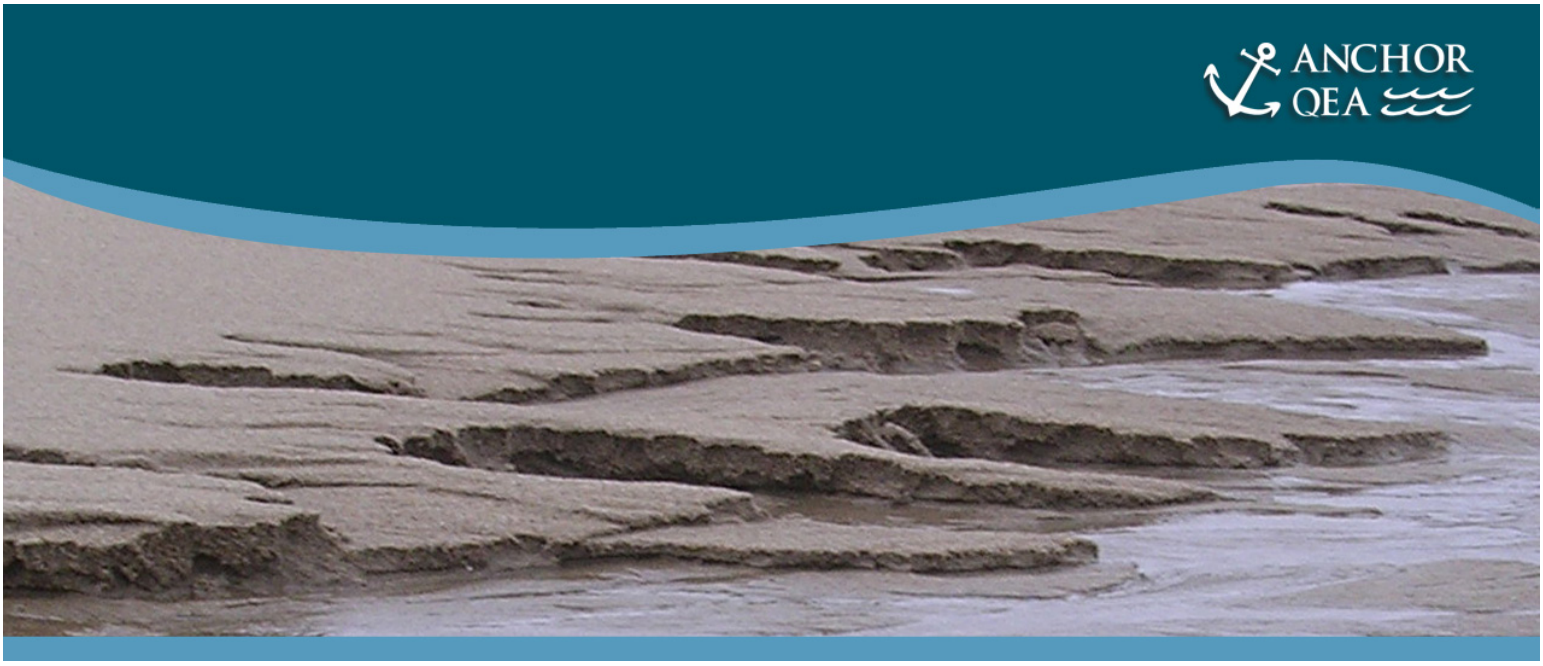

DRAFT FEASIBILITY STUDY REPORT
SAN JACINTO WASTE PITS SUPERFUND SITE

Prepared for

McGinnes Industrial Maintenance Corporation and

International Paper Company

Prepared by

Anchor QEA, LLC

614 Magnolia Avenue

Ocean Springs, Mississippi 39564

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LIST OF ACRONYMS AND ABBREVIATIONS

2H:1V	2 horizontal to 1 vertical
3H:1V	3 horizontal to 1 vertical
5H:1V	5 horizontal to 1 vertical
AOC	Agreement and Order on Consent
ARAR	Applicable or Relevant and Appropriate Requirements
BERA	Baseline Ecological Risk Assessment
BHHRA	Baseline Human Health Risk Assessment
BMP	Best Management Practices
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
cm/year	centimeters per year
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
GLO	Texas General Land Office
GRA	General Response Action
HSC	Houston Ship Channel
I-10	Interstate Highway 10
IC	Institutional Controls
IP	International Paper Company
MIMC	McGinnes Industrial Maintenance Corporation
mm/year	millimeters per year
MNR	Monitored Natural Recovery

MSL	mean sea level
NCP	National Contingency Plan
ng/kg	nanograms per kilogram
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRHP	National Register of Historic Places
NSR	net sedimentation rate
OMM	Operations, Monitoring, and Maintenance
PCB	polychlorinated biphenyl
PCL	Protective Concentration Level
PM	particulate matter
$PM_{2.5}$	fine partical particulate matter
PRG	preliminary remedial goals
PSCR	Preliminary Site Characterization Report
RACR	Removal Action Completion Report
RALs	remedial action levels
RAM	Remedial Alternatives Memorandum
RAO	Remedial Action Objective
RI	Remedial Investigation
RME	Reasonable Maximum Exposure
ROD	Record of Decision
ROW	right-of-way
S/S	solidification/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 microextraction
SWAC	surface-weighted average concentration
SWPPP	Storm Water Pollution Prevention Plan
TBC	to-be-considered

TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TCDF	2,3,7,8-tetrachlorodibenzofuran
TCEQ	Texas Commission on Environmental Quality
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
TMV	toxicity, mobility, or volume
TPDES	Texas Pollutant Discharge Elimination System
TxDOT	Texas Department of Transportation
UAO	Unilateral Administrative Order
USACE	U.S. Army Corps of Engineers
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 as a companion to the related Remedial Investigation (RI) Report (Integral and Anchor QEA 2013a). Both this FS Report and the RI Report were 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. The SJRWP Site was added to the National Priorities List (NPL) under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) in 2008. The Preliminary Perimeter, designated by USEPA in the UAO for purposes of the RI/FS investigation required by the UAO (USEPA's Preliminary Site Perimeter), encompasses several impoundments, built in the mid-1960s for disposal of paper mill wastes, and surrounding in-water and upland areas. The impoundments are on the western side of the San Jacinto River, in Harris County, Texas, north and south of Interstate Highway 10 (I-10).

A time critical removal action (TCRA) was implemented to stabilize materials within the impoundments located north of I-10 (the TCRA Site). The TCRA included construction of an armored cap (together with underlying geotextile and geomembrane layers), and installation of engineering controls around the perimeter of the TCRA Site, including warning signs and fencing. The TCRA has been effective in abating releases of materials from the TCRA Site and is currently under an ongoing inspection and maintenance program in accordance with a USEPA approved Operations, Monitoring, and Maintenance (OMM) plan (Appendix N of the RACR, Anchor QEA 2012a).

The RI Report prepared in response to the UAO identified protective concentration levels (PCLs) for soil and sediment, potentially applicable to various areas within the USEPA's Preliminary Site Perimeter consistent with reasonably anticipated futures uses. This FS Report uses these PCLs to develop a range of remedial alternatives addressing the impoundments both north and south of I-10, and to evaluate those alternatives relative to the CERCLA FS criteria described in the Code of Federal Regulations (CFR), Title 40, Part 300.430(e)(9). The alternatives considered include:

- Alternative 1 – No Further Action

- Alternative 2 – Institutional Controls (ICs) and Monitored Natural Recovery (MNR)
- Alternative 3 – Permanent Cap, ICs, and MNR
- Alternative 4 – Partial Solidification/Stabilization (S/S), Permanent Cap, ICs, and MNR
- Alternative 5 – Partial Removal, Permanent Cap, ICs, and MNR
- Alternative 6 – Full Removal of Materials Exceeding the Protective Concentration Level, ICs, and MNR

Each of these alternatives meets the CERCLA threshold criteria that a remedy: 1) provides 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.

To evaluate and compare these alternatives, chemical fate and transport modeling and hydrodynamic modeling were performed as documented in Appendix A and Appendix B, respectively, to this FS Report. The chemical fate and transport modeling was employed to assess the long-term effectiveness of each alternative. Short-term effectiveness was evaluated considering environmental impacts (to soil/sediment, water and tissue) during construction (based in part on chemical fate modeling), worker health and safety, and sustainability (qualitatively considered relative to greenhouse gas and particulate matter [PM] emissions and ozone impacts from construction equipment). Detailed costs were prepared for each alternative, as presented in Appendix C.

On a comparative basis, Alternatives 1, 2, and 3 provide greater long-term effectiveness than Alternatives 4, 5, and 6 because they avoid potentially significant environmental impacts related to releases during construction for the latter alternatives. Implementation of the TCRA effectively contained the waste deposits and impacted sediment in the TCRA Site. Implementation of Alternatives 1 and 2 would maintain the TCRA cap, and Alternative 3 would increase the long-term stability and provide for maintenance of the cap without disturbing the material that is already contained and isolated from potential receptors. Engineering analysis of the stability of a permanent cap (Alternative 3) has determined that the cap would remain protective when subjected to the erosive forces under any of the flow scenarios evaluated in the hydrodynamic modeling (Appendix B). In contrast, implementation of Alternatives 4, 5, or 6 would require removing all or part of the TCRA cap

and moving waste deposits in the water column, resulting in suspension of waste and impacted sediment in the river. There is no increased long-term benefit from implementing Alternatives 4, 5, or 6; releases expected from these alternatives are found to result in a long-term detriment when compared to Alternatives 1, 2, and 3.

For short-term effectiveness, Alternatives 1 and 2 are most favorable, followed by Alternative 3. Alternatives 4, 5, and 6 are significantly less favorable due to environmental impacts and worker safety concerns. Risks of implementation of Alternatives 4, 5, and 6 include the potential for unavoidable release of dioxins/furans into the water column outside of the work area (both from impacted sediments, as well as dissolved phase), an outcome that has been documented at other sediment remediation projects in spite of significant efforts made to prevent or control such releases. Worker safety risks, greenhouse gas, and PM emissions and ozone impacts are estimated to be more than 8 to 20 times higher for Alternatives 4, 5, and 6 compared to Alternative 3. Traffic and community impacts for Alternatives 4, 5, and 6 (measured as truck trips) are estimated to range from 6 to 70 times greater than Alternative 3.

Costs for the response action alternatives range from $1.3 million to over $600 million. Costs for Alternatives 4, 5, and 6 are significantly higher than for Alternatives 1, 2, and 3, reflecting the difficulty of implementing these alternatives, as well as the high cost of disposal of dioxin-impacted sediments.

