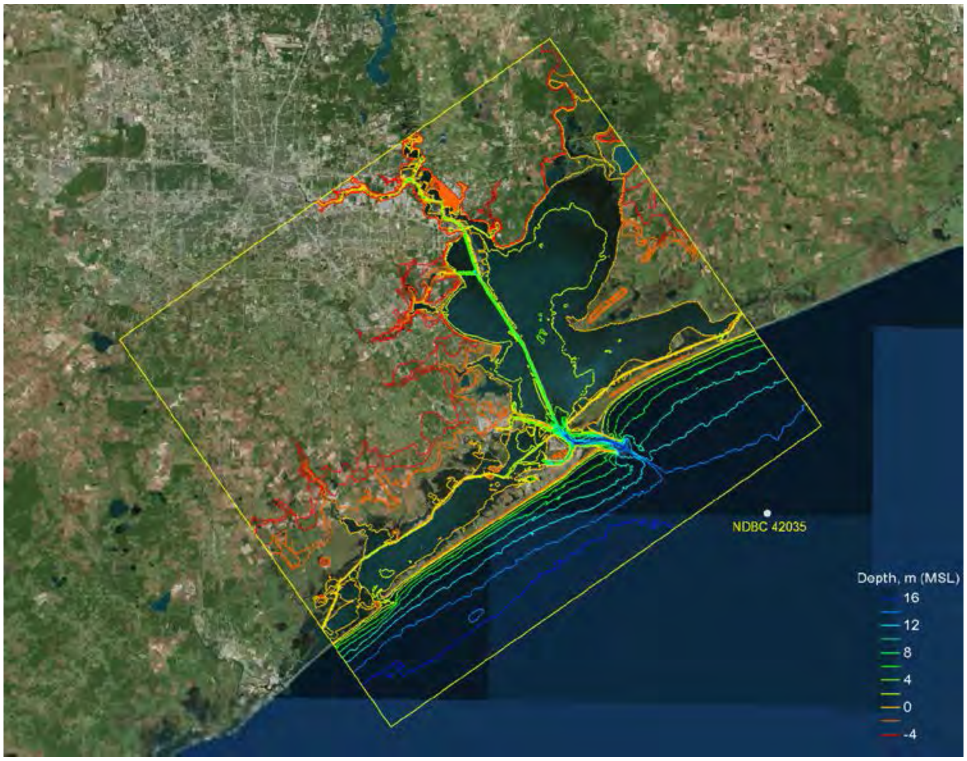


Figure E-2. CMS-Wave model domain and depth contours

Model Simulation

Wave simulation was conducted for Hurricane Ike for period of 15 August to 30 September 2008 with the wind, water level, and incident wave input in 1-hr interval. The wind and incident wave input was based on Buoy 42035 data. The water level input was based on NOAA Sta 8771013 at Eagle Point. Wave runup and wave setup calculations were included in the model simulation. Figure E-5, as an example, shows the model wave field under pre-Ike condition (incident wave height = 0.60 m, mean period = 6.2 sec, water level = 0 m, MSL, and wind speed = 6.7 m/sec from SSE) at 0100 GMT, 15th August 2008. Maximum wave height along the north perimeter of Galveston Bay is 0.28 m (mean period = 2.3 sec). Figure E-6 shows the storm wave field under high water level during Ike inside Galveston Bay (incident wave height = 5.3 m, mean period = 14.3 sec, water level = 2.5 m, MSL, and wind speed = 30.0 m/sec from SE) at 0400 GMT, 13th September 2008. Maximum wave height inside the bay is 1.4 m (mean period = 4.0 sec). Model results clearly show larger waves under strong wind and over high water level during Ike along the northern perimeter of Galveston Bay and around the Port of Houston area.

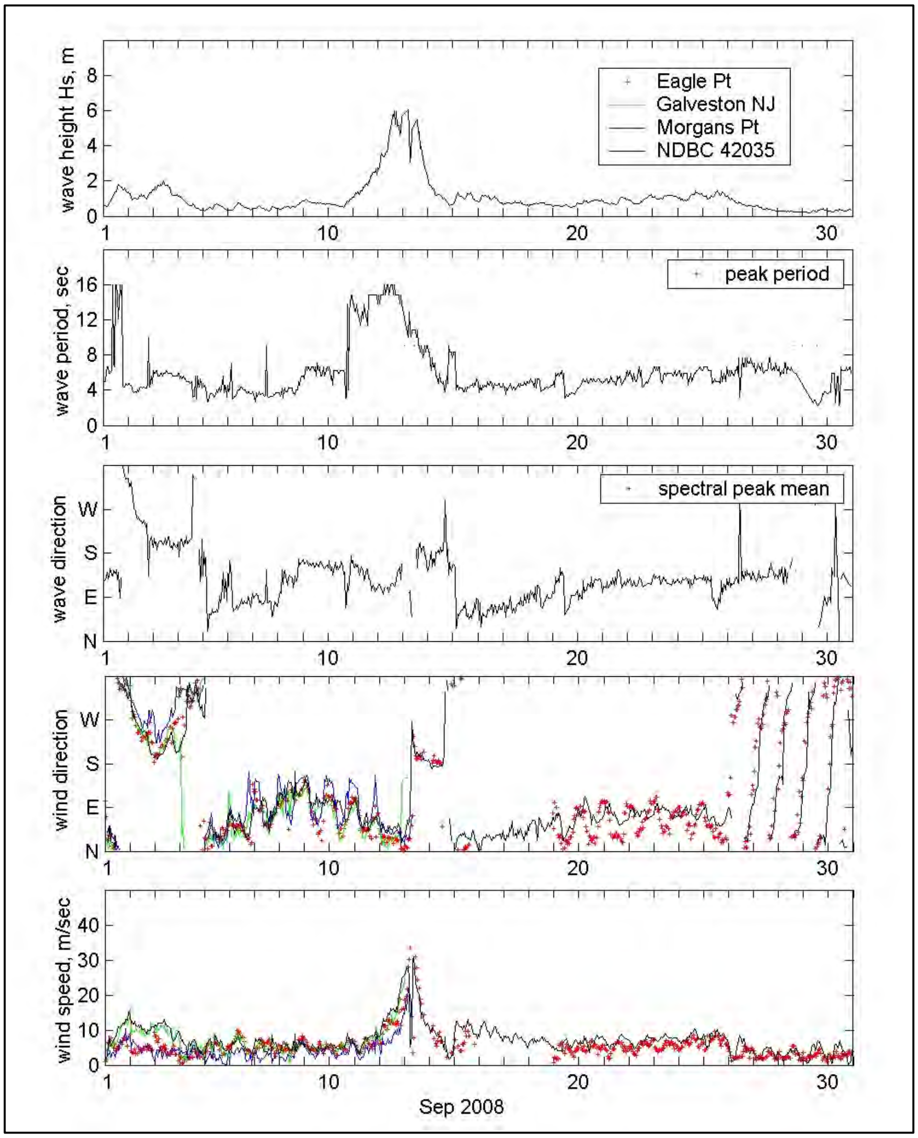


Figure E-3. Available wind and wave data in September 2008

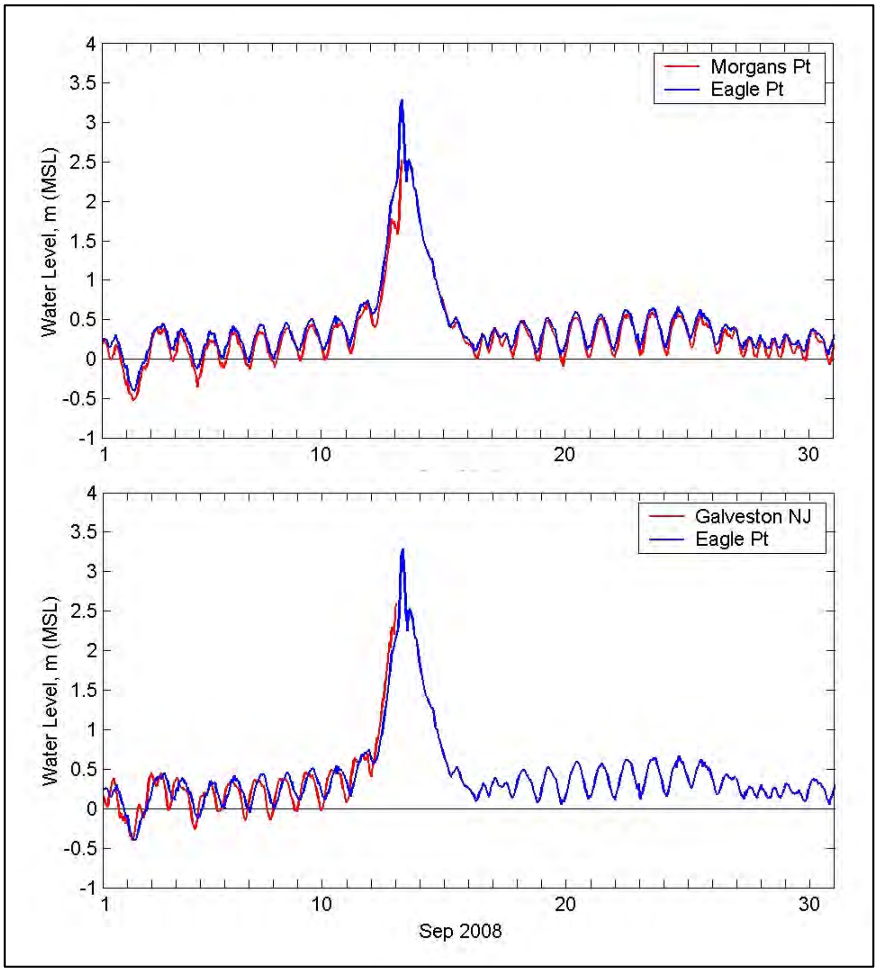


Figure E-4. Water level measurements in September 2008

Figure E-5. Model calculated wave field at 0100 GMT, 15th August, 2008

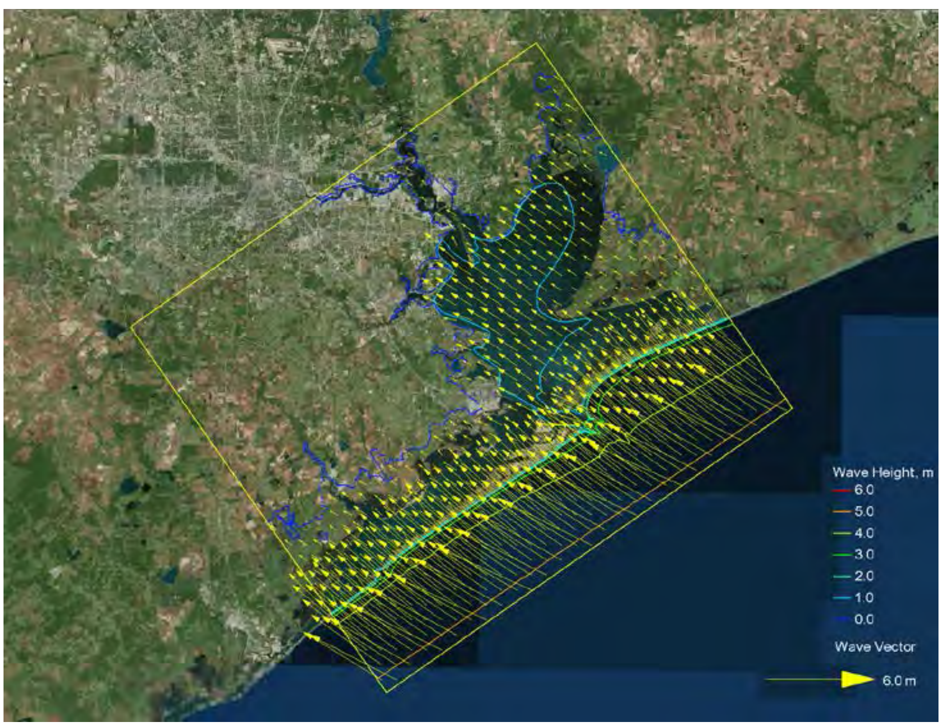


Figure E-6. Model calculated wave field at 0400 GMT, 13th September, 2008

INTERIM-FINAL
FEASIBILITY STUDY REPORT

APPENDIX B:

EVALUATION OF THE SAN JACINTO WASTE PITS CAP DEFECT

U.S. ARMY CORPS OF ENGINEERS
ENGINEER RESEARCH AND DEVELOPMENT CENTER

SAN JACINTO RIVER WASTE PITS SUPERFUND SITE

ERDC Letter Report

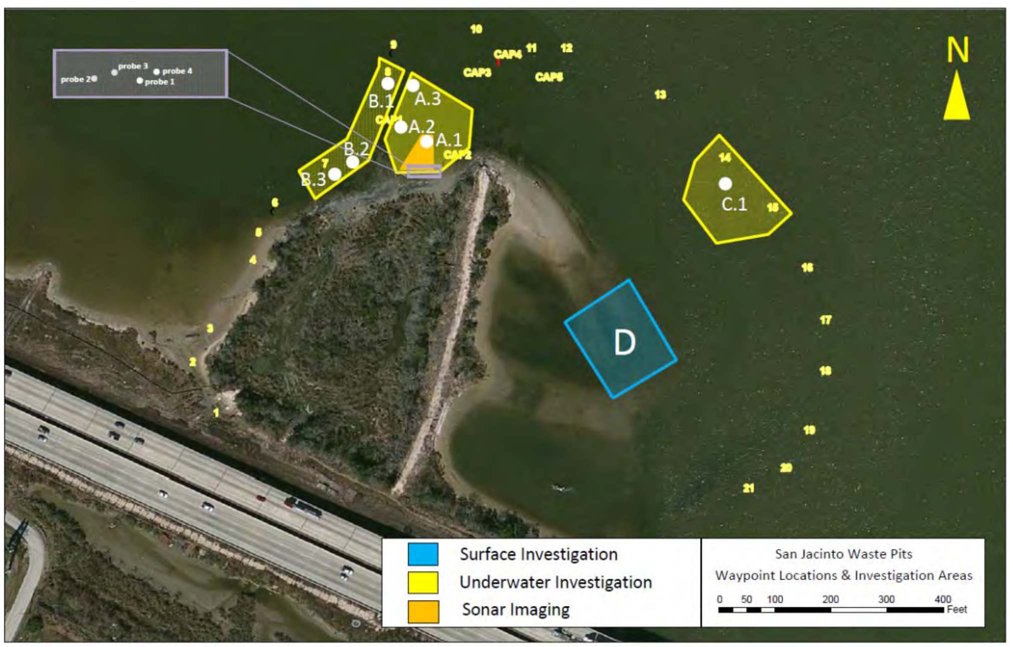
Environmental Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Evaluation of the San Jacinto Waste Pits Cap Defect

June 2016

Carlos E. Ruiz



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ERDC Letter Report

Evaluation of the San Jacinto Waste Pits Defect

Carlos E. Ruiz

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Letter Report

Prepared for U.S. EPA, Region 6
Dallas, TX 75202

077782

Abstract

The U.S. Army Engineer Research and Development Center (ERDC) is providing technical support to the US Environmental Protection Agency (EPA), the goal of which is to prepare an independent assessment of an armor cap deficiency area on the northwest part of the San Jacinto River Waste Pits armor cap at the San Jacinto River Waste Pits Superfund Site, Texas. Specific tasks of this study are the following:

1) Conduct a review of the construction, inspection, and maintenance documents for the cap.
2) Prepare recommendations for additional underwater inspections and surveying of the entire site to insure there are no more deficient areas in the cap.
3) Conduct a review of the inspection protocols and prepare recommendations for improvement.
4) Consider alternatives for the cause of the deficient area and prepare a determination of the most likely cause.
5) Conduct a review of the available sampling results and prepare a determination of the extent of any release of material from the deficient area and the need for any additional sampling, if appropriate, to determine the nature and extent of any release.
6) Prepare an evaluation of the contents of the release with respect to all major contaminants at the site.
7) Prepare recommendations for any steps to prevent any future breaches to the cap.

This report presents the results of these seven tasks that were identified by EPA for the ERDC to perform in their assessment of armor cap deficiencies. The results are summarized in the Executive Summary section which precedes the reports individually of the seven tasks.

Contents

Figures and Tables

Figures

Tables

Preface

This study was performed at the request of the U.S. Environmental Protection Agency (EPA) – Region 6 by the Environmental Laboratory (ERDC-EL) of the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS.

At the time of publication, the Deputy Director of ERDC-EL was Dr. Jack Davis and the Director of ERDC-EL was Dr. Elizabeth C. Fleming. Commander of ERDC was COL Bryan S. Green. The Director of ERDC was Dr. Jeffery P. Holland.

Unit Conversion Factors

Multiply	By	To Obtain
Feet	0.3048	meters
miles (U.S. nautical)	1,.852	kilometers
miles (U.S. statute)	1.609347	kilometers
Acres	4,046.873	Square meters
cubic yards	0.7645549	cubic meters
Knots	0.5144444	Meters per second

Executive Summary

Numerous tasks were performed to assess the armor cap deficiency area on the northwest part of the San Jacinto River Waste Pits armor cap. The technical evaluation included a) an evaluation of the armor cap inspection protocol and recommendations for its improvement, b) a recommendation for underwater inspection and surveys to identify and correct other potential cap deficiency areas, c) an assessment of the probable cause of the cap deficiency area and if it was a vessel strike, recommendations for what can be done to prevent further incidents, and d) an assessment of the potential releases from the exposed cap in the deficiency area and the need to further collect samples to determine the impact of the cap deficiency area on the surrounding sediments. Tasks 1, 2, and 3 addressed the site inspections, maintenance, repair, and ways to improve the cap integrity and thus ensure its performance. Task 4 evaluates the probable cause of the armor cap deficiency area and Task 7 recommends measures to prevent another cap breach. Tasks 5 and 6 evaluate the releases from the exposed cap in the deficiency area and the need to further collect samples to assess the short-term and long-term impact of the cap deficiency area on the surrounding sediments. Specific objectives of this study are the improvement of the armor cap inspections and maintenance to ensure the integrity of the cap, the identification of what caused the cap deficiency area, and the assessment of what is the impact of the exposed sediment in the armor cap area on the surrounding sediments of the San Jacinto River.