Based on the considerations presented in this FS Report, Alternative 3 is the preferred alternative for the SJRWP Site. Alternatives 4, 5, and 6 each offer less environmental benefit or reduction in risks, greater uncertainties related to implementation, an extended construction schedule, higher short-term environmental impacts, increased safety risks, higher community impacts, and significantly greater cost.

1 INTRODUCTION

This Feasibility Study (FS) Report was prepared for the San Jacinto River Waste Pits (SJRWP) Superfund Site (Site) (Figure 1-1, showing the time critical removal action [TCRA] Site and vicinity) on behalf of IP and MIMC (collectively referred to as the Respondents for the Site). The location of U.S. Environmental Protection Agency [USEPA's] Preliminary Site Perimeter is shown on Figure 1-2. This FS Report builds upon the final Remedial Alternatives Memorandum (RAM), which presented the screening of remedial technologies and the development of preliminary remedial alternatives. The Draft RAM was conditionally approved by USEPA on November 14, 2012 (USEPA 2012b) and the revised, final version was submitted to USEPA on December 3, 2012 (Anchor QEA 2012b). This FS Report develops and 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 2013a), and based on results of the Baseline Human Health Risk Assessment (BHHRA) (Integral 2013b) and Baseline Ecological Risk Assessment (BERA) (Integral 2013a). The BERA and BHHRA were conditionally approved by USEPA on February 26, 2013 and May 22, 2013, respectively. The Final BERA and BHHRA were submitted to USEPA on May 6, 2013 and May 22, 2013, respectively.

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) as required by the Unilateral Administrative Order (UAO; USEPA 2009a). 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 (CSM) for the SJRWP Site. The other sections of the FS Report address the following:

- Section 3 identifies the protective concentration levels (PCLs) 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, and describes the recommended remedy
- 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 metals and 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.

This document satisfies the requirement of the Statement of Work in the UAO for the submittal of a FS Report following receipt of USEPA approval of the Final RI Report (Integral and Anchor QEA 2013a). 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. The remedial action plan will be incorporated into a USEPA Record of Decision (ROD) that outlines cleanup actions to address potential threats to human health and the environment at the SJRWP Site.

The UAO describes a basic history of the SJRWP Site, but it addresses only 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 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 TCRA stabilized pulp waste and sediments within the original 1966 perimeter berm of the Northern Impoundments to prevent any releases of dioxins and furans and other chemicals of potential concern (COPCs) to the environment (Anchor QEA 2011a, 2012a). More information about the TCRA is provided in Section 2.5.3.

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 2013a).

2.1 Location and History

USEPA's Preliminary Site Perimeter includes several waste impoundments within the estuarine section of the San Jacinto River, as well as surrounding in-water and 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 impoundments adjacent to the river on both the north and south sides of I-10 were built in the mid-1960s for disposal of paper mill wastes, reportedly barged from the Champion Paper Inc. paper mill in Pasadena, Texas. These wastes are considered to be a source of dioxins and furans present 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 2.6.4. 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, resulting in regional subsidence of land in the vicinity of the SJRWP Site, as well as dredging and sand mining within the river and marsh to the west

and northwest of the Northern Impoundments through the 1990s and early 2000s, resulted in exposure of the contents of the Northern Impoundments to surface waters. Historical documents indicate that dredging actions also occurred in the river in the vicinity of the upland sand separation area. In addition, barge maintenance and cleaning activities conducted on and adjacent to the upland sand separation area (west of the Northern Impoundments) 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 2013a). 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 2013a).

2.2 Land Use

The land use types in the area surrounding the USEPA's Preliminary Site Perimeter are shown on 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.

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 (ADV-49[1]) 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 2013a) discuss surface water use and fishing advisories. Although fishing was reported to have occurred prior to TCRA implementation, 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 TCRA. The completion of the TCRA resulted in reduced public access to the Northern Impoundment area. Perimeter fencing was installed and warning buoys and signs were placed around the TCRA Site. In addition, access to the TCRA Site 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).

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 TCRA 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 upland sand separation area west and northwest of the TCRA Site (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

[1] http://www.dshs.state.tx.us/seafood/survey.shtm and http://www.tpwd.state.tx.us/regulations/outdoor-annual/fishing/general-rules-regulations/fish-consumption-bans-and-advisories.

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 2013). 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 2013a).

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 2013a) and in Section 3.4 of the BERA (Integral 2013a).

2.4 Physical Description

2.4.1 Waterway Hydrodynamics

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). The typical tidal range in the river is about 1 to 2 feet, with neap and spring tide conditions corresponding to minimum and maximum tidal ranges, respectively. Tropical storms and wind storms from the north can have significant effects on water levels within the USEPA's Preliminary Site Perimeter. Tropical storms can cause storm surges with water levels that are 4 to 6 feet higher than typical tidal elevations, and storms with strong winds from the north can cause water to be transported out of the Galveston Bay system, which can result in water levels that are much lower than low tide elevations.

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 2013a). The average flow rate in the river is 2,200 to 2,600 cubic feet per second (cfs), based on a flood frequency analysis presented in the RI Report (Integral and Anchor QEA 2013a). Floods in the river primarily occur during tropical storms (e.g., hurricanes) or intense thunderstorms. Flood events with return intervals of 25 years or more have flow rates of 200,000 cfs or greater (Integral and Anchor QEA 2013a). In October 1994, an approximate 100-year flood event had a peak discharge of 360,000 cfs, and a maximum river stage height of 27 feet above mean sea level (MSL) (Integral and Anchor QEA 2013a).

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 2013a).

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 2013a). 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 2013a):

- Near-bed velocities generated by episodes of propeller wash are expected to be significantly 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). 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.
- Although the rate of subsidence has significantly decreased during the last 35 to 40 years, due to controls on groundwater usage within Harris County, the effect of subsidence in the future, if it occurs on bed sediments in the San Jacinto River, will be to reduce the potential for erosion. Subsidence lowers the sediment bed elevation,

and thus, increases water depth and decreases current velocities, which in turn reduces potential for bed erosion.

- 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 effect of sea level rise on bed sediment in the San Jacinto River will be to reduce the potential for erosion because rising sea level increases water depths, which generally decreases current velocities.

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 PCLs (discussed in Section 3.1) for the areas within the USEPA's Preliminary Site Perimeter. Evaluation of the radioisotope coring data from within the USEPA's Preliminary Site Perimeter indicates the net sedimentation rate (NSR) is approximately 0.4 to 3.9 centimeters per year (cm/year) in depositional areas (Anchor QEA 2012c). The effects of changes in sediment load from upstream sources on long-term sedimentation were evaluated during the modeling study and are discussed in the Chemical Fate and Transport Modeling Report (Anchor QEA 2012c), as well as in Appendix A of this report. 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 2013a) contains an in-depth discussion of the process involved to identify COCs within the USEPA's Preliminary Site Perimeter, and 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). 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.

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 TCRA. Outside of the TCRA Site, $TEQ_{DF,M}$ 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 PCLs in Section 3.1.

The RI Report also examined concentrations of polychlorinated biphenyls (PCBs) and mercury in the TCRA 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 upland sand separation area located on the SJRF property (as shown on Figure 1-2), are higher than they are in the wastes within the Northern Impoundments, the wastes within the Northern Impoundments are not the primary source of mercury in the aquatic environment under investigation.

2.5.2 Area of Investigation South of I-10

Available historical documentation indicates that 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 three individual 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. A full 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 PCLs 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 PCL 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 concentrations throughout a 10 foot soil depth, but the most elevated $TEQ_{DF,M}$ concentrations are found in samples from 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 Prior Actions at the SJRWP Site

As discussed in Section 1.2, a TCRA was implemented, pursuant to an AOC, to stabilize pulp waste and sediments within the original 1966 perimeter berm of the Northern Impoundments (Anchor QEA 2011a; Anchor QEA 2011b). 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).

During the design of the TCRA, 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 2-6). In general, the TCRA design included an armor rock cap placed atop a geotextile bedding layer in all but the Northwestern Area. Additionally, the Western Cell received treatment through stabilization/solidification (S/S) of approximately 6,000 cubic yards (cy) of material in the upper 3 feet of soil over a 1.2 acre portion of the area, and a geomembrane cover layer prior to armor rock installation. The TCRA cap is discussed further in Section 4 relative to the remedial alternatives, and shown on the figures from that Section. In addition to capping the Northern Impoundments, the TCRA upland perimeter was fenced and signage was installed to prevent unauthorized access to the TCRA Site. A description of the TCRA implementation is provided in the Removal Action Completion Report (RACR) (USEPA 2012c).

2.5.3.1 Effect of Time Critical Removal Action

The post-TCRA evaluation indicates that the TCRA's implementation has effectively reduced potential risks from dioxins and furans associated with baseline conditions. The following sections discuss effects of TCRA implementation on sediment, water, and tissue.

2.5.3.1.1 Sediment

Implementation of the TCRA has eliminated the potential transport of waste associated COCs from the Northern Impoundments. The effect of the TCRA 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 TCRA Site, as indicated by the long-term chemical fate model simulations presented in Appendix A.

2.5.3.1.2 Water

As shown in the TCRA cap porewater assessment in Section 5.3 of the RI Report, sampling conducted after construction of the TCRA cap was completed of surface water and porewater with solid phase microextraction (SPME) fibers 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 armor cap. Data generated from this porewater assessment support evaluation of remedial alternatives that incorporate the TCRA cap into the final remedy.

The chemical fate and transport modeling presented in Appendix A was used to evaluate the potential for reductions in surface water concentrations associated with implementation of the TCRA. The model results showed that as a result of the TCRA cap, annual average concentration estimates of 2,3,7,8-TCDD predicted by the model in surface water have decreased by approximately 85 percent in the area of the TCRA Site and by 40 percent when averaged over the USEPA's Preliminary Site Perimeter. As discussed in Appendix A, the concentrations predicted by the model for post-TCRA conditions reflect dioxin/furan inputs associated with a number of sources, including transport from upstream, atmospheric deposition, surface runoff, point discharges (industrial and municipal treatment plant effluents), and fluxes from surface sediment outside the footprint of the TCRA Site.

2.5.3.1.3 Tissue

Completion of the TCRA construction in July 2011 rendered sediments in the TCRA Site inaccessible for direct contact by humans, benthos, fish, and aquatic dependent wildlife, and are therefore expected to lead to reductions in tissue concentrations in catfish and clams within the USEPA's Preliminary Site Perimeter.