Cap Integrity and Performance

To maintain and ensure the desired performance of the cap, cap integrity must be verified and maintained. Cap integrity requires a determination of cap stability and permanence; in particular, a determination as to whether the cap was constructed as designed and whether displacement of cap material has occurred. As a minimum the semiannual bathymetric survey with increased manual probing should be maintained. This will build confidence that the survey's results can be used to create a better trigger in the future, resulting in less deficient areas. The trigger to perform manual probing needs to be reevaluated and a correlation developed that better relates the survey's results to discontinuities in the armor cap that are newly deficient areas. The only other alternative is to develop a new manual probing schedule with input from the underwater surveys. The inspection events need to line up with events that facilitate and enhance the ability to evaluate cap integrity such as extreme low tides and low barge traffic. A database of aerial photograph can serve as a baseline for future inspections.

Cap Deficiency

The assessment of the probable cause of the missing armor stone in the identified cap deficiency area included the evaluation of a possible barge or tug strike under normal flow conditions and under flood events and the thorough evaluation of the inspection and maintenance records performed to address the integrity of the existing repaired TCRA cap. After the evaluation of several flow events in the moderate slope of the Western Cell it is evident that a barge or tug strike would have resulted in greater damage, evidence of cap displacement, and more disruption to the cap than what was present. The deficiency area is most probably associated with the construction of the cap. Ground surveys show subsidence over time in the deficient area. The data leads us to belief that the defect area was caused by sinking of the cap over time due to either improper filter/support layer under the rock cap or unusual decomposition of organic matter under the area. The initial construction in the northwest area was spotty and a large area was deficient and required a second pass of capping to achieve sufficiency. This suggests that the construction did not have sufficient controls which probably led to the cause for the deficiencies. Additional deficient areas were found by manually probing the Eastern Cell, indicating potential construction deficiencies. None of the deficiencies found in the Eastern Cell compare in size to the area of the Western Cell.

Impacts of Release

The potential short-term and long-term impacts of the release of sediments from the exposed cap was evaluated using sediment data collected from the impacted area and nearby stations. Looking at the fingerprint of the sediment dioxins and furan data clearly shows that very little, if any; sediment from the cap deficiency area reached the two stations near the exposed sediment in the armor cap area. If one looks at the fingerprint of the data collected from the exposed area one sees that the fraction of TCDD to TCDF is not the similar to the fingerprint of the two sites away from the exposed cap where the fraction of OCDD is dominant. As presented in the Feasibility Report the fingerprint from the SJRWP exhibits a different pattern than the pattern from other sources of dioxins and furans in the vicinity of the site. The data from the sediment collection shows similar patterns; the exposed area has the fingerprint of the SJRWP and the data for the other two sites show similar fingerprint as that of other sources of dioxins and furans in the vicinity of the site. This further confirms that the exposed area did not release significant contaminants before it was repaired.

Project Background, Objectives and Tasks

Background

The San Jacinto River Waste Pits Superfund Site (Site) consists of several waste ponds, or impoundments, approximately 14 acres in size, built in the mid-1960s for the disposal of paper mill wastes as well as the surrounding areas containing sediments and soils potentially contaminated by the waste materials that had been disposed in these impoundments. The impoundments are located immediately north and south of the I-10 Bridge and on the western bank of the San Jacinto River in Harris County, Texas (see Figure 1).

Large scale groundwater extraction has resulted in regional subsidence of land in proximity to the Site that has caused the exposure of the contents of the northern impoundments to surface waters. A time-critical removal action was completed in 2011 to stabilize the pulp waste material in the northern impoundments and the sediments within the impoundments to prevent further release of dioxins, furans, and other chemicals of concern into the environment. The removal consisted of placement of a temporary armor rock cap over a geotextile bedding layer and an impermeable geomembrane in some areas. The total area of the temporary armor cap is 15.7 acres. The cap was designed to withstand a storm or flood event with a return period of 100 years.

The southern impoundments are located south of I-10 and west of Market Street, where various marine and shipping companies have operations (see Figure 1a). The area around the former southern impoundments is an upland area that is not currently in contact with surface water.

Goal and Objectives

The goal of this study is to provide technical support to U.S. Environmental Protection Agency (EPA) by conducting an independent assessment of an armor cap deficiency area on the northwest part of the San Jacinto River Waste Pits armor cap at the San Jacinto River Waste Pits Superfund Site, Texas. The assessment includes a review of existing information, identification of the possible cause for the deficiency, an evaluation of the potential releases from the deficiency, recommendations for additional data collection and inspections, and recommendations for improvements at the site or in the inspection and maintenance protocols.

Study Tasks

The following specific tasks were identified by EPA to accomplish the stated goal and objectives.

Task 1: Conduct a review of the construction, inspection, and maintenance documents for the cap.

Task 2: Prepare recommendations for additional underwater inspections and surveying of the entire site to insure there are no more deficient areas in the cap.

Task 3: Conduct a review of the inspection protocols and prepare recommendations for improvement.

Task 4: Consider alternatives for the cause of the deficient area and prepare a determination of the most likely cause.

Task 5: Conduct a review of the available sampling results and prepare a determination of the extent of any release of material from the deficient area and the need for any additional sampling, if appropriate, to determine the nature and extent of any release.

Task6: Prepare an evaluation of the contents of the release with respect to all major contaminants at the site.

Task 7: Prepare recommendations for any steps to prevent any future breaches to the cap.

Task 1

Statement

Conduct a review of the construction, inspection, and maintenance documents for the cap.

Findings

This task was performed by first reading all identified resources (*e.g.*, reports, letter reports, field activity reports, and the Operations, Monitoring, and Maintenance Plan (OMMP): Appendix N of the RACR – Anchor QEA 2012) provided by the Remedial Project Manager, Mr. Gary Miller. This information assisted in performing the requested assessment of the San Jacinto River Waste Pits (SJRWP) armor cap deficiency.

Construction of the existing TCRA cap was divided into three sections, each of which has different cap components (Figure 2). The Western Cell is generally above the water line; the Eastern Cell is mostly covered with less than 5 ft (1.5 m) of water; and the Northwestern Area is mostly in greater than 10 ft (3.0 m) of water. The Western Cell cap is composed of a geotextile filter, a geomembrane, geotextile cushion and armor stone. The Eastern Cell has a geotextile filter and armor stone. The Northwestern Area has predominantly granular filter blended with armor stone. These three sections were further subdivided into subsections with varying armor stone.

The inspections reported were conducted in accordance with the schedule established in the OMMP. The OMMP specifies the timing, pertinent items, tolerances, and procedures for inspection, maintenance, and repair of the armor cap, protective cover, fencing, and signage installed for the TCRA Site (Figure 2).

The EPA R6 Dive Team Operations Report dated 9-10 December 2015 documents the discovery of the deficiency in the Western Cell of the SJRWP armor cap. The study/inspection designed to safely assess ongoing SJRWP armor cap integrity and performance as measured by the continued physical integrity of the cap and lack of migration of dioxin from the waste pit beneath the Cap and into the San Jacinto River.

Figure 1a shows the areas of investigation and the area of the deficiency. The maintenance and repairs documented in the letter reports and field activity reports summarized the events and actions that followed the discovery of a deficiency in the western section of the SJRWP cap.

Maintenance and Repair Reports of the Deficiency of the SJRWP Armor Cap

Field Activity Report from EA Engineering dated 5 January 2016 describes the activities performed by the contractor EA Engineering, Science, and Technology, Inc., PBC (EA) performed oversight of field activities performed by the Potentially Responsible Party's (PRP) consultant, Anchor QEA (Anchor).

Activities included collected sediment samples from the following locations:

- Three samples from the suspected damaged cap area in the northwestern area of the cap
- Two samples from the northwest toe of the cap's sloped area
- Two samples approximately 50 feet from the northwest toe of the cap.

Other activities included the probing and repair of the deficiency by placing a non-woven geotextile in the location of the deficiency (Figures 3, 4, and 5) and placing armor stone over the textile to achieve the required depth of armor.

After the discovery of the SJRWP armor cap deficiency and the subsequent repair, the PRPs proposed further probing of the Eastern Cell as part of the OMMP for the site. The document proposes modifications of the OMMP by increasing the probing in the Eastern Cell and installing a camera monitoring system to record unauthorized visits/contact with the SJRWP armor cap and the site. Figure 6 shows the new probing and Table 1 the areas that were found to be deficient in armor thickness or exposed geotextile. The results of the probing and visual inspection identified several discrete areas (e.g. 1' x 1') where geotextile was exposed and subsequently repaired as summarized in Table 1. Figure 7 shows one of the cameras of the new security system installed.

Table 1
Armored Cap Maintenance Locations
March 2016

Maintenance Location	Comment	X (UTM NAD83 - 15N)	Y (UTM NAD83 - 15N)	Maintenance Plan
0	Exposed Geotextile with rock beneath. Indicative of Lap Joint.	300665.5156	3297847.47	Add rock
1	Exposed Geotextile is 2x2 feet. Some rock aggregate present. Thin cap rock region is 2x6 feet.	300672.5976	3297832.841	Add rock
2	Exposed geotextile 2x2 feet in area. Some rock aggregate present.	300672.013	3297833.713	Add rock
3	Exposed Geotextile 2x3 feet in area. Some rock aggregate present.	300680.1521	3297833.27	Add rock
4	Exposed Geotextile is 1x3 feet in area. Some rock aggregate present.	300675.29	3297763.589	Add rock
5	Exposed Geotextile is 1x1 feet in area. Some rock aggregate present.	300674.1382	3297763.769	Add rock
6	Exposed Geotextile is 1x1 feet in area. Some rock aggregate present.	300670.6068	3297767.763	Add rock
7	Exposed Geotextile is 1x1 feet in area. Some rock aggregate present.	300672.5902	3297771.977	Add rock
8	Exposed Geotextile is 2x1 feet in area. Some rock aggregate present.	300668.9628	3297815.019	Add rock
9	Exposed Geotextile is 1x1 feet in area. Some rock aggregate present.	300664.2992	3297818.844	Add rock
10	Exposed Geotextile is 2x2 feet in area. Some rock aggregate present.	300662.8045	3297821.023	Add rock
11	Exposed Geotextile, cause unknown. Some rock aggregate present. Possible joint.	300665.6821	3297858.861	Add rock and geotextile
12	Centroid for area of exposed geotextile and thin cap rock. Some rock aggregate present. 20 square feet of area total.	300676.9607	3297852.277	Add rock

Task 2

Statement

Prepare recommendations for additional underwater inspections and surveying of the entire site to insure there are no more deficient areas in the cap.

Methodology

This task was performed in two steps. The first step evaluated the OMMP for the SJRWQ site, the past inspections, the current inspections and the proposed modifications to the OMMP. The second step extracted what has worked and combined it with the site constraints (low underwater visibility, steep slopes, river traffic, and unstable environment) to develop a more thorough inspection protocol that would enhance the confidence of the cap integrity.

Evaluation of the inspections

The OMMP for the SJRWP site recommends semiannual (after 2014) surveys of the armor cap with manual probing of armor cap thickness at areas identified by the topographic or bathymetry surveys as more than 6 inches lower in elevation than during the prior survey. The problem with the trigger is that the cap surface is fairly rough and uneven resulting in a scenario that under predicts defects due to the nature of the cap surface (large stones and uneven surface). It is even more uncertain in the deeper sections of the cap due to low visibility, potentially unstable surfaces, and hard to work environment and in areas of steeper slopes due to positioning uncertainties and errors.

The surveys and trigger mechanism in place to monitor/inspect the armor cap would be applicable to a granular cap, like a sand or gravel cap, because of the smooth and continuous layer at the top of the cap. Surveys of sand caps are more useful, since the layers behave more like a continuous layer; in the armor cap, there are significant discontinuities in the surficial layer that could mask small imperfections in the armor cap. Therefore, a trigger based on changes in the surficial layer is not conservative, not unless there has been significant ground truthing of the bathymetric data against actual deficiencies. The probing done by the EPA team, the proposed supplemental probing (Figure 6) and the results of those inspections increase the confidence of the integrity of the cap. The surveys, though useful, have not shown the reliability of the probing; the problem with the probing is the lack of coverage of the site. To build the confidence of the cap integrity, more than ninety-five percent of the cap that is probed should be without defects. The results from the Eastern Cell were 12 deficiencies in four hundred probes; that is around ninety seven percent (97%) without significant defect, suggesting that defects are outliers of limited size.

The underwater scans and bathymetric surveys in combination with probing should improve the confidence in the cap integrity. The OMMP should strive to develop a consistent protocol for the surveys; at normal to low flows, with minimum winds/waves, and low barge traffic. The consistent surveys and the increased knowledge of the cap from the previous manual probing should lead to more confidence in the trigger. To increase the confidence in the cap integrity ground truthing of the surveys with manual probing is recommended to develop a relationship that will lead to a better trigger and more confidence in the cap integrity.

So as a recommendation, semiannual bathymetric survey with manual probing should be maintained; this will build up the confidence that the survey's results can be used to create a better trigger for manual probing. The results from the four hundred probing are encouraging, but we need to realize that the actual area of the cap that has been probed is probably less than thirty percent of the actual area. And again, this is not a smooth cap layer, so any method that will integrate over large surface area will not be conservative. Manual probing, though slow and hard at the deeper areas of the armor cap, is probably the more conservative method to guarantee the armor cap integrity.

The only way to guarantee that we will not find any more deficient areas is by inspecting all the surface of the cap below the water level; one can inspect it all at once or over a period of time when the conditions are more suitable to achieve our goal.

Task 3

Statements

Conduct a review of the inspection protocols and prepare recommendations for improvement.

Findings

Background

Inspection protocols for both the land portion of the armor cap and the submerged portion rely on surveys with triggers based on change in elevation as compared to an earlier survey or the baseline survey. For the land based cap it states that portions of the armor cap that are located above the water surface, or at a water depth too shallow to access by boat, will be surveyed using conventional land-based topographic survey techniques. The survey contractor will prepare a survey transect plan that will be sufficient to adequately measure the armor cap, but not less than an equivalent 25-foot by 25-foot grid. Horizontal and vertical measurements will be collected at 5-foot intervals and major breaks along these grid lines.

For the portion of the cap under water a bathymetry survey will be performed by boat at 25-foot intervals and the elevations will be compared to previous surveys to determine change in elevation over the discrete area. Elevation changes of more than 6 inches between surveys will be cause for additional evaluation. The elevations obtained from the survey will be re-checked and the survey benchmarks will be verified. If the most recent survey elevation differs by more than 6 inches when compared to the prior survey for an area larger than 30 feet by 30 feet, manual armor cap probing will be initiated to measure the cap thickness.

As stated in the previous task, the survey and technique can give us great insight on sections of the cap, but are not able to find minor imperfections as the ones discovered in the March Supplemental Probing and by the EPA diver team in December. The site has improved its monitoring in case of unauthorized contact or intrusion into the armor cap area. The cameras, the surveys and the supplemental probing are all moving in the right direction, but the cap integrity and the confidence in the cap integrity will not be achieve unless more discrete inspections are performed.

In particular the Northwestern Area, where construction of the cap in the very different than the other two cells and does not provide the same level of confidence in its long-term stability and performance due to its steep slope. The area is largely capped with twelve inches of non-uniform recycled concrete blended with granular filter material. Since it does not have a geotextile or a geomembrane, it's even more difficult to ensure that even the manual probing will result in assurances that the proper armor cap exists without mixing with the sediment. In both the Eastern and Western Cells the probing was done till it encounters the geotextile or geomembrane; distance above that is the thickness of the armor layer. Therefore more care and a more consistent approach needs to be develop to estimate where the probing encounters the sediment and where the bottom of the cap is. In addition, this area is probably the hardest to evaluate because of the slope, water depth, and lack of visibility.

Recommendations

The improvements to the inspection protocols are mostly based in what has worked before, the dive team, manual probing, and building a better database to relate the surveys with manual probing and develop a more relevant trigger. The OMMP should be modified to take advantage of low tides and extreme low tides, in particular, to perform visual inspections and look for defects, deficiencies, or disturbances in the armor cap.

Recommendations include supplemental probing like the one performed in the Eastern Cell; the goal is to reduce the number of deficiencies. Probing should continue to the Western Cell with the same density as what was performed in the Eastern Cell (200-250), and the finally to the Northwestern Area. Here is where it gets trickier; this area requires the greatest density of manual probing since it is the steepest and does not have a geotextile or geomembrane. Manual probing in the order of 300-400 is not out of the question based on the potential for deficiencies in this area due to construction and post-construction conditions.

Collect bathymetry and or ground surveys of area in need of maintenance or repair to aid in determining the cause of those repairs, thus gaining an inside long-term performance of the cap.

Task 4

Statement

Consider alternatives for the cause of the deficient area and prepare a determination of the most likely cause.

Findings

The methodology used to determine the cause of the deficient area included the following steps:

1) Evaluate the documents from the EPA Dive team, the action team, and other reports describing the area and deficiency.

2) Evaluate whether a barge or tug strike was the potential cause.

Deficiency Report

The EPA diver report and the Action reports described in Task 1 defined the area of the cap in the Northwestern Area that had no armor stone cover. The team did not mention the movement or displacement of stone or a ridge formed by a potential strike to the cap. The action reports mentions that there were some aggregates near the site where they collected sediment samples, but they do not mention the displacement of rock or the formation of a berm next to the deficiency or down slope of the deficiency. The sampling of the deficiency area showed the presence of some rock, characteristic of the blended filter rock but not of the larger recycled concrete, but not of nearly sufficient thickness as specified in the design.

The sonar evidence is not supportive of a barge strike, the quote from the report states that"Imaging sonar was utilized in this area in an attempt to visualize the area of deficiency. This area was not identifiable via sonar, but other areas of interest were identified based on changes in color within the sonar image (Image 4 and Map)." The sonar shows neither a depression nor a mound of displaced material. The pictures if they were collected from the impacted site show the only evidence of a potential berm or rock displacement, though not significant to account for a potential strike. Discoloration shows intrusion of sediment into the cap or mixing of cap with the surficial sediment or deposition of new sediment.

Another fact that support the ‘no strike hypothesis’ is that the EPA diver team on the ground did not see/report displaced rock or some unusual deformation of the armor stone placement. All of the above indicates that the deficiency is probably a cap defect during construction. In addition the diver team penetrated the deficiency and there was no mention of a depression in the area of the deficiency. The cap would either be displaced into a ridge or/and pushed down into the sediment bed because the sludge has little strength. If the cap was pushed down, then a depression should exist. The repair team mentioned that rocks and material appear as if they were pushed deeper into the sediments as a typical strike would do, however, there was no mention of a depression and there is no significant sediment transport in the area to fill a depression from a barge or tug strike. The repair team mentioned that visual inspections of the area in January 2013 and 2014 show no deficiency area.

Another potential cause of the deficiency is that the material (rocks) placed on the area sinked/settled over time, either because of bearing capacity of the sediment or excess load of the rocks placed at the area.