2.5.4 Sources of COCs

The chemical fate and transport modeling, discussed in Section 2.6.7 and Appendix A, concluded that ongoing deposition of sediment within the USEPA's Preliminary Site Perimeter will continue to reduce concentrations of dioxins and furans in sediment. 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 found within the USEPA's Preliminary Site Perimeter.

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 dioxins and furans and other COCs (metals, and PCBs) found in the TCRA 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.

The "unmixing" evaluations based on fingerprinting evaluations of dioxin and furan mixtures in soil and sediment samples described in the RI Report demonstrate that not all of the dioxins and furans in sediment and soils within the Northern Impoundment and Soil Investigation Area 4 are from paper mill wastes. Sediments within the USEPA's Preliminary Site Perimeter contain a specific distribution of individual dioxin and furan congeners that is likely attributable to the urban background and specific regional sources surrounding the USEPA's Preliminary Site Perimeter, as well as at least one point source within the USEPA's Preliminary Site Perimeter.

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 unmixing 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 unmixing 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 dioxins and furans in soils in the area of investigation south of I-10 (see RI Report Section 6.6).

2.5.5 Chemical Fate and Transport

Section 5.6 of the RI Report contains a summary of the chemical fate and transport processes affecting the concentrations of dioxins and furans within the USEPA's Preliminary Site Perimeter. The most significant points of this discussion are summarized below:

- Sediment-water interactions – Dioxins and furans are hydrophobic and preferentially bind to particulate matter (PM). Particulate-associated dioxins and furans within the sediment bed enter the water column through sediment deposition and erosion processes described in Section 2.5. Deposition of sediments with low concentrations of chemicals may support natural recovery.
- Partitioning and dissolved phase flux – Because dioxins and furans are hydrophobic, they will be present primarily in particulate form, and their fate is therefore determined largely by sediment transport processes. Dioxins and furans within the sediment matrix include dissolved-phase dioxins and furans in porewater through partitioning processes, which can result in a transfer of dissolved-phase mass to the water column under certain conditions.
- Transport in the water column – Dioxins and furans present in the water column in any phase are transported by surface water currents, which are affected by hydrodynamic processes within the larger San Jacinto River.
- External sources – Publicly owned treatment plant outfalls, other point-source discharges, storm water runoff and atmospheric deposition are all sources of dioxins and furans within USEPA's Preliminary Site Perimeter. As documented in the RI Report, groundwater is not a significant source of dioxins or furans to the San Jacinto River. The modeling described in Appendix A includes contributions from these external sources.

A detailed description of the modeling is provided in the Chemical Fate and Transport Modeling Report (Anchor QEA 2012c), and supporting documentation. More detailed discussions of dioxin and furan bioaccumulation in aquatic biota are presented in the Technical Memorandum on Bioaccumulation Modeling (Integral 2010), Section 5.6 of the RI Report (Integral and Anchor QEA 2013), and in the BERA (Integral 2013).

2.5.5.1 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. However, even these correlations are weak, and are associated with high uncertainty (Integral 2010a).

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 TCRA 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. Combined with 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).

2.5.6 Fate and Transport Modeling

A comprehensive fate and transport model was developed to support the RI/FS. The fate and transport model development and calibration is provided in the Chemical Fate and Transport Modeling Study Report (Anchor QEA 2012c). The primary goal of the modeling study was to simulate physical and chemical processes that are controlling chemical fate and transport of selected dioxins and furans within the aquatic environment of the area within the USEPA's Preliminary Site Perimeter. Specifically, the primary objectives of the chemical fate and transport analysis were threefold:

- Develop a CSM for sediment transport and chemical fate and transport.
- Develop and apply quantitative methods (i.e., computer models) that can be used to evaluate the effectiveness of various remedial alternatives during the FS.
- Address specific questions about sediment transport and chemical fate and transport processes within the USEPA's Preliminary Site Perimeter.

The mathematical modeling framework that was applied consists of three models that were linked together: hydrodynamic, sediment transport, and chemical fate and transport. These models were developed, calibrated, and tested (as described in Anchor QEA 2012c) and together form a quantitative framework that can be used as a management tool that can help guide remedial decision making. The calibration and validation of the model framework indicates that that it can simulate hydrodynamics, sediment transport, and chemical fate and transport within the Model Study Area (i.e., San Jacinto River from Lake Houston Dam to the confluence with the HSC) with sufficient accuracy to support its use to make relative comparisons among remedial alternatives in the FS Report. The above notwithstanding, the models do have uncertainty due to data limitations, particularly for dioxins and furans in surface water.

Overall, the modeling framework provides a useful management tool to develop future predictions of dioxin and furan concentrations in sediment and surface water within the USEPA's Preliminary Site Perimeter. Specific FS model applications, which are presented in Appendix A, included the following:

- Long-term simulations of post-TCRA future conditions (i.e., starting from current conditions, which include the presence of the TCRA cap over the TCRA Site) were conducted. These simulations provide estimates of rates of natural recovery (i.e., reductions in estimated water column and surface sediment dioxin and furan concentrations over time) in various portions of the Model Study Area, which are representative of conditions anticipated for Alternatives 1 through 3 described in Section 4 below.
- In addition, long-term simulations of alternatives containing in-water sediment remediation (i.e., Alternatives 4 through 6 described in Section 4 below) were also conducted. Future sediment and water column dioxin and furan concentrations from these simulations were used to evaluate potential short- and long-term impacts associated with the construction activities (i.e., sediment resuspension and release during sediment remediation and effects of dredge residuals).