Probing of the Eastern Cell, after the deficiency area was discovered, resulted in another twelve areas with some deficiencies, so now this is not a single site without rock cover. The twelve defects in the Eastern Cell were much smaller; around one to two square feet each. The dispersed, isolated, small areas of mild slope would suggest that these additional deficient areas could not have been caused by erosion, slope failure or barge strikes. In addition, the presence of the geotextile would also suggest that the defects were not caused by subsidence or bearing capacity issues, leaving construction defects as the only remaining probable explanation. However, it tends to explain how difficult is to build a greater than ninety-nine percent perfect cap with large rocks, the tolerance for imperfections in such a large area is extremely small.

Barge Accidents/Strikes

Incidents involving barges are relatively infrequent. Hayter et al. 2015 estimated the probability of a barge striking the cap at 1 in 400 for a significant strike (flood conditions) and 1 in 50 for a low severity impact strike in a year; that is once in 50 years. That strike probability is the greatest for the Northwestern Area and much lower for the Western and

Eastern Cells. A significant strike for the Western and Eastern Cells is less than half of the strike probability of the Northwestern Area.

Impacts of Barge Strikes

Background

The potential impacts of barge strikes vary greatly with the nature and location of the barge strike. River barges have flat bottoms and square sides that influence the damage it can inflict to the cap; it is also a function of the angle of the strike and the slope of the cap. Empty barges have a draft much lower draft than loaded barges (2 ft versus 10 ft).

Water depth under normal conditions varies across the site such that the cap may be a couple of feet above the water level in the Western Cell, may be more than 15 feet below the water surface in the Northwestern Area, and generally between 0 and 5 feet below the water surface in the Eastern Cell. Slopes are very steep on the cell berms and shorelines including the Northwestern Area adjacent to the Western Cell.

Two potential barge impact conditions can be addressed to understand the potential for a barge to strike the armor cap north of the Western Cell (location shown in Figures 3, 4, and 5) based on flow condition, bottom slope, and water depth. Water depths under normal flow conditions greatly restrict the conditions and locations where a strike may occur. Moderate slope occurs throughout much of the interior of the Eastern Cell and along the northern end of the site, including north of the Western Cell in the Northwestern Area where the cap deficiency was discovered.

Normal Flow Strike

Shallow water (< 5 feet). Only the northern and easternmost sections of the Eastern Cell and the area immediately north of the Western Cell would be particularly susceptible to being struck by the nearby barge operations due to the currents. Of these sections only the northern end of the center berm and the area directly north of the Western Cell would have highly contaminated sediments. The only strike potential is grounding or beaching of the barge. The grounded barge would shear the armor layer and push some of the armor material ahead of the barge up the slope during grounding and pull some armor down the slope during barge removal, exposing perhaps as much as a thousand square feet of the sediment for moderate slopes and as little as several hundred square feet for mild slopes.

This strike would be expected to be a little bigger than what was discovered by the EPA diver team and the footprint of the defect does not match the approach/strike of the vessel. In addition, there was no significant displacement of the armor stone found and therefore this type of barge strike is unlikely to be the cause of the deficiency.

Flood Strike

Under flood scenarios, the water depths would tend to be 3 to 10 feet greater than under normal flow conditions. This would essentially eliminate any shallow water conditions except for the berms and shoreline; however, the potential for erosion of impacted areas becomes much greater.

Shallow water (normally <5 feet). Only the northern and easternmost sections of the Eastern Cell and the area immediately north of the Western Cell would be particularly susceptible to being struck by the nearby barge operations due to the currents. Of these sections only the area directly north and northeast of the northern end of the center berm and the area directly north of the Western Cell would have highly contaminated sediments. The only strike potential is grounding or beaching of the barge. The grounded barge would shear the armor layer and push some of the armor material ahead of the barge up the slope during grounding and pull some armor down the slope during barge removal, exposing perhaps as much as a thousand square feet of the sediment for moderate slopes and as little as several hundred square feet for mild slopes. Under this strike conditions the loss of sediment would be very large because of the river flow, Hayter et al. 2015 estimate up to 50 cubic yards could be lost. This would represent less than 0.1 percent of the contaminated sediment, and it would be widely dispersed and diluted with the suspended solids of the flood waters. This strike would be much bigger than what was discovered by the EPA diver team; it would have caused significant displacement of the rip rap and significant release of sediment, none of what was found at the site. Again, this type of barge strike is unlikely to be the cause of the deficiency.

Summary

The probability that a barge caused the deficiency of the SJRWP armor cap in the Northwestern Area is very small; the size of the impact (7 ft by 22 ft) is too small for a flat barge strike. The probability that a tug caused deficiency as the result of an impact with armor cap in the Northwestern Area is also very small due to the size of the potentially impacted area (slightly over 200 sq ft), the angle of the impact, and the shape of the deficiency where the wider section is next to the land side and the smallest section to the deeper water. The strike of a tug would leave the inverse footprint; it would be like the wake that a tug makes. All of the above leads us into the conclusion that the probability that the deficiency was caused by a vessel strike is extremely small, much smaller than the probability of the deficiency being the result of a flaw in the cap construction.

Appendix A shows why it is very hard to imagine that a vessel strike was responsible for the deficiency area. The discussion in Appendix A was after communication with the repair team; on what was found as they sample the deficiency area, and there speculation on a probable barge strikes. The lack of visual trace and the potential angle of impact does not lead us into accepting the vessel strike hypothesis.

Appendix B shows that the area of the defect has been changing in elevation since at least 2013 and maybe even 2012. The discussion in Appendix B was after communication with the repair team and there wiliness to provide us with ground surveys for the deficient area for the last six years. The data leads us to belief that the defect area was caused by sinking of the cap over time due to either improper filter/support layer under the rock cap or unusual decomposition of organic matter under the area.

Task 5

Statement

Conduct a review of the available sampling results and prepare a determination of the extent of any release of material from the deficient area and the need for any additional sampling, if appropriate, to determine the nature and extent of any releases.

Findings

Figure 8 shows the probing transects and samples collected as part of the assessment of the cap deficiency in December 2015. Figures 9 and 10 show the level of contaminant in the three sediment samples collected from the cap deficiency. Figure 9 is from the exposed sediment, the sample was split with EPA and documented in the report 05_San Jacinto RIFS OS Data Validation for December 2015 Split Sampling, a letter report.

The levels of the three samples collected from within the cap deficiency zone vary significantly; two are around 40,000 ng/kg and one is nearly an order of magnitude less (8180 ng/kg).

The levels of the two samples (SJNE085 and SJNE 086) from the northwest toe of the cap's sloped area near the cap deficiency area are shown in Figure 9. The levels are 500 times lower than the two highest values at the impacted zone and 100 times lower than the lowest value from the impacted zone.

The third set of sediment samples collected were two samples (SJNE87 and SJNE88) approximately 50 feet from the northwest toe of the cap also shown in Figure 8 and the results are also included in Figure 10. The levels are three orders of magnitude lower than the two highest values at the impacted zone and 300 times lower than the lowest value from the impacted zone. The values are three times lower than those samples collected near the northwest toe.

Based on the reduction in magnitude from the sediment in the impacted zone versus the levels of the sediment collected by the northwestern toe, one can say that there were no significant releases from the exposed cap. If one compares the values by the toe and fifty feet from the toe to the data from the Feasibility Document shown in Figure 11, the sediment collected from the non-impacted sites is close to the values in the historical data; both showing an increase as you get closer to the armor cap. Based on simple comparison and trends, one can say that the exposed sediment caused little increase, if any, in contaminant concentration to the surrounding sediment, in particular to those areas where the sediment was collected.

It would be desirable also to estimate the sediment concentration closer to the area that was repaired, in addition to the two other sites (the northwestern toe, and 50 ft from the toe) that were collected to determine the potential effect of the deficiency. A reduction in contaminant concentration at increasing distance from the deficiency would indicate a release from the exposed sediment; if the values in the proximity approach those of samples SJNE87 and SJNE88 then release from the exposed sediment would not have been significant.

In addition, the samples outside the armor cap area do not contain significant TCDD and TCDF levels as compared to those from the exposed sediment in the armor cap area (see Figure 9). This difference in the distribution of dioxins and furans between the two samples indicates that the contamination outside the armor cap area did not come from the exposed sediment in the armor cap area, providing another piece of evidence that the exposed sediment from the armor cap area did not contributed significant releases to the surrounding sediment.

Task 6

Statement

Prepare an evaluation of the contents of the release with respect to all major contaminants at the site.

Findings

The same analysis that was done for Task 5 applies here too. Since it was demonstrated that there was no significant increase in contamination at the two sites away from the exposed sediment in armor cap area as compared to historical data (Feasibility Report, Figure 11) then the release from the other contaminants should behave similarly. If one looks at the fingerprint of the contamination for the samples collected from the exposed sediment, one sees that ratio of TCDD to TCDF is not similar to the fingerprint of the two sites ((1)SJNE085 and SJNE 086, (2) SJNE87 and SJNE88) outside the armor cap where the fraction of OCDD is dominant. As presented in the Feasibility Report the fingerprint from the SJRWP exhibits a different pattern than the pattern from other sources of dioxins and furans in the vicinity of San Jacinto. Figure 12 shows the two models for dioxin and furan that describe the pit (EM2) and the outside of the pit (EM1).

Comparison of Figure 12 with Figures 9 and 10 shows that the fingerprint from the sediments collected in the deficient area is close to the EM2 model, while the data from the sites outside the exposed area follow the EM1 model. If sediment from the deficient area was released the impacted sites would exhibit a form of the EM2 model (fingerprint), one can say that there is a slight contribution by the short peak of TCDF, so most of the sediment from the toe and outside areas receive most of the loadings from other areas beside the SJRWP. In addition, the samples from the deficient area show evidence of deposition of sediment from outside the SJRWP due to presence of higher distribution of OCDD than in the EM2 model. The presence of deposition in the deficient area would indicate the long-term presence of the defect, the stability of sediment at the defect, and no significant release of contaminants from the deficient area.

Task 7

Statement

Prepare recommendations for any steps to prevent any future breaches to the cap.

Findings

If the concern is that the cap could be impacted from vessels or other external sources in the navigation channel, then one needs to address the needs for controls. The PRPs already installed a camera system to monitor the site and alert the PRPs that the cap has been impacted or that non-authorized personnel is in the site. As mentioned in Task 4, the probability of a vessel impacting the cap is very low (once every fifty years), and that the areas of concern are the Northwestern Area, north and northwestern part of the Western Cell, and the northeastern side of the Eastern Cell. In those areas more robust engineering controls to restrict vessel traffic over the long term could be considered such as the use of lighted buoys, caissons, or vessel exclusion barriers.

The FS suggested a five-foot high submerged rock berm outside the perimeter of the Permanent Cap to protect from potential vessel traffic. Shallow areas can be isolated using steel cable or chain with appropriate marine and land-based signage and markers to prevent vessel access.

Conclusions

Very small amount of sediment was released from the deficient area before it was repaired based of the comparison to the historical data, the SJRWP sediment chemical fingerprint (model EM@2), and the collected samples.

Samples from the deficient area show evidence of deposition of sediment from outside the SJRWP due to higher fraction of OCDD than in the EM2 model.

Presence of deposition in the deficient area indicates the long-term presence of the defect, the stability of sediment at the defect, and no significant release of contaminants from the deficient area.

Based on the angles of potential strike, the lack of a berm next to the defect area, the lack of impact to the rock berms near the defect area, and the ground surveys of the cap near the defect we can conclude that the probability of a tug or barge strike causing the defect is extremely small.

Based on all the above the most likely cause of the defect is subsidence due to inadequate construction controls.

Figures

Figure 1. San Jacinto River Waste Pits Superfund Site.

Figure 1a. San Jacinto River Waste Pits Superfund Site Location.

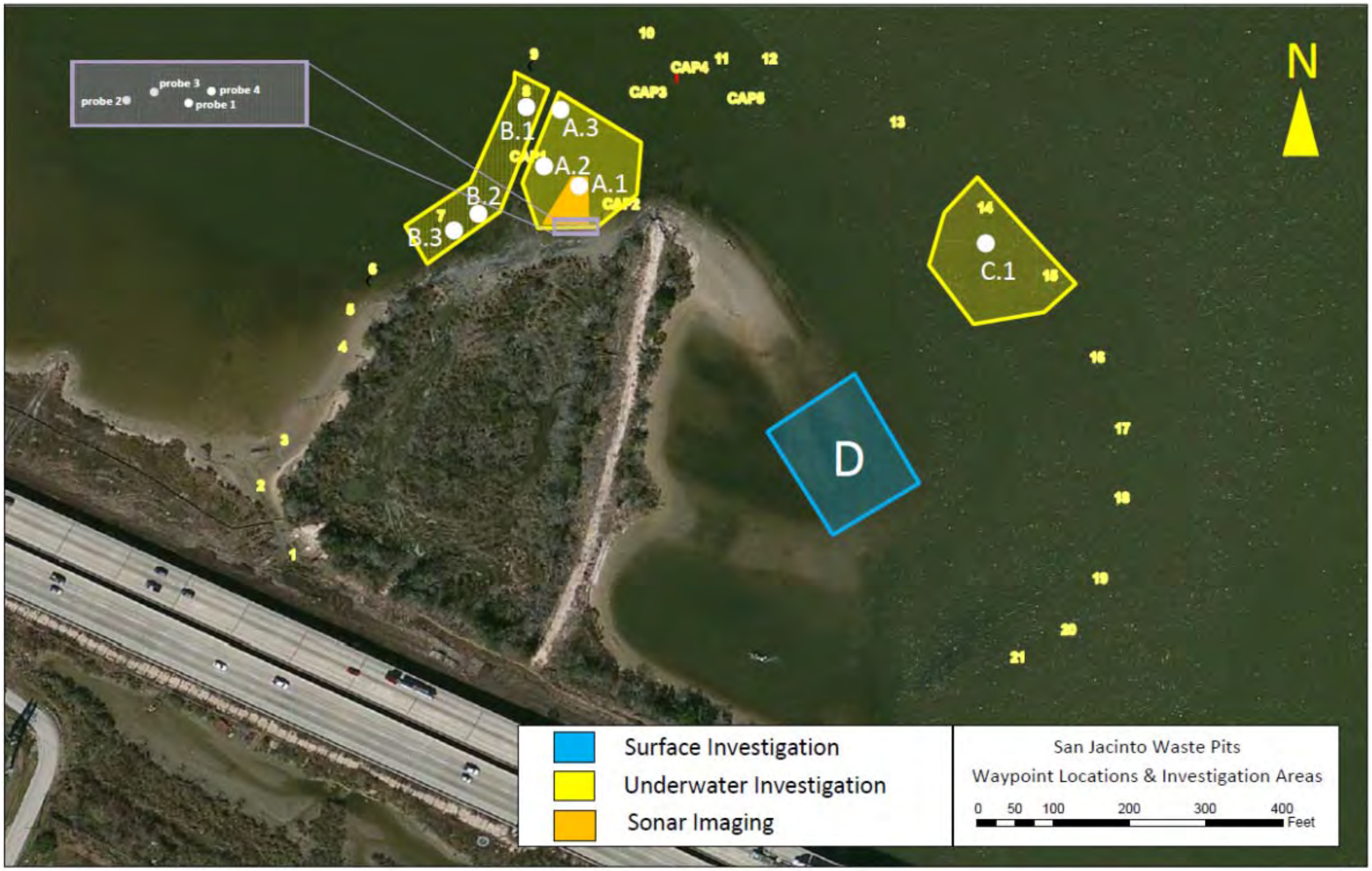


Figure 2. Cap components.

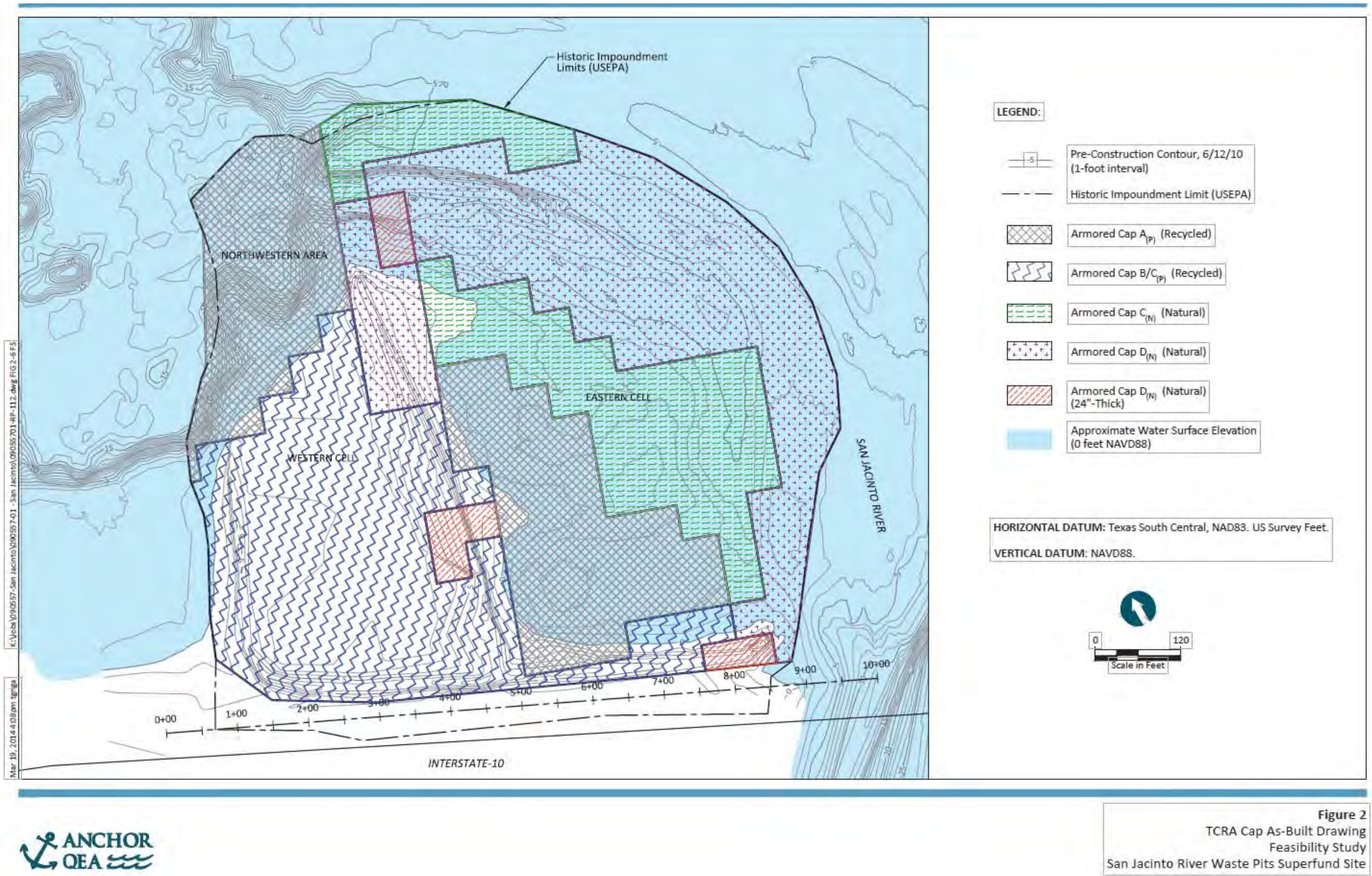


Figure 2
TCRA Cap As-Built Drawing
Feasibility Study
San Jacinto River Waste Pits Superfund Site

Figure 3. Summary of Probing Data Post TCRA Inspection.

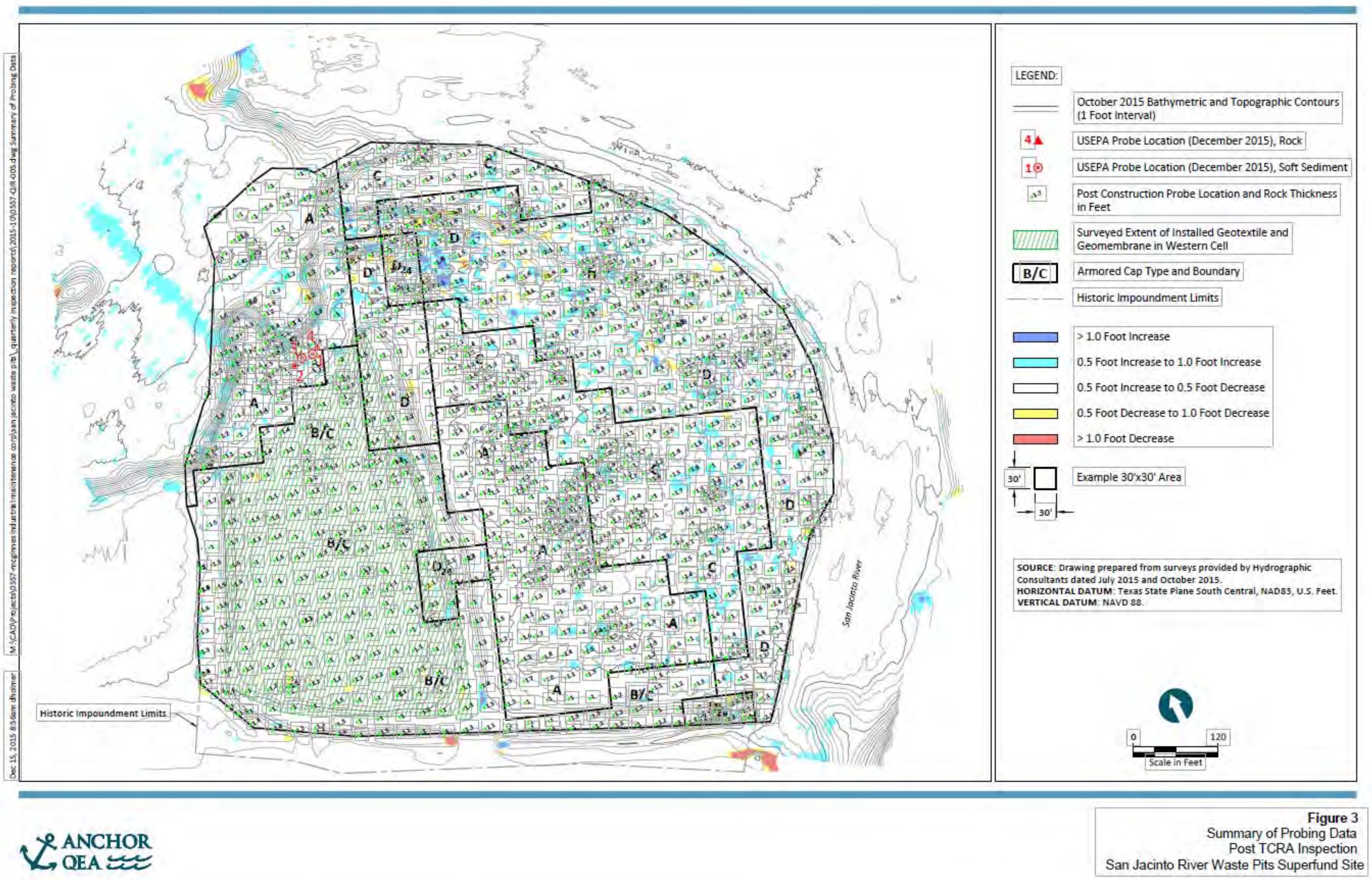


Figure 4. Armor Rock Placement Plan and Cross Sections Post TCRA Inspection

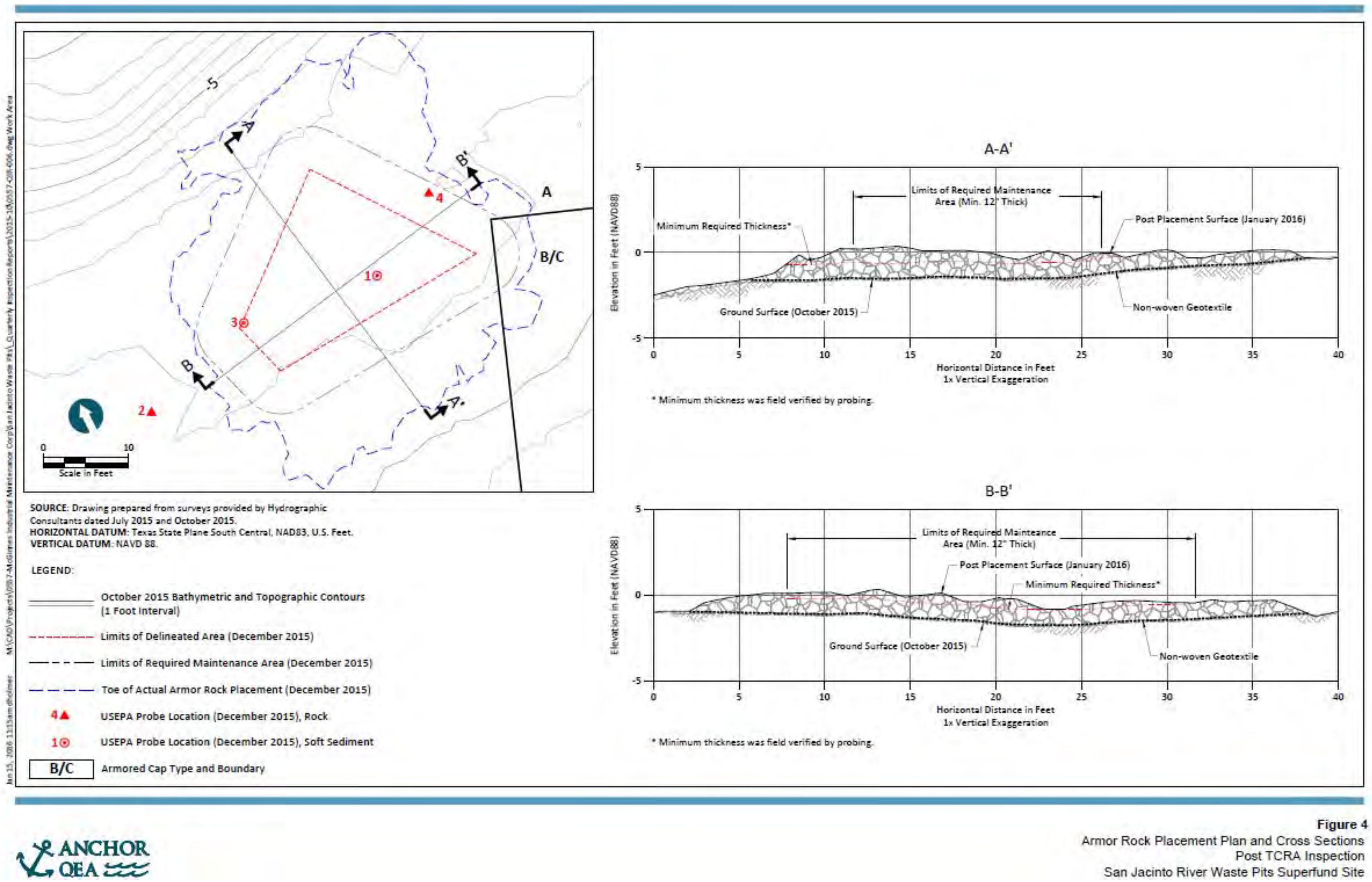


Figure 5. Rock Placement Area Post TCRA Inspection.

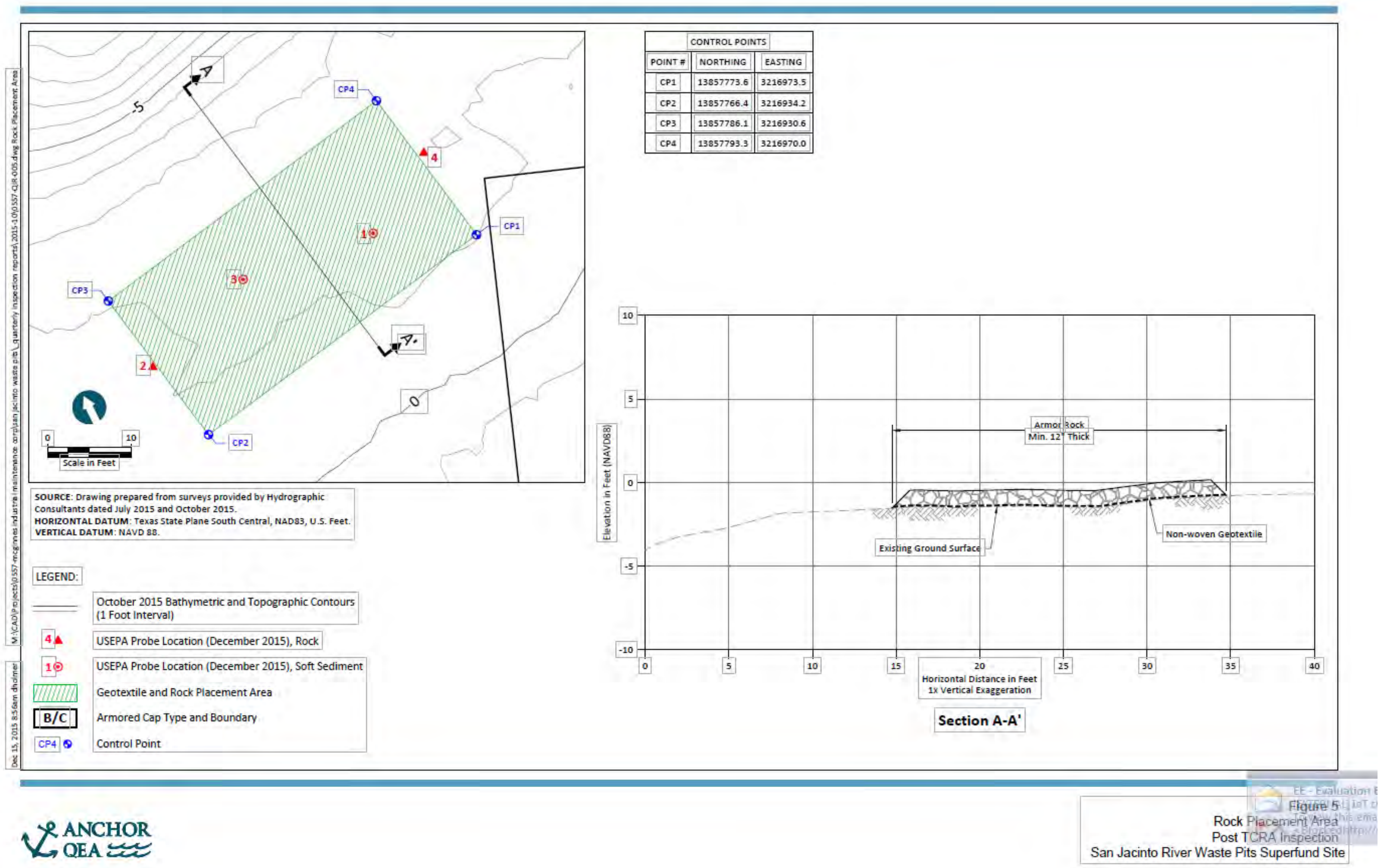


Figure 6. Proposed Supplemental Probing.

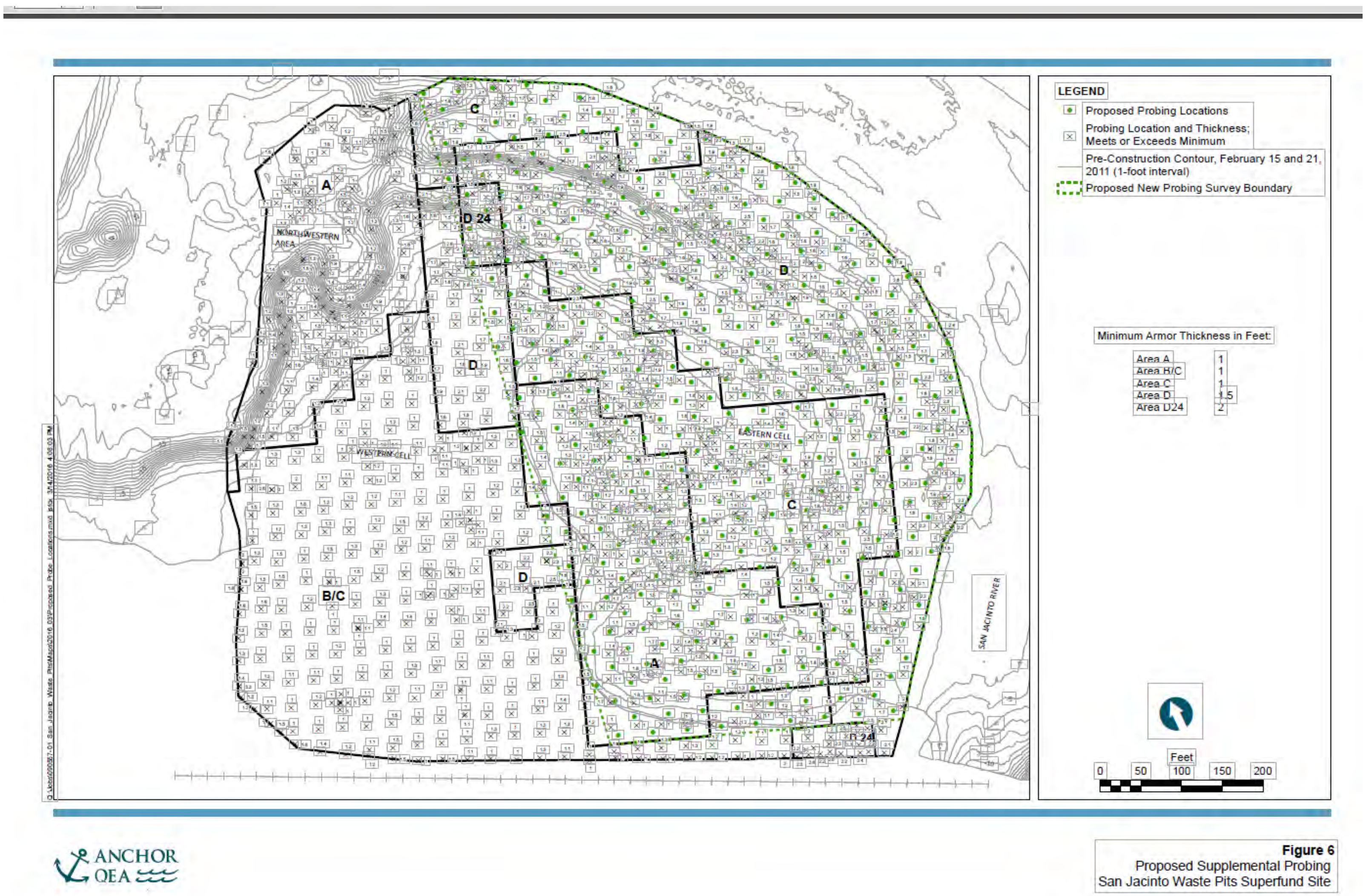
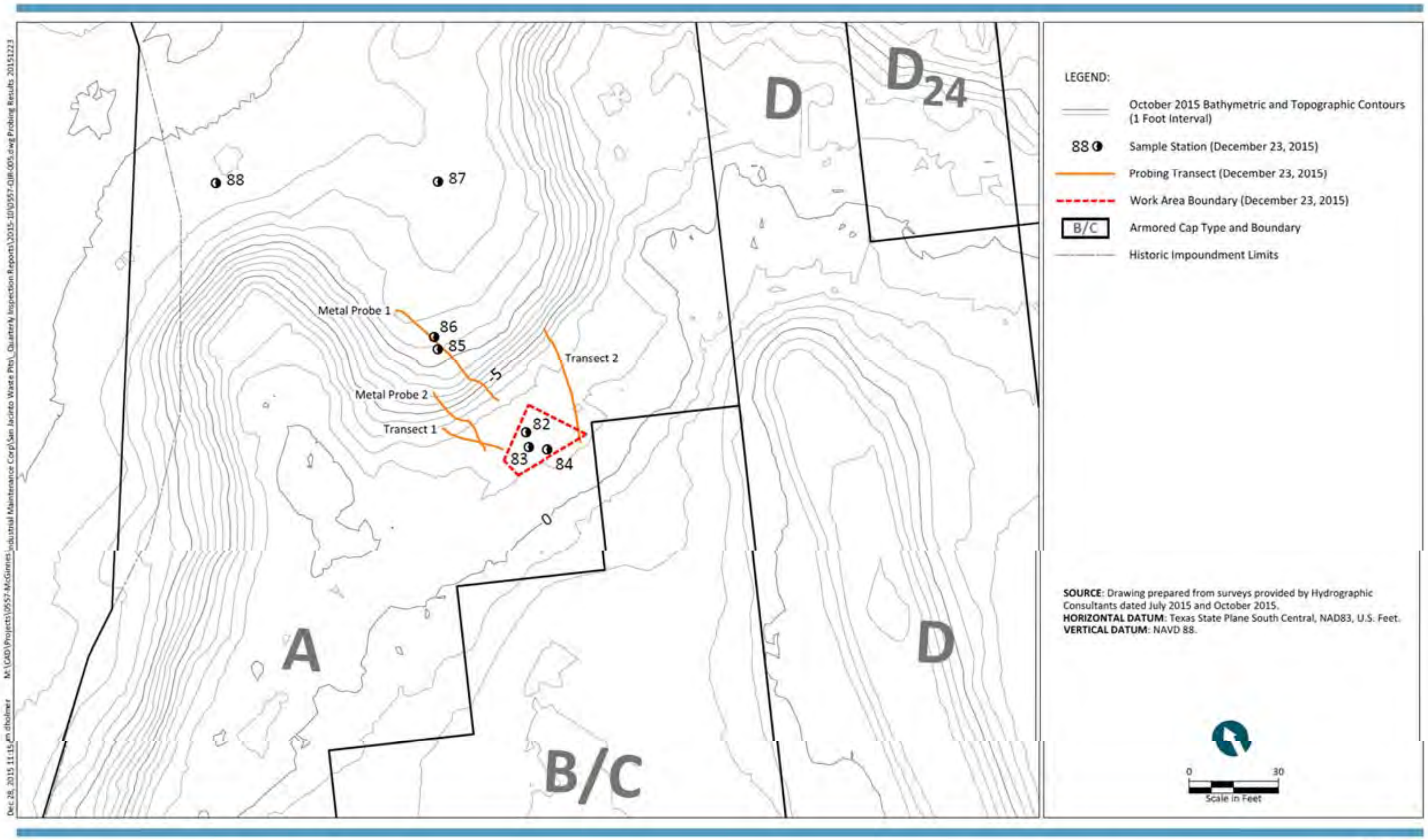


Figure 7. Security Camera Installed.