Results from the fate and transport modeling conducted to support the alternatives analysis are described in detail in Appendix A to this FS Report. Appendix A also includes a description of model uncertainty analyses that were conducted to develop uncertainty

bounds around its predictions, as well as a summary of certain sensitivity analyses that were performed with the hydrodynamic and sediment transport models at the request of USEPA in its letter approving the draft final report for the modeling study.

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 sediment resulting from historical paper mill waste disposal in the Northern Impoundments, as well paper mill wastes present in the Soil Investigation Area 4, south of I-10. This section discusses the development of PCLs, 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.

3.1 Recommended Protective Concentration Levels

The RAOs are focused on remedial measures applicable to sediments and soils within the USEPA's Preliminary Site Perimeter to reduce potential exposure pathways to humans and ecological receptors. Therefore, the PCLs utilized in the development of remedial alternatives are those developed for soils and sediments. All of the PCLs 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.

PCLs were developed as described in the RI Report and the May 14, 2013 letter from Anchor QEA to USEPA Region 6 (Anchor QEA 2013). The PCLs for the hypothetical recreational visitor and hypothetical future construction worker were presented in the RI Report, which was approved by USEPA; the PCL for the hypothetical future outdoor commercial worker was developed in cooperation with the USEPA during preparation of the FS using methodologies contained in USEPA guidance documents and presented in the May 14, 2013 letter. The development of PCLs considered all potential exposure pathways associated with hypothetical receptor exposure scenarios approved by USEPA, including reasonably anticipated future uses of specific areas within the USEPA's Preliminary Site Perimeter, and all COCs for each medium. Based on consideration of reasonable potential future uses within the USEPA's Preliminary Site Perimeter, four PCLs were developed for use in the FS Report for evaluation of the remedial alternatives of 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

sediments, and hypothetical construction and hypothetical commercial workers for soils. Exposure assumptions for hypothetical subsistence fisher scenarios provided in the RI Report are not consistent with the anticipated future uses within USEPA's Preliminary Site Perimeter, so the PCL for that scenario was not used in the development of alternatives.

PCLs were also developed for total PCBs and arsenic for soils and sediments, and for total PCBs, arsenic, and mercury in tissue in the RI Report. Cancer based PCLs for total PCBs and arsenic were developed at the request of USEPA. However, 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 outlined in the Exposure Assessment Memorandum (EAM) and the BHHRA. Also, 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. Moreover, concentrations of each dioxin-like PCB congener in sediments were either significantly correlated with concentrations of TCDD and TCDF (Integral 2011), indicating that remediation for dioxins and furans will also address these PCBs (Anchor QEA and Integral 2010a, Appendix C), or were generally below detection limits. The elevated mercury concentrations in the soils on the upland 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 PCLs for $TEQ_{DF,M}$.

The $TEQ_{DF,M}$ PCL for sediment outside the footprint of the TCRA cap is based on exposure to dioxins and furans by a hypothetical recreational visitor, as evaluated in the BHHRA. For a noncancer hazard quotient equal to 1[2], the $TEQ_{DF,M}$ concentration in sediment for this PCL is 220 nanograms per kilogram (ng/kg) (Integral and Anchor QEA 2013a). Although the PCL for the hypothetical recreational fisher would also be appropriate, the PCL for the hypothetical recreational visitor is more conservative. Figures 3-1 and 3-2 present $TEQ_{DF,M}$ concentrations in surface and subsurface sediment, respectively, outside the footprint of the TCRA cap. The measured $TEQ_{DF,M}$ concentrations in sediments exceeded this PCL in only

[2] The noncancer $TEQ_{DF,M}$ PCL is always lower than the PCL for the cancer endpoint for any given media and exposure scenario, and is therefore the more conservative PCL (see RI Report Tables 5-29 and 5-31).

one location, northwest of the TCRA Site near the upland sand separation area, in two subsurface sample intervals at depths of 4 and 6 feet below ground surface.

The PCL for soil/sediment within the footprint of the TCRA is based on the reasonable future use of this area, which is industrial or commercial. A PCL was derived as presented in the May 14, 2013 letter (Anchor QEA 2013) for a hypothetical future outdoor commercial worker assumed to be exposed to soil/sediment in the TCRA footprint. For a noncancer hazard quotient equal to 1, the PCL as a $TEQ_{DF,M}$ concentration in soil/sediment is 1,300 ng/kg. Figures 3-3 and 3-4 present $TEQ_{DF,M}$ concentrations in surface and subsurface sediment, respectively, within the footprint of the TCRA cap relative to this PCL.

The PCL for soil within USEPA's Preliminary Site Perimeter is based on exposure to dioxins and furans by a hypothetical future recreational visitor, as evaluated in the BHHRA. For a noncancer hazard quotient equal to 1, the $TEQ_{DF,M}$ concentration in soil for this PCL is 1,300 ng/kg (Integral and Anchor QEA 2013a). The measured $TEQ_{DF,M}$ concentrations in surface soils do not exceeded this PCL in any locations outside of the TCRA footprint.

For soil in the area south of I-10, a PCL was derived based on the reasonable maximum exposure scenario for a hypothetical future construction worker. For a noncancer hazard quotient equal to 1 the $TEQ_{DF,M}$ PCL for soil is 450 ng/kg (Integral and Anchor QEA 2013a). The development of the PCL considers exposure to soil through the total depth interval (0 to 10 feet) to which a hypothetical future construction worker could be exposed. Figure 3-5 presents the depth-weighted average $TEQ_{DF,M}$ concentrations for the 0- to 10-foot depth interval for samples in the area south of I-10 relative to this PCL.