Figure 8. Probing and Sample Collection as part of Maintenance and Repair of the Deficiency Area of the SJRWP Armor Cap.



ANCHOR QEA

Figure 8
Summary of Probe and Sample Data Collected on December 23, 2015
Post TCRA Inspection
San Jacinto River Waste Pits Superfund Site

Figure 9. Dioxin and Furan Fingerprints for 2015 Sediment Samples Collected from Within the Delineated Area.

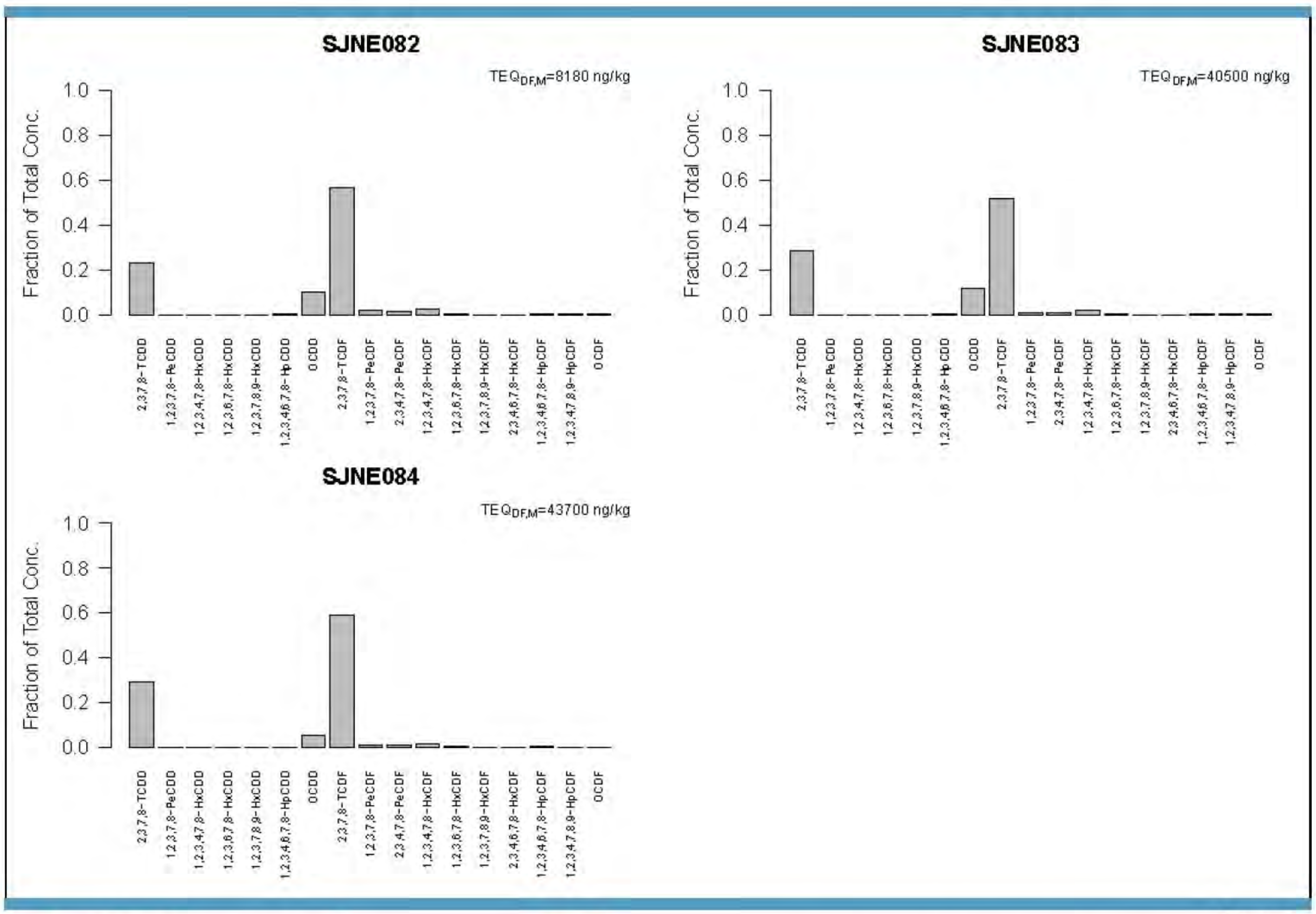


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Figure 9

Dioxin and Furan Fingerprints for 2015 Sediment Samples
Collected from Within the Delineated Area
SJRWP Superfund/MIMC and IPC

Figure 10. Dioxin and Furan Fingerprints for 2015 Sediment Samples Collected from Outside the Delineated Area.

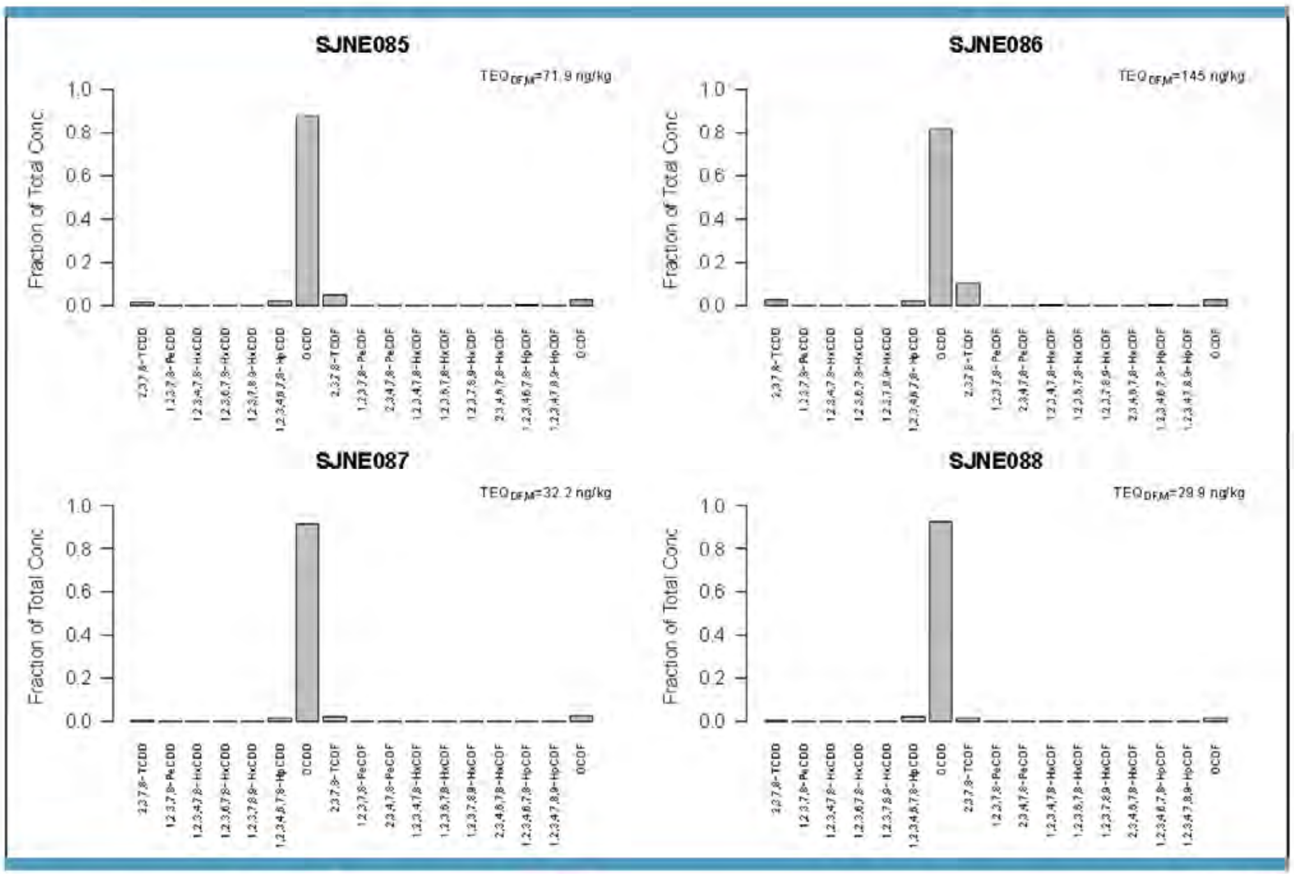

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Figure 10

Dioxin and Furan Fingerprints for 2015 Sediment Samples
Collected from Outside the Delineated Area
SJRWP Superfund/MIMC and IPC

Figure 11. TEQDF Concentrations (ng/kg dw) in Surface Sediment and Soils Within and in the Vicinity of the Northern Impoundments.

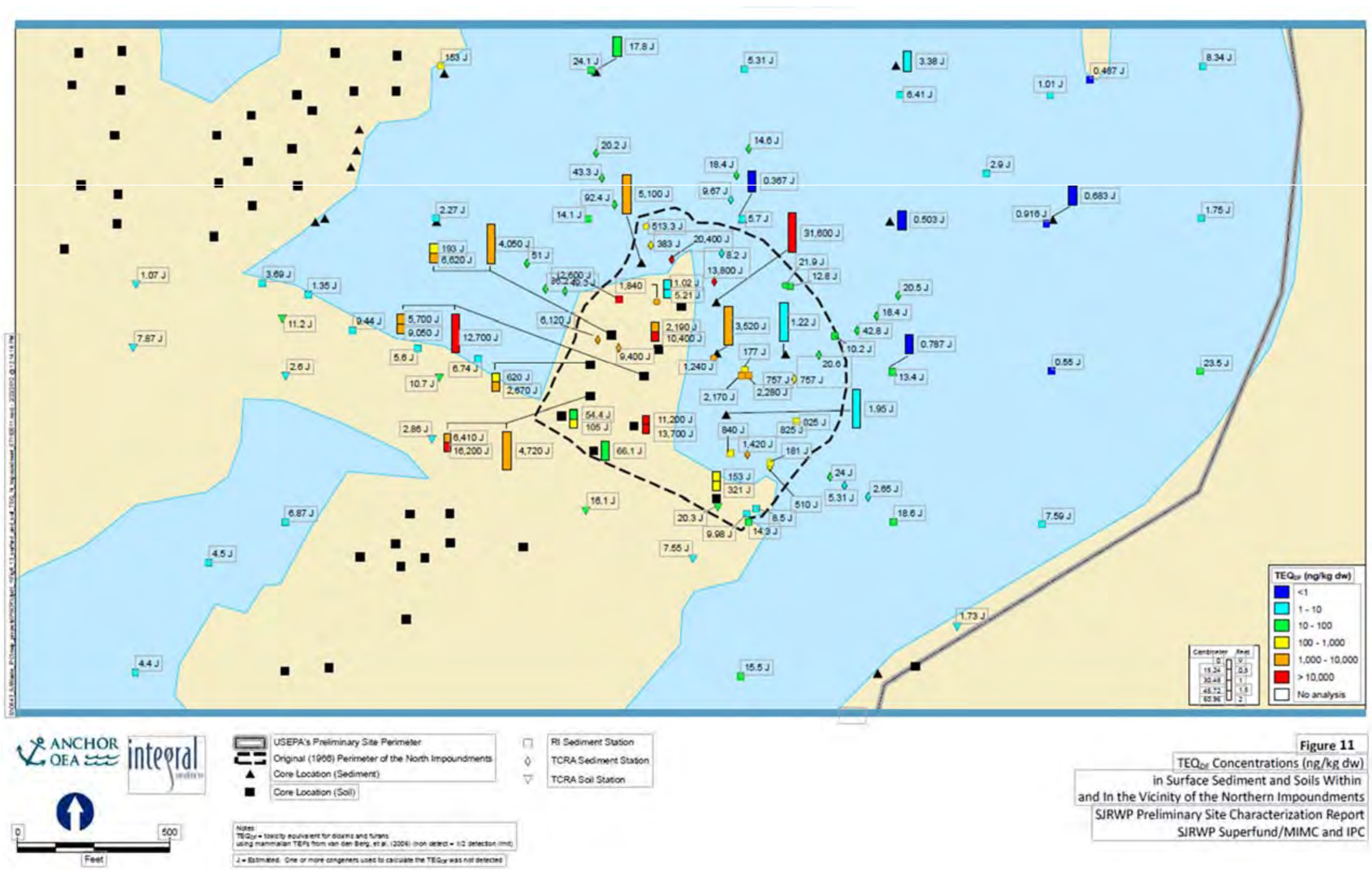

Figure 12. Patterns of Dioxin and Furan Congeners in the End Members of the Best Fit Unmixing Model.

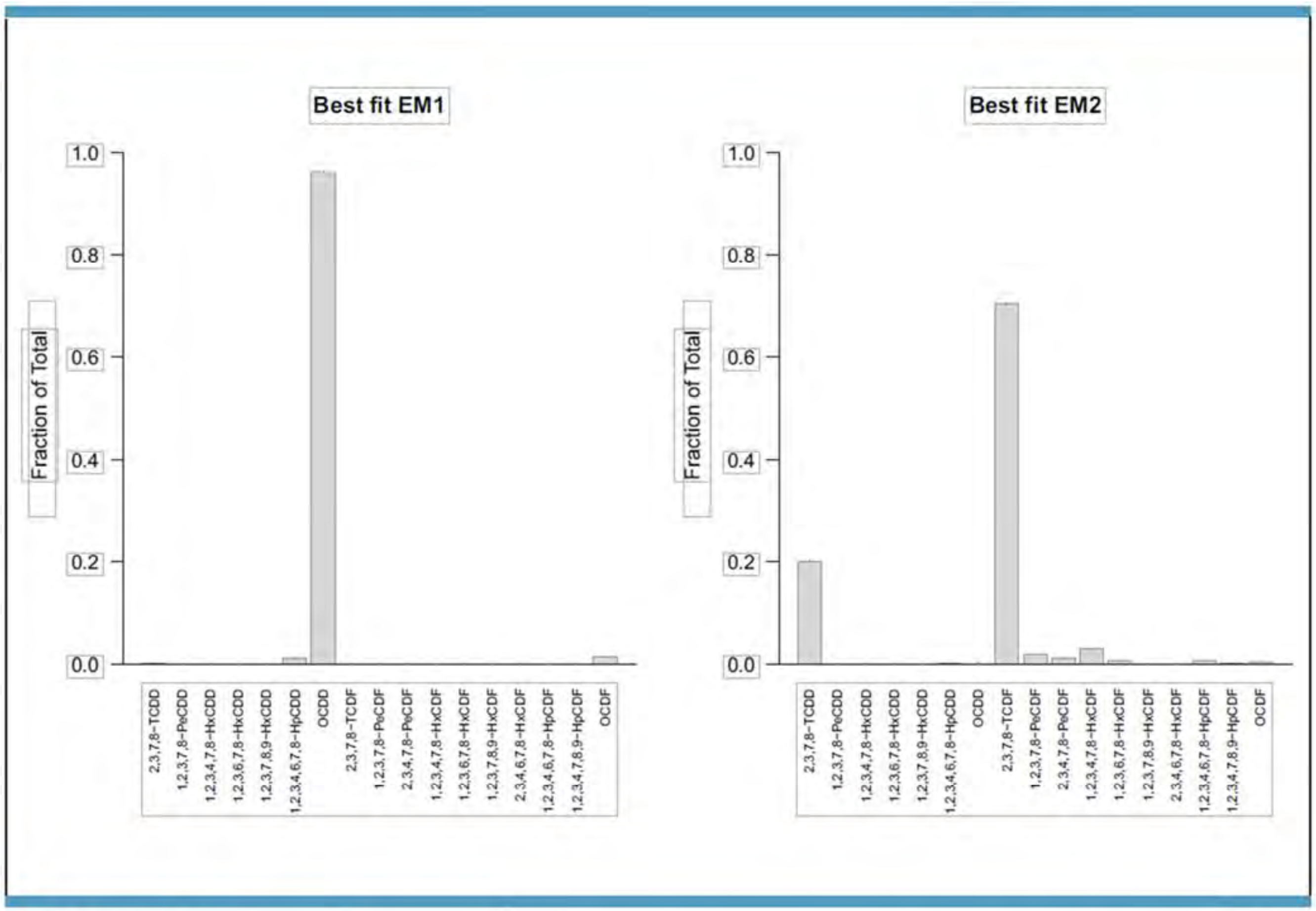

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Figure 12
Patterns of Dioxin and Furan Congeners in the End Members of the Best Fit Unmixing Model
SJRWP Preliminary Site Characterization Report
SJRWP Superfund/MIMC and IPC

References

Anchor QEA. 2012. "Revised final removal action completion report San Jacinto River Waste Pits Superfund Site," Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of McGinnes Industrial Maintenance Corporation and International Paper Company. http://galvbay.org/docs/SJRWP_Final_RACR_May%202012.pdf.

Anchor QEA. 2014. "Draft final interim feasibility study report San Jacinto River Waste Pits Superfund Site," Ocean Springs, MS.

Hayter, E.J., Schroeder, P.R., Rogers, N., Bailey, S., Kreitinger, J., Channell, M. 2015. "Evaluation of the San Jacinto Waste Pits Feasibility Study Remediation Alternatives," Letter Report, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Appendix A

Figure A1 shows the area where the EPA dive team found the deficiency area. Figures A2-A5 shows the site from different angles and views. All the pictures show that there is a ridge, mostly the berm of the original impoundment that is higher than the deficient area (elevation of the rocks); in particular Figure A4 and A5. Figure A5, the area after repairs; show that the only possible strike would have to occur between the two rock ridges, since neither ridge shows any impact. Figure A6 shows the ridges around the deficient area from the northeast view; no impact on the rocks on either site of the impacted area can be observed. Figure A7 shows the impacted area delineated after the probing.

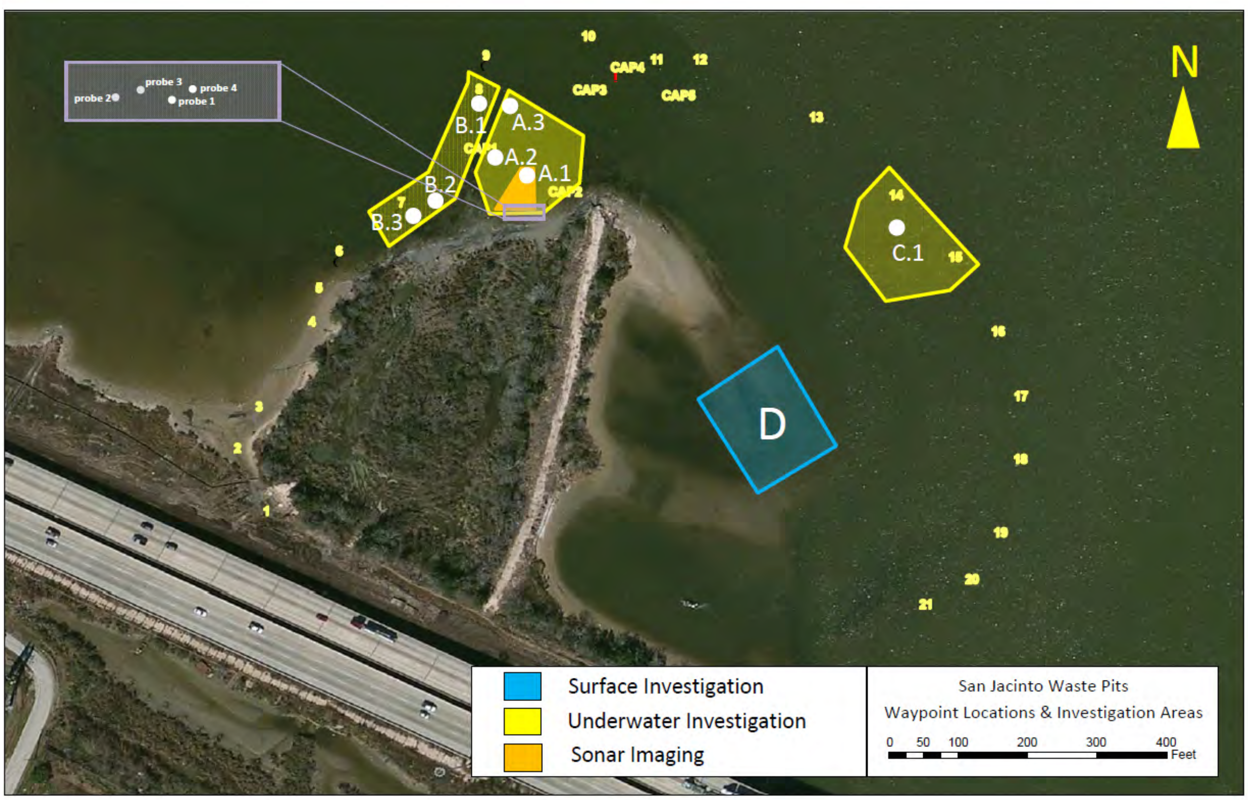


Figure A1. Site investigation area.

Figure A2. Site investigation work area.

Figure A3. Deficiency area marked with pvc pipe.

Figure A4. Top view of the site investigation work area.

Figure A5. Site investigation/maintenance area after repairs.

Northern edge of Western Cell (view northeast). December maintenance area marked with arrow.

Figure A6. Northeast view of the site investigation/maintenance area after repairs.

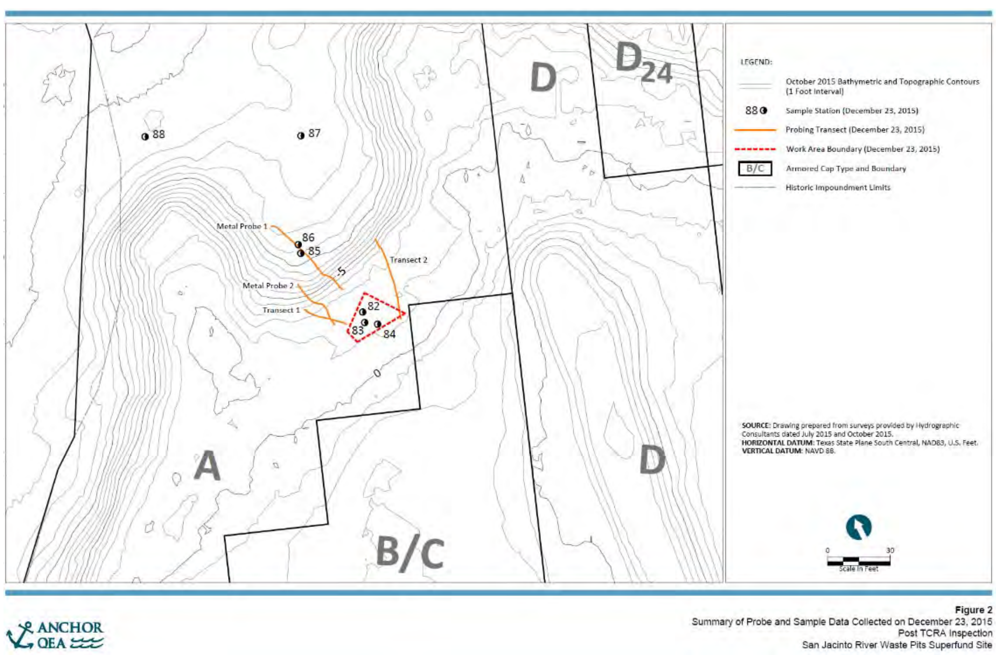


Figure A7. Work area boundaries and sample collection.

Looking at the area of impact/deficiency as delineated in Figure A7 shows that angle of impact from a barge/tug strike should had occurred from the northwest (where sample 82 was collected, toward sample 83, see Figure A8). That follows the wedge that a tug would had created. The difficulty with that strike is that there is a ridge on that side of the deficient area as shown in Figures A2-A6, and that ridge/rocks on that area do not show any impact or disturbance (see Figures A5 and A6).

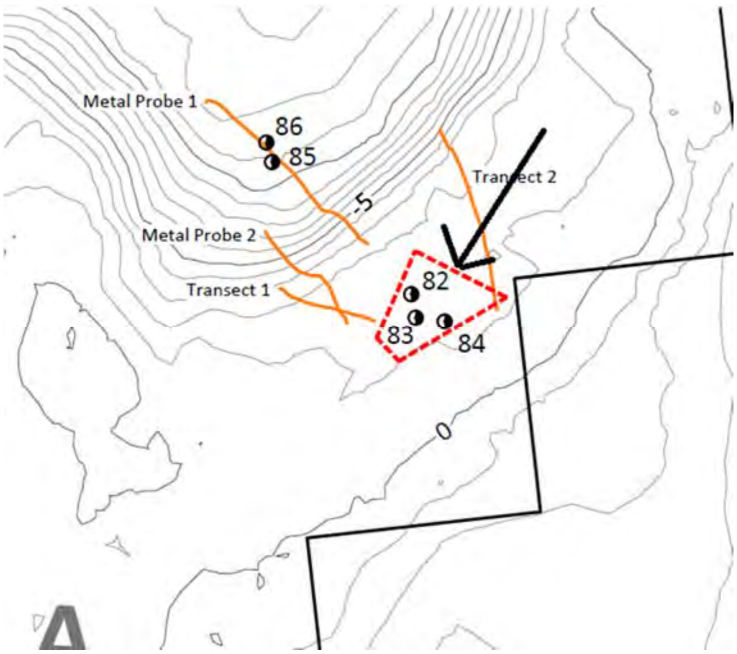


Figure A8. Strike direction.

The other potential strike as shown in Figure A9 is from the west side, again the ridge/rocks on that side (see Figures A5 and A6) show no disturbance.

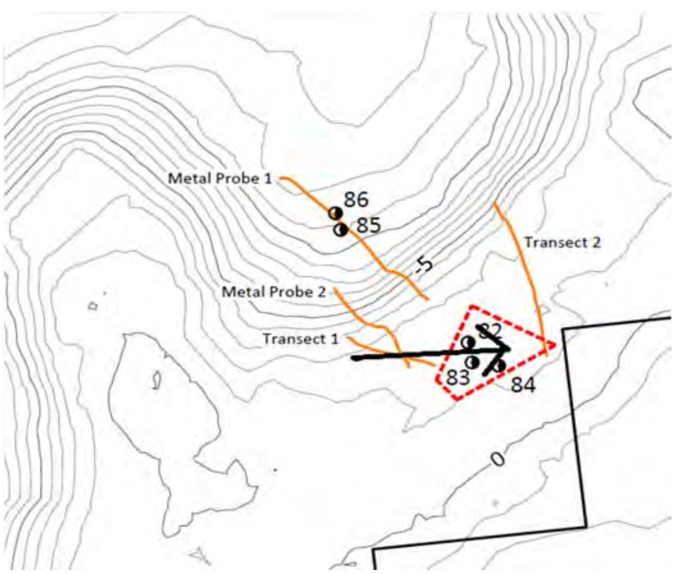


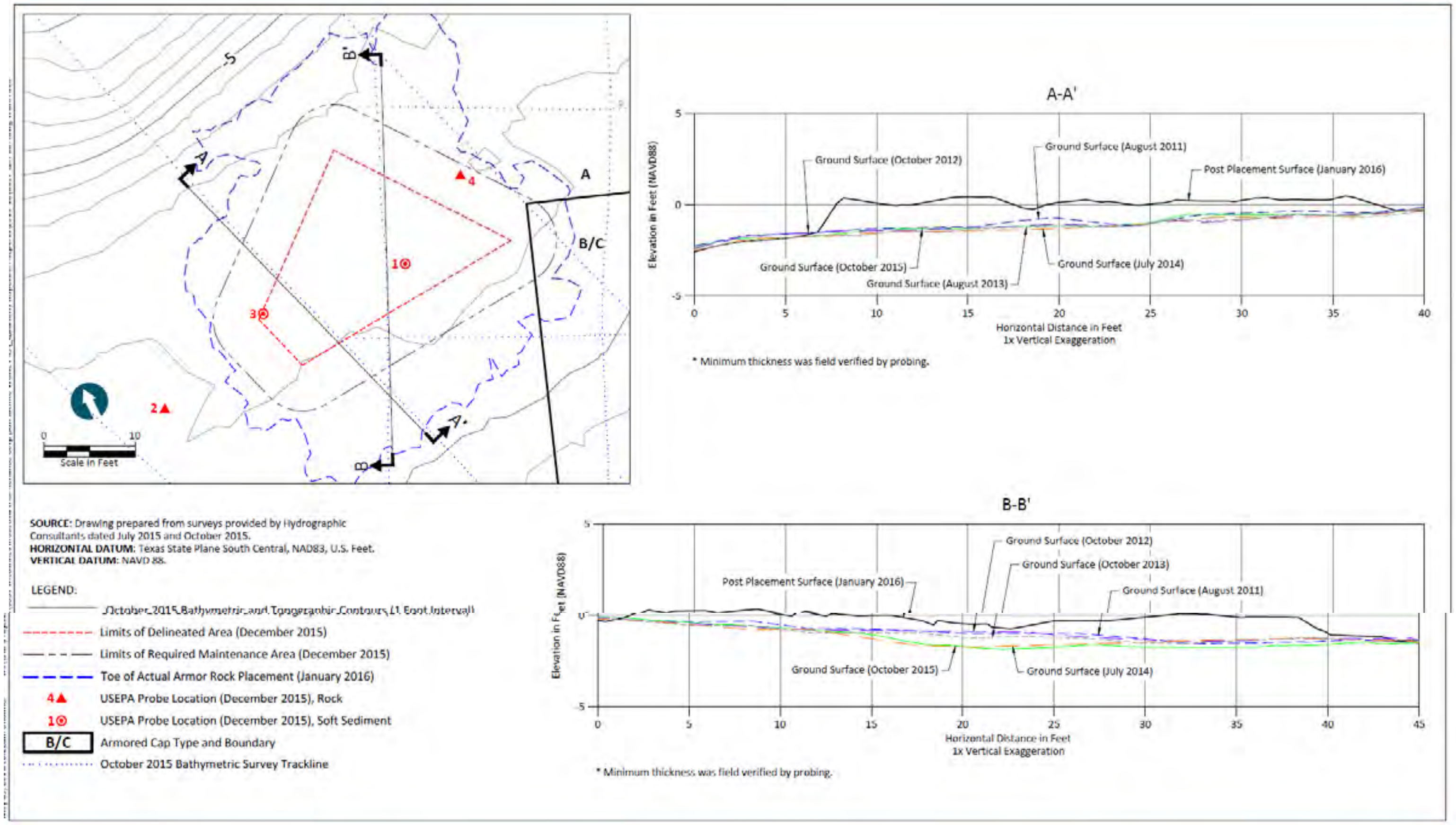
Figure A9. Second strike direction.

So based on the angles, the lack of impact around the surrounding areas where the approach would have occurred, and the lack of depression in the deficiency area we can say that a barge/tug strike was very unlikely.

Appendix B

Figure B1 shows the area where the EPA dive team found the deficiency area and was later repaired. The Figure also shows ground surveys from 2011 till 2015, an eastern transect A-A and a northwestern transect B-B, and the probing locations that defined the defect area. The B-B transect clearly shows that part of the defect area was showing a dip in elevation or subsidence since 2013 and maybe even 2012. Figure B2 shows the elevations for transect B-B in more detail; the subsidence starts in 2013 (at least two inches as compared to 2012) by 2014 the subsidence is at least 8-12 inches. The fact that we see a gradual loss or dip in elevation points to subsidence rather than impact. The cause of the subsidence is probably due to lack of support of the larger rocks in the upper cap layer. This area does not have a geotextile under the cap, so if the filter layer under the cap was not properly placed or if the mud underneath exhibit decay or uneven consolidation, then the rocks would begin to sink causing subsidence of the area. In the future it would be very useful to collect bathymetry and ground surveys prior to repairing the cap due to either scheduled maintenance or probing. The collected bathymetry or surveys would be extremely useful in understanding the cause of an event that resulted in a repair or assessment.

Figure B1. Bathymetric and topographic surveys for the defect area.

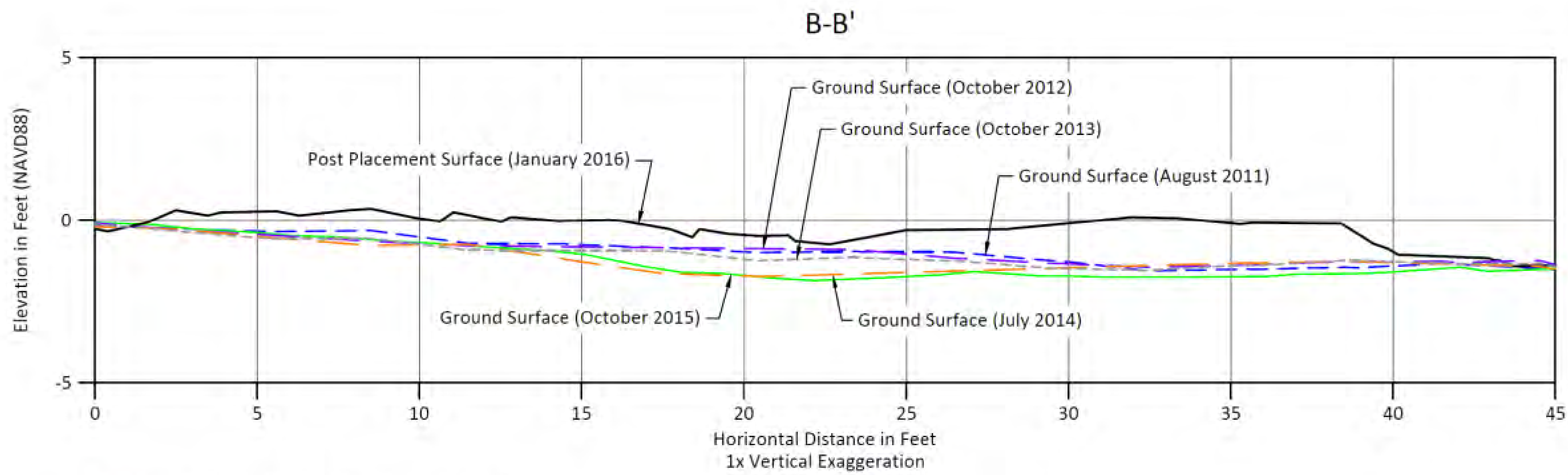


ANCHOR QEA

Draft - Privileged and Confidential

Figure
Armor Rock Placement Plan and Cross Sections
Post TCRA Inspection
San Jacinto River Waste Pits Superfund Site

Figure B2. Ground survey at the defect area: transect B-B.



* Minimum thickness was field verified by probing.

INTERIM-FINAL INTERIM FEASIBILITY STUDY REPORT

APPENDIX C: REMEDIAL ALTERNATIVE COST DEVELOPMENT

SAN JACINTO RIVER WASTE PITS SUPERFUND SITE

Prepared for

International Paper Company

McGinnes Industrial Maintenance Corporation

Prepared by

Anchor QEA, LLC

614 Magnolia Avenue

Ocean Springs, Mississippi 39564

Modified by

U.S. Environmental Protection Agency

REMEDIAL ALTERNATIVE COST DEVELOPMENT

This appendix summarizes the approaches used to develop remedial alternative quantities and cost estimates for the San Jacinto River Waste Pits Superfund Site Feasibility Study (FS). *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (USEPA 2000) was followed to develop these cost estimates and was supplemented with professional judgment where appropriate in estimating daily costs and production rates. Professional judgment drew on the recently completed Time Critical Removal Action (TCRA; Anchor QEA 2011), as well as other construction projects in the region.