3.2 Remedial Action Objectives

The RAOs discussed in this section were established to support the initial development and refinement of preliminary remediation goals (PRG) 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 along with a brief summary of the extent to which RAOs have been addressed through implementation of the TCRA. The RI Report provides additional detail support for the development of the RAOs.

RAO 1: Eliminate loading of dioxins and furans from the former paper mill waste impoundments north and south of I-10, to sediments and surface waters of the San Jacinto River.

As outlined in the RI Report (Integral and Anchor QEA 2013a), the RACR (USEPA 2012c), and subsequent ongoing TCRA monitoring, the TCRA cap has achieved RAO 1. Groundwater and porewater monitoring of the TCRA Site demonstrate that dissolved transport and loading of dioxins and furans through these pathways has been effectively addressed (Integral and Anchor QEA 2013a).

The potential pathway for dioxin and furan loading to surface water and sediment from the possible impoundment south of I-10 described in the PSCR was surface runoff of soil particles. In comments on the Draft PSCR and on the Draft RI Report, USEPA raised concerns about migration of dissolved dioxins and furans with groundwater. The results of the RI Report indicate that $TEQ_{DF,M}$ concentrations in surface soils are below PCLs for the areas within Soil Investigation Area 4 south of I-10 and that pockets of dioxin-bearing waste are buried beneath several feet of soil; therefore, surface runoff of soil particles to surface water in this area is not an ongoing concern, and risk to hypothetical future commercial workers is also not a concern. Groundwater monitoring in the area south of I-10 also indicates that there is no potential for transport and loading of dioxins and furans to the aquatic environment through a groundwater pathway[3]. Therefore, existing conditions in the area of investigation south of I-10 are consistent with RAO 1.

[3] Groundwater sampling and data evaluation specific to this area have been conducted and a supplement to the RI Report is in preparation as described in the Sampling and Analysis Plan Addendum (Anchor QEA and Integral 2013).

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

Implementation of the TCRA has substantially reduced exposures of aquatic biota to wastes from within the Northern Impoundments, and therefore has reduced potential human exposures via fish and shellfish consumption. Implementation of the TCRA has achieved these objectives through elimination of direct contact exposure for fish and shellfish to wastes in the Northern Impoundments and impacted sediments. Implementation of ICs (fencing and warning signs) have also mitigated potential human exposures to fish and shellfish within USEPA's Preliminary Site Perimeter.

RAO 3: Reduce human exposures to paper mill waste-derived dioxins and furans from direct contact with intertidal sediment by remediating sediments affected by paper mill wastes to appropriate cleanup levels.

Estimated baseline risks under hypothetical exposure scenarios that involved direct contact with all areas within the USEPA's Preliminary Site Perimeter other than the Northern Impoundments, but did not involve ingestion of fish and shellfish, were below risk and hazard thresholds of concern. Implementation of the TCRA has substantially reduced potential cancer and noncancer dioxin hazards to people within USEPA's Preliminary Site Perimeter. An analysis of post-TCRA human health risk (Appendix F to the BHHRA Report) for the hypothetical recreational visitor and hypothetical recreational fisher found that both the noncancer and cancer hazard indices were reduced to below 1 for these receptors by implementation of the TCRA. Therefore, RAO 3 has been successfully achieved through implementation of the TCRA. $TEQ_{DF,M}$ concentrations in surface sediment in all intertidal and subtidal areas outside of the TCRA Site are below applicable PCLs provided in Section 3.1.

RAO 4: Reduce human exposures to paper mill waste-derived dioxins and furans from direct contact with upland soils to appropriate cleanup levels.

The TCRA cap prevents exposure to soils containing paper mill waste within the TCRA Site unless the soil is exposed through excavation.

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 column, in three specific locations. However, the dioxin and furan concentrations that cause the elevated exposures are in pockets of soil, each of which is at least 4 feet below the surface, and are therefore isolated from human contact as long as subsurface exposure during construction does not occur.

RAO 5: Reduce exposures of fish, shellfish, reptiles, birds, and mammals to paper mill waste-derived dioxins and furans by remediating sediment affected by paper mill wastes to appropriate cleanup levels.

Baseline risks associated with dioxins and furans to benthic macroinvertebrate communities and populations of fish, birds, mammals, and reptiles in the area north of I-10 and the aquatic environment were determined in the BERA to be negligible, except for risks to shorebirds (represented by the spotted sandpipers) and small mammals (represented by the marsh rice rat) that could live or forage in direct contact with the wastes or intertidal sediments in the impoundments north of I-10. Baseline ecological risks include reproductive risks to mollusks from exposure to 2,3,7,8-TCDD, primarily in the area of the Northern Impoundments. Baseline ecological risks elsewhere within the USEPA's Preliminary Site Perimeter were negligible, or were very low and the result of exposures to chemicals from sources other than paper mill wastes.