The remainder of this appendix discusses the following:

- Method for developing unit costs for the construction elements, including:
  - Defining each construction task
  - Discussion of the cost approach for each construction task
- Method for developing quantities for each construction element

UNIT COST DEVELOPMENT

The cost estimate consists of direct and indirect cost elements:

- Direct Construction Tasks
  - Mobilization/Demobilization and Setup
  - Permanent Cap Protective Berm
  - Permanent Cap Construction
  - Treatment
  - Removal and Disposal
  - Armored Cap Restoration
  - Demolition (Area South of Interstate-10)
  - Replacement (Area South of Interstate-10)
  - Soil Management Plan and Notices (Institutional Controls; Area South of Interstate 10)
- Indirect Construction Tasks
  - Engineering Design

- Construction Administration/Observation
- U.S. Environmental Protection Agency (USEPA) 5-Year Review (net present value)
- Institutional Controls (Northern Impoundments and Area South of Interstate 10; net present value)
- Long-Term Armored Cap Monitoring (net present value)
- Long-Term Natural Recovery Monitoring (net present value)
- Cap Maintenance (Armored Cap and Permanent Cap; net present value)

Table 1 provides a summary of unit cost assumptions for the cost sub-elements of each cost element bulleted above. Where appropriate, the source of the assumption is presented.

USEPA (2000) states that contingencies for detailed analysis of alternatives can be as high as 50 percent. For this FS, a contingency of 30 percent of the total direct construction costs was assumed.

As described in the Final Interim Feasibility Study Report, the cost of designing and implementing the TCRA exceeded $9 million. The construction cost, as reported in the Remedial Action Completion Report (RACR) (USEPA 2012), is $8.7 million. Additional costs not reported in the RACR include design and construction oversight. For purposes of these cost estimates, the cost of the TCRA has been assumed to be $9 million.

REMEDIAL ELEMENT QUANTITY ASSUMPTIONS

The total cost of a remedial alternative will be a function of the unit costs for each remedial element (Table 1) and the quantity of each remedial element. Table 2 summarizes assumptions used to develop the quantities of the remedial alternative elements.

REFERENCES

Anchor QEA, LLC, 2011. *Final Removal Action Work Plan, Time Critical Removal Action, San Jacinto River Waste Pits Superfund Site*. Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of McGinnes Industrial Maintenance

Corporation and International Paper Company. November 2010. Revised February 2011.

USEPA (U.S. Environmental Protection Agency), 2000. *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*. USEPA 540-R-00-002 OSWER 9355.0-75. July 2000.

USEPA, 2012. Revised Final Removal Action Completion Report, San Jacinto River Waste Pits Superfund Site. May 2012.

Table 1
Unit Cost Assumptions

Element		Unit Cost	Unit	Source and/or Comment
Mobilization/ Demobilization and Setup	Mobilization and Demobilization – Northern Impoundments	8 to 15% of Direct Construction Costs	%	Engineering judgment. Higher due to marine work/equipment. Includes property rental for transfer sites.
	Mobilization and Demobilization – Area South of Interstate 10	$50,000 - $250,000	Lump Sum	Engineering judgment. Dependent on scope.
	Environmental Protection and Erosion Control	$5,000 - $300,000	Lump Sum	TCRA contractor bids and similar work with larger scope.
	Construction, Payment, and As-built Surveys – Northern Impoundments	$100,000 - $300,000	Lump Sum	Engineering judgment and TCRA contractor bids.
	Construction, Payment, and As-built Surveys – Area South of Interstate 10	$20,000	Lump Sum	Engineering judgment and limited confined area.
	Construction Materials Testing	$15,000	Each	Engineering judgment and TCRA contractor bids.
	Water Quality Engineering Controls	$100,000 - $1,600,000	Lump Sum	Engineering judgment and TCRA contractor bids. Lower cost for silt curtain; higher cost for combination rock berm and sheetpiling.
Permanent Cap Protective Berm	Rock Rubble Mound Construction	$107	Ton	USA Environment costs for installing D rock for TCRA construction. Assumed site access and production rates consistent with those achieved during the TCRA construction.
Permanent Cap Construction	Additional Armor Rock Placement	$107	Ton	USA Environment costs for installing D rock for TCRA construction; assumed site access and production rates consistent with those achieved during the TCRA construction.

Element		Unit Cost	Unit	Source and/or Comment
Treatment	Temporary Sheetpile Installation	$1,300	Linear Foot	TCRA contractor bids used as basis. Increased to account for additional king piles to support dewatering within the sheet piling.
	In Situ Solidification	$34	Cubic Yard	Actual USA Environment TCRA costs.
	Sheetpile Dewatering	$7,800	Day	RS Means and prior project bids for treatment costs.
Removal and Disposal	Upland Armored Cap Removal	$72	Cubic Yard	TXDOT average bid costs. Increased cost to account for slower production (thinner precision cuts) and assumed work can be performed in the dry with land-based construction equipment during low tide windows.
	In-water Armored Cap Removal	$92	Cubic Yard	TCRA contractor bid prices for dredging. Increased due to thinner precision cuts. Assumed that water based excavation equipment is necessary.
	Land-based Sediment Excavation	$12	Cubic Yard	TXDOT Average Bid Costs with increase for environmental considerations and slower production; assume that work can be performed in the dry with land based construction equipment during low tide windows.
	Water-based Sediment Excavation/Dredging	$46	Cubic Yard	TCRA contractor bids.
	Armored Cap Wash Water Treatment and Disposal	$530	Ton	Quote from Veolia assuming > 5% solids to treat water.
	Wellpoint Dewatering and Treatment	$400,000	Lump Sum	Previous project estimates.
	Replace Excavated Soil	$3.50	Cubic Yard	RS Means.

Element		Unit Cost	Unit	Source and/or Comment
	Offsite Haul and Disposal of Armored Cap (Debris Landfill)	$48	Ton	Actual USA Environment TCRA cost.
	Stabilization of Sediment/Soil prior to Shipment	$30	Cubic Yard	Engineering judgment and information from Waste Management. Assumed mixing diatomaceous earth with sediment.
	Offsite Haul and Disposal of Sediment (Class 1)	$110	Ton	Discussion with U.S. Department of Ecology.
	Offsite Haul and Disposal of Soil (Class 2)	$55	Ton	Prior experience in Texas on other similar projects.
	Dredge Residuals Cover/Backfill	$30	Cubic Yard	Prior project experience.
Armored Cap Restoration	Replacement Cap Geotextile	$6.25	Square Yard	USA Environmental TCRA costs.
	Replacement Cap Armor Stone A/B	$78	Ton	USA Environmental TCRA costs.
	Replacement Cap Armor Stone C/D	$107	Ton	USA Environmental TCRA costs.
Ground Water Monitoring Wells	Install Wells	$50,000	Lump Sum	Engineering judgement.
Demolition (Area South of Interstate 10)	Concrete Pad (6 inch thick)	$7.54	Square Foot	RS Means.
	House with 4-inch-thick foundation	$7.89	Square Foot	RS Means.
Replacement Construction (Area South of Interstate 10)	Concrete Pad (6 inch thick)	$5.38	Square Foot	RS Means.
	House with 4-inch-thick foundation	$125	Square Foot	Review of online Houston housing costs.
Soil Management Plan	Bollards	$741.26	Each	RS Means.

Element		Unit Cost	Unit	Source and/or Comment
and Notices (Institutional Controls; Area South of Interstate 10)	Marker Layer	$0.67	Square Yard	Prior project experience.
Indirect Construction Costs	Engineering Design – Northern Impoundments	6 to 12% of Direct Construction Costs	$	Engineering judgment and complexity of marine work.
	Engineering Design – Area South of Interstate 10	$40,000 to $200,000	Lump Sum	Engineering judgment.
	Construction Administration/Observation – Northern Impoundments	6 to 12% of Direct Construction Costs	%	Engineering judgment. More extensive monitoring than upland.
	Construction Administration/Observation – Area South of Interstate 10	5 to 10% of Direct Construction Costs	%	Engineering judgment.
	USEPA 5-Year Review	Net Present Value	Lump Sum	Assumed $50,000 for USEPA costs every 5 years for 30 years for the Northern Impoundments and $50,000 for the Area South of Interstate 10. Assumed discount rate of 7% to determine net present value.
	Institutional Controls – Northern Impoundments	Net Present Value	Lump Sum	Assumed that as part of construction there are Institutional Controls costs for enforcement tools, proprietary controls, and informational devices. After construction, yearly costs of $10,000 for enforcement tools and $5,000 for informational devices for Alternatives 1N through 5aN and $4,000 per year for Alternative 6N for 30 years. Assumed discount rate of 7% to determine net present value.

Element		Unit Cost	Unit	Source and/or Comment
	Soil Management Plan and Notices (Institutional Controls) – Area South of Interstate 10	$100,000	Lump Sum	Two elements: 1) deed notices that document the presence of contamination, specific locations of affected areas, and if appropriate, protective measures that need to be used (e.g., PPE and HAZWOPER training); 2) soil management plan that would be recorded with the deed to describe how any excavated soil would be managed. Engineering judgment.
Indirect Construction Costs (continued)	Long-Term Armored Cap Monitoring	Net Present Value	Lump Sum	Assumed $25,000 cap monitoring events in Year 1, 2, 5, 10, 15, and 30. Assumed discount rate of 7% to determine net present value.
	Long-Term Natural Recovery Monitoring	Net Present Value	Lump Sum	Assumed $75,000 cap monitoring events in years 1, 2, 5, 10, 15, and 30. Assumed discount rate of 7% to determine net present value.
	Armored Cap Maintenance	Net Present Value	Lump Sum	Assumed $100,000 cap maintenance in Year 1 and 2. Assumed discount rate of 7% to determine net present value.
	Ground Water Monitoring	Net Present Value	Lump Sum	Assumed $30,000 ground water monitoring per year. Assumed discount rate of 7% and inflation rate of 3% to determine net present value.

Notes:
% = percent
PPE = personal protective equipment
TCRA contractor bids = prices were based on the bids received for the 2010 TCRA removal action
TXDOT average bid costs = Texas Department of Transportation average low bid unit prices 3-month statewide average January through March 3013 (http://www.txdot.gov/business/letting-bids/average-low-bid-unit-prices.html)
RS Means = prices obtained from 2014 RS Means Online library for the Houston area.
USEPA = U.S. Environmental Protection Agency

Table 2
Quantity Assumptions

Element	Assumption	Source and/or Comment
Sediment and Soil Unit Weight	1.4 tons per cubic yard	Typical assumption for silty and sandy sediments (excavated material)
Armor Stone Unit Weight	1.8 tons per cubic yard	Typical assumption for engineered cap material
Sediment Residual Cover Thickness	12-inch sand layer applied as two 6-inch-thick layers	Assumes 18 inches placed to obtain a 12-inch cover
Rock Rubble Mound Construction	5 foot high, 2 feet horizontal to 1 foot vertical (2H:1V) side slopes along the northwestern perimeter	Create a 5-foot-high rubble mound with the intent of stopping any larger vessels from striking the cap
Permanent Armor Rock on Slopes	5H:1V for upland armor rock and 3H:1V for offshore armor rock	Volume determined from CAD
Removal of Armored Cap	18-inch-thick cap over the area of removal	Typical Armored Cap thickness
Dredging/Excavation	Total removal volume is neat line volume plus 1-foot overdredge plus 10% to account for side slopes	Neatline volume determined from CAD, depths vary with target removal concentrations
Armored Cap Stone Washing	Assumes 0.025 tons of water needed to wash a ton of rock	Based on Armored Cap stone removal volumes and commercial pressure water volumes
Sheetpile Wall	Measured length	Area determined from CAD
Solidification/Stabilization	Volume the same as the calculated excavation volumes with 1-foot overstabilization and 10% growth	Neatline volume determined from CAD, depths vary with target removal concentrations
Landfill Disposal	Tonnage is the calculated excavation volumes increased by the unit weight and amount of additive needed for handling	From dredge volumes
Armor Stone Replacement	1 foot for A and B/C rock and 2 foot for C/D rock	Area determined in CAD and converted to tons
House and Concrete Pad in Area South of Interstate 10	4-inch-thick house foundation and 6-inch-thick concrete pad with rebar	Areas measured in Google Earth. Assumed house debris was 50 pounds per square feet and concrete pad debris was 150 pounds per cubic feet

Estimate of Project Quantities & Probable Cost Worksheet
Alternative 1N
No Further Action

Item	Description	Plan Qty.	Unit	Unit Price	Total
DIRECT CONSTRUCTION COSTS					
0001	Mobilization/Demobilization	$ -	%	15%	$ -
0002	Environmental Protection and Erosion Control	0	LS	$100,000	$ -
0003	Construction Payment and As-Built Surveys	0	LS	$100,000	$ -
0004	Construction Materials Testing	0	EA	$15,000	$ -
0005	Additional Armor Rock Placement	0	TON	$107	$ -
DIRECT CONSTRUCTION TOTAL:					$ -
IN-DIRECT CONSTRUCTION COSTS					
0006	Engineering Design	$ -	%	12%	$ -
0007	Construction Administration/Observation	$ -	%	12%	$ -
0008	EPA 5 Year Review (Net Present Value)	1	LS	$108,000	$ -
0009	Institutional Controls (Net Present Value)	0	LS	$286,000	$ -
0010	Long Term MNR Monitoring (Net Present Value)	0	EA	$264,000	$ -
0011	Long Term Cap Monitoring (Net Present Value)	1	LS	$88,000	$ 88,000.00
0012	Cap Maintenance (Net Present Value)	1	LS	$181,000	$ 181,000.00
IN-DIRECT CONSTRUCTION TOTAL:					$ 269,000.00
PROJECT TOTAL					$ 269,000.00
PROJECT ROUNDED TOTAL:					**$** 300,000.00
30% Contingency					**$** 90,000.00
TOTAL ESTIMATED COST					**$** 390,000.00

Estimate of Project Quantities & Probable Cost Worksheet
Alternative 2N
Cap, ICs, Ground Water Monitoring, and MNR

Item	Description	Plan Qty.	Unit	Unit Price	Total
DIRECT CONSTRUCTION COSTS					
0001	Mobilization/Demobilization	$ -	%	15%	$ -
0002	Environmental Protection and Erosion Control	0	LS	$100,000	$ -
0003	Construction Payment and As-Built Surveys	0	LS	$100,000	$ -
0004	Construction Materials Testing	0	EA	$15,000	$ -
0005	Additional Armor Rock Placement	0	TON	$107	$ -
DIRECT CONSTRUCTION TOTAL:					$ -
IN-DIRECT CONSTRUCTION COSTS					
0006	Engineering and Monitoiring Well Design	$ -	%	12%	$ 50,000
0007	Construction Administration/Observation	$ -	%	12%	$ -
0008	EPA 5 Year Review (Net Present Value)	1	LS	$108,000	$ 108,000.00
0009	Institutional Controls (Net Present Value)	1	LS	$286,000	$ 286,000.00
0010	Long Term MNR & GW Monitoring (Net Present Value)	1	LS	$264,000	$ 794,000.00
0011	Long Term Cap Monitoring (Net Present Value)	1	LS	$88,000	$ 88,000.00
0012	Cap Maintenance (Net Present Value)	1	LS	$181,000	$ 181,000.00
IN-DIRECT CONSTRUCTION TOTAL:					$ 1,507,000
PROJECT TOTAL:					$ 1,507,000
30% Contingency					**$** 452,000
TOTAL ESTIMATED COST					**$** 1,959,000

Estimate of Project Quantities & Probable Cost Worksheet
Alternative 3N
Upgraded Cap, ICs, Ground Water Monitoring, and MNR

Item	Description	Plan Qty.	Unit	Unit Price	Total
DIRECT CONSTRUCTION COSTS					
0001	Mobilization/Demobilization	$ 1,181,135	%	15%	$ 177,170.25
0002	Environmental Protection and Erosion Control	1	LS	$100,000	$ 100,000.00
0003	Construction, Payment and As-Built Surveys	1	LS	$100,000	$ 100,000.00
0004	Construction Materials Testing	1	EA	$15,000	$ 15,000.00
0005	Rock Rubble Mound Construction	2,900	TON	$107	$ 311,300.00
0006	Additional Permanent Cap Rock Placement	6,100	TON	$107	$ 654,835.00
DIRECT CONSTRUCTION TOTAL:					$ 1,358,000.00
IN-DIRECT CONSTRUCTION COSTS					
0007	Engineering & Monitoring Well Design	$ 1,358,000	%	12%	$ 213,000,00
0008	Construction Administration/Observation	$ 1,358,000	%	12%	$ 162,960.00
0009	EPA 5 Year Review (Net Present Value)	1	LS	$108,000	$ 108,000.00
0010	Institutional Controls (Net Present Value)	1	LS	$286,000	$ 286,000.00
0011	Long Term MNR & GW Monitoring (Net Present Value)	1	LS	$264,000	$ 794,000.00
0012	Long Term Cap Monitoring (Net Present Value)	1	LS	$88,000	$ 88,000.00
0013	Cap Maintenance (Net Present Value)	1	LS	$181,000	$ 181,000.00

IN-DIRECT CONSTRUCTION TOTAL: $ 1,833,000

PROJECT TOTAL: $ 3,191,000

30% Contingency $ 957,000

TOTAL ESTIMATED COST $ 4,148,000

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Estimate of Project Quantities & Probable Cost Worksheet
Alternative 3aN
Enhanced Cap, Pilings, ICs, Ground Water Monitoring, and MNR

Item	Description	Plan Qty.	Unit	Unit Price		Total
DIRECT CONSTRUCTION COSTS						
0001	Mobilization/Demobilization	$13,152,500	%	15%	$	1,972,875
0002	Environmental Protection and Erosion Control	1	LS	$100,000	$	100,000
0003	Construction, Payment and As-Built Surveys	1	LS	$100,000	$	100,000
0004	Construction Materials Testing	1	EA	$15,000	$	15,000
0005	Rock Rubble Mound Construction	2,900	TON	$107	$	310,300
0006	Pilings	57	EA	$12,500	$	712,500
0007	Additional Permanent Cap Rock Placement	6,100	TON	$107	$	652,700
0008	Coarse Gravel Filter Layer	1,300	TON	$60	$	78,000
0009	Enhanced Permanent Cap Rock Placement	93,200	TON	$120	$	11,184,000
DIRECT CONSTRUCTION TOTAL:					$	15,125,375
IN-DIRECT CONSTRUCTION COSTS						
0010	Engineering & Monitoring Well Design	$ 15,125,375	%	8%	$	1,260,030
0011	Construction Administration/Observation	$ 15,125,375	%	8%	$	1,210,030
0012	EPA 5 Year Review (Net Present Value)	1	LS	$108,000	$	108,000
0013	Institutional Controls (Net Present Value)	1	LS	$286,000	$	286,000
0014	Long Term MNR & GW Monitoring (Net Present Value)	1	LS	$794,000	$	794,000
0015	Long Term Cap Monitoring (Net Present Value)	1	LS	$88,000	$	88,000
0016	Cap Maintenance (Net Present Value)	1	LS	$181,000	$	181,000
IN-DIRECT CONSTRUCTION TOTAL:					$	3,927,060
PROJECT TOTAL:					$	19,052,435
30% Contingency						**5,715,731**
TOTAL ESTIMATED COST					**$**	**24,768,166**

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Estimate of Project Quantities & Probable Cost Worksheet
Alternative 4N
Partial Solidification, Upgraded Cap, ICs, Ground Water Monitoring, and MNR

Item	Description	Plan Qty.	Unit	Unit Price	Total
DIRECT CONSTRUCTION COSTS					
0001	Mobilization/Demobilization	$ 7,445,315	%	15%	$ 1,117,000.00
0002	Environmental Protection and Erosion Control	1	LS	$100,000	$ 100,000.00
0003	Construction Payment and As-Built Surveys	1	LS	$100,000	$ 100,000.00
0004	Construction Materials Testing	2	EA	$15,000	$ 30,000.00
0005	Rock Rubble Mound Construction	2,900	TON	$107	$ 311,315.00
0006	Additional Armor Rock Placement	6,100	TON	$107	$ 655,000.00
0007	Remove Armored Cap - Land Based	6,200	CY	$72	$ 443,000.00
0008	Remove Armored Cap - Water Based	2,300	CY	$92	$ 212,000.00
0009	Wash Water Armored Cap - Treat and Dispose	800	TON	$530	$ 424,000.00
0010	Dispose Armored Cap - Debris Landfill	15,300	TON	$48	$ 730,000.00
0011	Temporary Sheet Pile	800	LF	$1,300	$ 1,040,000.00
0012	Sheet Pile Dewatering	22	DAY	$7,800	$ 171,000.00
0013	In situ Solidification	52,000	CY	$34	$ 1,783,000.00
0014	Replace Geotextile	22,600	SY	$6.25	$ 141,000.00
0015	Replace Armor Rock A/B	8,280	TON	$78	$ 648,000.00
0016	Replace Armor Rock C/D	6,120	TON	$107	$ 657,000.00
DIRECT CONSTRUCTION TOTAL:					$ 8,562,000.00
IN-DIRECT CONSTRUCTION COSTS					
0017	Engineering & Monitoring Well Design	$ 8,562,000	%	8%	$ 734,960.00
0018	Construction Administration/Observation	$ 8,562,000	%	8%	$ 684,960.00
0019	EPA 5 Year Review (Net Present Value)	1	LS	$108,000	$ 108,000.00
0020	Institutional Controls (Net Present Value)	1	LS	$286,000	$ 286,000.00
0021	Long Term MNR & GW Monitoring (Net Present Value)	1	LS	$264,000	$ 794,000.00
0022	Long Term Cap Monitoring (Net Present Value)	1	LS	$88,000	$ 88,000.00
0023	Cap Maintenance (Net Present Value)	1	LS	$181,000	$ 181,000.00
IN-DIRECT CONSTRUCTION TOTAL:					$ 2,877,000
PROJECT TOTAL					$ 11,439,000
30% Contingency					**$ 3,400,000**
TOTAL ESTIMATED COST					**$ 14,839,000**

Estimate of Project Quantities & Probable Cost Worksheet
Alternative 5N
Partial Removal, Upgraded Cap, ICs,
Ground Water Monitoring, and MNR

Item	Description	Plan Qty.	Unit	Unit Price		Total
DIRECT CONSTRUCTION COSTS						
0001	Mobilization/Demobilization	$ 17,701,315	%	8%	$	1,420,000.00
0002	Environmental Protection and Erosion Control	1	LS	$300,000	$	300,000.00
0003	Construction Payment and As-Built Surveys	1	LS	$300,000	$	300,000.00
0004	Construction Materials Testing	2	EA	$15,000	$	30,000.00
0005	Silt Curtain	1	LS	$100,000	$	100,000.00
0006	Rock Rubble Mound Construction	2,900	TON	$107	$	311,315.00
0007	Additional Armor Rock Placement	6,100	TON	$107	$	655,000.00
0008	Remove Armored Cap - Land Based	6,200	CY	$72	$	443,000.00
0009	Remove Armored Cap - Water Based	2,300	CY	$92	$	212,000.00
0010	Wash Water Armored Cap - Treat and Dispose	766	TON	$530	$	406,000.00
0011	Dispose Armored Cap - Debris Landfill	15,300	TON	$48	$	730,000.00
0012	Water-based Excavation/Dredging	7,300	CY	$46	$	336,000.00
0013	Land-based Excavation	44,700	CY	$12	$	536,000.00
0014	Sediment Residuals Cover/Backfill	52,000	CY	$30	$	1,560,000.00
0015	Sediment Stabilization prior to Shipment	52,000	CY	$30	$	1,536,000.00
0016	Haul & Disposal of Sediment to Class 1 Landfill	80,000	TON	$110	$	8,800,000.00
0017	Replace Geotextile	22,600	SY	$6.25	$	141,000.00
0018	Replace Armor Rock B/C	8,280	TON	$78	$	648,000.00
0019	Replace Armor Rock C/D	6,120	TON	$107	$	657,000.00
DIRECT CONSTRUCTION TOTAL:					$	19,121,000.00
IN-DIRECT CONSTRUCTION COSTS						
0020	Engineering and Monitoring Well Design	$ 19,121,000	%	6%	$	1,197,000.00
0021	Construction Administration/Observation	$ 19,121,000	%	6%	$	1,147,000.00
0022	EPA 5 Year Review (Net Present Value)	1	LS	$108,000	$	108,000.00
0023	Institutional Controls (Net Present Value)	1	LS	$286,000	$	286,000.00
0024	Long Term MNR & GW Monitoring (Net Present Value)	1	LS	$264,000	$	794,000.00
0025	Long Term Cap Monitoring (Net Present Value)	1	LS	$88,000	$	88,000.00
0026	Cap Maintenance (Net Present Value)	1	LS	$181,000	$	181,000.00
IN-DIRECT CONSTRUCTION TOTAL:					$	3,801,000
PROJECT TOTAL					$	22,922,000
30% Contingency Cost					**$**	**6,900,000**
TOTAL ESTIMATED COST					**$**	**29,822,000**

Estimate of Project Quantities & Probable Cost Worksheet
Alternative 5aN
Partial Removal, Upgraded Cap, ICs, Ground Water Monitoring, and MNR

Item	Description	Plan Qty.	Unit	Unit Price	Total
DIRECT CONSTRUCTION COSTS					
0001	Mobilization/Demobilization	$ 43,006,315	%	8%	$ 3,440,000.00
0002	Environmental Protection and Erosion Control	1	LS	$300,000	$ 300,000.00
0003	Construction Payment and As-Built Surveys	1	LS	$300,000	$ 300,000.00
0004	Construction Materials Testing	2	EA	$15,000	$ 30,000.00
0005	Temporary Sheet Pile	1,200	LF	$650	$ 780,000.00
0006	Temporary Perimeter Berm Fill	6,400	TON	$136	$ 871,000.00
0007	Rock Rubble Mound Construction	2,900	TON	$107	$ 311,315.00
0008	Additional Armor Rock Placement	2,500	TON	$107	$ 268,000.00
0009	Remove Armored Cap - Land Based	6,192	CY	$72	$ 443,000.00
0010	Remove Armored Cap - Water Based	21,208	CY	$92	$ 1,951,000.00
0011	Wash Water Armored Cap - Treat and Dispose	2,452	TON	$530	$ 1,300,000.00
0012	Dispose Armored Cap - Debris Landfill	49,000	TON	$48	$ 2,337,000.00
0013	Water-based Excavation/Dredging	137,600	CY	$46	$ 6,330,000.00
0014	Land-based Excavation	0	CY	$12	$ -
0015	Sediment Residuals Cover/Backfill	13,700	CY	$30	$ 411,000.00
0016	Sediment Stabilization prior to Shipment	137,600	CY	$30	$ 4,065,000.00
0017	Haul & Disposal of Sediment to Class 1 Landfill	211,900	TON	$110	$ 23,309,000.00
0018	Replace Geotextile	0	SY	$6.25	$ -
0019	Replace Armor Rock A/B	0	TON	$78	$ -
0020	Replace Armor Rock C/D	0	TON	$107	$ -
DIRECT CONSTRUCTION TOTAL:					$ 46,446,000.00
IN-DIRECT CONSTRUCTION COSTS					
0021	Engineering and Monitoring Well Design	$ 46,446,000	%	6%	$ 2,837,000.00
0022	Construction Administration/Observation	$ 46,446,000	%	6%	$ 2,786,760.00
0023	EPA 5 Year Review (Net Present Value)	1	LS	$108,000	$ 108,000.00
0024	Institutional Controls (Net Present Value)	1	LS	$286,000	$ 286,000.00
0025	Long Term MNR & GW Monitoring (Net Present Value)	1	LS	$264,000	$ 794,000.00
0026	Long Term Cap Monitoring (Net Present Value)	1	LS	$88,000	$ 88,000.00
0027	Cap Maintenance (Net Present Value)	1	LS	$181,000	$ 181,000.00

IN-DIRECT CONSTRUCTION TOTAL: $ 7,081,000

PROJECT TOTAL $ 53,527,000

30% Contingency Cost $ 16,058,000

TOTAL ESTIMATED COST $ 69,585,000

Estimate of Project Quantities & Probable Cost Worksheet
Alternative 6N
Removal of Waste Materials, ICs, and MNR

Item	Description	Plan Qty.	Unit	Unit Price	Total
DIRECT CONSTRUCTION COSTS					
0001	Mobilization/Demobilization	$ 54,941,650	%	8%	$ 4,395,332
0002	Environmental Protection and Erosion Control	1	LS	$300,000	$ 300,000
0003	Construction Payment and As-Built Surveys	1	LS	$300,000	$ 300,000
0004	Construction Materials Testing	2	EA	$15,000	$ 30,000
0005	Shallow Berms and Temporary Sheet Pile	1	LS	$9,164,500	$ 9,164,500
0006	Sheet Pile Dewatering and Treatment	280	DAY	$8,000	$ 2,240,000
0007	Remove Armored Cap - Land Based	6,200	CY	$72	$ 446,400
0008	Remove Armored Cap - Water Based	23,700	CY	$92	$ 2,180,400
0009	Wash Water Armored Cap - Treat and Dispose	2,175	TON	$530	$ 1,152,750
0010	Dispose Armored Cap - Debris Landfill	43,500	TON	$48	$ 2,088,000
0011	Land-based Excavation	152,300	CY	$12	$ 1,827,600
0012	Sediment Residuals Cover	19,800	CY	$30	$ 594,000
0013	Residuals Armor	11,800	TON	$120	$ 1,416,000
0014	Sediment Stabilization prior to Shipment	152,300	CY	$30	$ 4,569,000
0015	Haul & Disposal of Sediment to Class 1 Landfill	260,300	TON	$110	$ 28,633,000

DIRECT CONSTRUCTION TOTAL:	$ 59,336,982

Item	Description	Plan Qty.	Unit	Unit Price	Total
IN-DIRECT CONSTRUCTION COSTS					
0020	Engineering Design	$ 59,336,982	%	6%	$ 3,560,219
0021	Construction Administration/Observation	$ 59,336,982	%	6%	$ 3,560,219
0022	EPA 5 Year Review (Net Present Value)	1	LS	$108,000	$ 108,000
0023	Institutional Controls (Net Present Value)	1	LS	$70,000	$ 70,000
0024	Long Term MNR Monitoring (Net Present Value)	1	LS	$264,000	$ 264,000
0025	Long Term Cap Monitoring (Net Present Value)	0	LS	$88,000	$ -
0026	Cap Maintenance (Net Present Value)	0	LS	$181,000	$ -

IN-DIRECT CONSTRUCTION TOTAL:	$ 7,562,438
PROJECT TOTAL	$ 66,899,420
30% Contingency	$ 20,069,826
TOTAL ESTIMATED COST	$ 86,969,246

Estimate of Project Quantities & Probable Cost Worksheet
Alternative 1S
No Action

Item	Description	Plan Qty.	Unit	Unit Price	Total
DIRECT CONSTRUCTION COSTS					
0001	Mobilization/Demobilization	0	LS	$0	$ -
0002	Environmental Protection and Erosion Control	0	LS	$5,000	$ -
0003	Construction Surveys, Site Preparation & Utility Clearance	0	LS	$5,000	$ -
DIRECT CONSTRUCTION TOTAL:					$ -
INDIRECT CONSTRUCTION COSTS					
0004	Engineering Design	$ -	%	12%	$ -
0005	Construction Administration/Observation	$ -	%	10%	$ -
0006	USEPA 5 Year Review (Net Present Value)	1	LS	$108,000	$ -
0007	Soil Management Plan and Notices	0	LS	$100,000	$ -
IN-DIRECT CONSTRUCTION TOTAL:					$ 0
PROJECT TOTAL:					$ 0
PROJECT ROUNDED TOTAL:					**$ 0**
Total Including 30% Contingency					**$ 0**

Estimate of Project Quantities & Probable Cost Worksheet
Alternative 2S
Institutional Controls and Ground Water Monitoring

Item	Description	Plan Qty.	Unit	Unit Price	Total
DIRECT CONSTRUCTION COSTS					
0001	Mobilization/Demobilization	0	LS	$0	$ -
0002	Environmental Protection and Erosion Control, GW Wells	0	LS	$50,000	$ 50,000
0003	Construction Surveys, Site Preparation & Utility Clearance	0	LS	$5,000	$ -
DIRECT CONSTRUCTION TOTAL:					$ 50,000
INDIRECT CONSTRUCTION COSTS					
0004	Engineering Design	$ -	%	12%	$ -
0005	Construction Administration/Observation	$ -	%	10%	$ -
0006	GW Well Monitoring & 5 Year Review (Net Present Value)	1	LS	$108,000	$ 638,000.00
0007	Soil Management Plan and Notices	1	LS	$100,000	$ 100,000.00
IN-DIRECT CONSTRUCTION TOTAL:					$ 738,000
PROJECT TOTAL:					$ 788,000
TTotal With 30% Contingency					$ 1,024,000

077853

Estimate of Project Quantities & Probable Cost Worksheet
Alternative 3S
Enhanced Institutional Controls and Ground Water Monitoring

Item	Description	Plan Qty.	Unit	Unit Price	Total
DIRECT CONSTRUCTION COSTS					
0001	Mobilization/Demobilization	1	LS	$50,000	$ 50,000.00
0002	Environmental Protection and Erosion Control	1	LS	$5,000	$ 5,000.00
0003	Construction Surveys, Site Preparation & Utility Clearance	1	LS	$20,000	$ 20,000.00
0004	Bollards	10	EA	$741.26	$ 7,400.00
0005	Land-based Soil Excavation	8,042	CY	$12.00	$ 96,504.00
0006	Marker Layer	12,000	SY	$0.67	$ 8,000.00
0007	Replace Excavated Soil	10,400	CY	$3.50	$ 36,000.00
0008	Vegetative Cover & GW Monitoring Well Installation	1	LS	$60,000.00	$ 60,000.00
DIRECT CONSTRUCTION TOTAL:					$ 283,000.00
INDIRECT CONSTRUCTION COSTS					
0009	Engineering Design	1	LS	$40,000	$ 40,000.00
0010	Construction Administration/Observation	$ 233,000	LS	10%	$ 23,300.00
0011	GW Well Monitoring & 5 Year Review (Net Present Value)	1	LS	$108,000	$ 638,000.00
0012	Soil Management Plan and Notices	1	LS	$100,000	$ 100,000.00

IN-DIRECT CONSTRUCTION TOTAL: $ 801,000

PROJECT TOTAL: $ 1,084,000

Total With 30% Contingency **$ 1,409,000**

077854

Estimate of Project Quantities & Probable Cost Worksheet
Alternative 4S
Removal with Off-site Dispoal, ICs

Item	Description	Plan Qty.	Unit	Unit Price	Total
DIRECT CONSTRUCTION COSTS					
0001	Mobilization/Demobilization	1	LS	$250,000	$ 250,000.00
0002	Environmental Protection and Erosion Control	1	LS	$5,000	$ 5,000.00
0003	Construction Surveys, Site Preparation & Utility Clearance	1	LS	$20,000	$ 20,000.00
0004	Bollards	0	EA	$741.26	$ -
0005	Land-based Soil Excavation	50,000	CY	$12.00	$ 600,000.00
0006	Marker Layer	0	SY	$0.67	$ -
0007	Replace Excavated Soil	0	CY	$3.50	$ -
0008	Vegetative Cover	3	AC	$4,000.00	$ 14,000.00
0009	Wellpoint Dewatering and Treatment	1	LS	$400,000.00	$ 400,000.00
0010	Stabilization of Soil Prior to Shipment	25,000	CY	$30.00	$ 750,000.00
0011	Off-site Haul and Disposal of Sediment (Class 2)	75,384	TON	$55.00	$ 4,146,000.00
0012	Backfill	50,000	CY	$11.25	$ 563,000.00
0013	Demo 6" Thick Concrete Pad	9,710	SF	$7.57	$ 74,000.00
0014	Demo House	800	SF	$7.89	$ 6,000.00
0015	Replace House	800	SF	$125.00	$ 100,000.00
0016	Replace 6" Thick Concrete Pad	9,710	SF	$5.38	$ 52,000.00
DIRECT CONSTRUCTION TOTAL:					$ 6,980,000.00
INDIRECT CONSTRUCTION COSTS					
0017	Engineering Design	1	LS	$200,000	$ 200,000.00
0018	Construction Administration/Observation	$ 6,980,000	%	5%	$ 349,000.00
0019	USEPA 5 Year Review (Net Present Value)	1	LS	$108,000	$ 108,000.00
0020	Soil Management Plan and Notices	0	LS	$100,000	$ -

IN-DIRECT CONSTRUCTION TOTAL:	$ 657,000
PROJECT TOTAL:	$ 7,637,000
PROJECT ROUNDED TOTAL:	**$ 7,640,000**
Total With 30% Contingency	**$ 9,932,000**