Analysis of post-TCRA risks to those ecological receptors that were potentially at risk under baseline conditions indicates that, because the TCRA eliminated exposures to dioxins and furans through direct ingestion of or direct contact with waste materials within the 1966 perimeter of the Northern Impoundments, the post-TCRA conditions do not pose a risk for ecological receptors. Remediation of sediments and soils within the TCRA footprint and ongoing natural recovery of sediments in areas outside of the TCRA footprint have reduced

COC concentrations in sediments, water, and biota. This RAO has been achieved through implementation of the TCRA.

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. Finally, USEPA may find during its review of remedial alternatives that the most suitable remedial alternative does not meet an ARAR. The National Contingency Plan (NCP) provides for waivers of ARARs under certain circumstances (see 40 CFR 300.430(f)(1)(ii)(C)).

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. The implementation of the remedy generally will not require Federal, State, or local permits because of the permit equivalency of the CERCLA remedy-selection process (40 CFR 300.400(e)(i)), but remedial actions will be completed in conformance with substantive technical requirements of applicable regulations.

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 PCLs 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 sediment, 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.

Demonstration of substantive compliance with these ARARs 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 silt fences to manage potential upland runoff, plastic sheeting to cover any required upland stockpiles, and other erosion control measures to be described in the plans and specifications of the final remedy.
- 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 potentially jurisdictional waters of the U.S. (including wetlands) report (Anchor QEA 2010; Anchor QEA 2011a) as part of the TCRA implementation in compliance with the 1987 U.S. Army Corps of Engineers (USACE) Wetlands Delineation Manual and Interim Regional Supplement to the Corps of Engineers 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, if necessary to minimize the impacts of discharges of fill into the water, include:

- The use of a 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 (TPWD 2008). 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 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). Moreover, the BERA concluded that under baseline and post-TCRA conditions, there is no risk to the protected species that were evaluated.

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

A hydrologic evaluation (Appendix B) subject to USEPA approval was performed to evaluate the impacts of the remedial alternatives on the water levels in the San Jacinto River. The evaluation of potential effects of the remedial alternatives on flooding is discussed in the detailed evaluation of the remedial alternatives in Section 5. USEPA's review of the FS Report and selection of the remedy will consider whether the placement of fill will significantly affect water levels within the floodplain of the San Jacinto River.

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 TCRA Site being bounded by water on three sides and adjacent to a highway overpass on the fourth side, 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 5 and 6 (presented in Section 4) include removal of sediments exceeding PCLs and transportation of the sediment to an off-site disposal facility. Off-site disposal would also be required for limited quantities of waste, such as used personal protective equipment 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 (Alternative 1). The contractor will be required to package any hazardous materials in appropriate containers and label containers in accordance with Texas Department of Transportation requirements. The development of remedial alternatives anticipates that all disposal will be at a permitted facility (e.g., landfill and/or incinerator). If an off-site facility needs to be established for dewatering sediment or transloading waste from barges to trucks or rail cars, it may require a solid waste permit.

4 DEVELOPMENT OF REMEDIAL ALTERNATIVES

The RAM (Anchor QEA 2012b) describes the identification of General Response Actions (GRAs) and the screening of remedial technologies. In addition, the RAM describes the development of a set of preliminary remedial alternatives, including a No Further Action alternative and remedial alternatives focused on removal or a combination of removal, treatment, and containment to achieve a range of post-remedy SWACs.

The preliminary remedial alternatives were modified in discussions with USEPA Region 6 subsequent to submittal of the RAM for a number of reasons. Most significantly, PCLs not available when the RAM was prepared have been developed for sediment and soil as described in Section 3.1. Based on a comparison of $TEQ_{DF,M}$ concentrations in sediment and soil to the PCLs, areas of affected 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. The remedial alternatives developed for the FS in coordination with USEPA Region 6 include:

- Alternative 1 – No Further Action
- Alternative 2 – Institutional Controls ("ICs") and Monitored Natural Recovery ("MNR")
- Alternative 3 – Permanent Cap, ICs, and MNR
  Alternative 4 – Partial Solidification/Stabilization, Permanent Cap, ICs, and MNR
- Alternative 5– Partial Removal, Permanent Cap, ICs, and MNR
- Alternative 6 – Full Removal of Materials Exceeding the Protective Concentration Level, ICs, and MNR

A brief description of the primary elements for each alternative is provided in the remainder of this section, and Table 4-1 provides a summary of the quantities of materials that may be used and durations associated with each of the alternatives.

Following the general descriptions of alternatives provided in the remainder of this section, Section 5 provides a detailed evaluation of the remedial alternatives with consideration of each of the criteria required by the NCP, 40 CFR Section 300.430(e)(9). Those criteria include overall protection, compliance with ARARs, long-term effectiveness, reduction of

toxicity, mobility, or volume (TMV), short-term effectiveness, implementability, cost, State acceptance, and community acceptance. USEPA Region 6 Clean and Green Policy (USEPA 2009c) was also considered in the development of all of the alternatives.

4.1 Alternative 1 – No Further Action

The No Further Action alternative serves as the baseline of comparison for the other remedial alternatives. The NCP requires the development and evaluation of the No Further Action alternative (40 CFR 300.430(e)(6)). As described in Section 2, the TCRA included capping the TCRA Site, installing a security fence, and posting warning signs. In the area of investigation south of I-10, soil exceeding PCLs is buried under at least 2 feet of surface soil (Figure 2-5). Under the No Further Action alternative, the controls installed as part of the TCRA would be left in place and no additional remedial action would be implemented. Ongoing inspection and maintenance of the TCRA would be performed in accordance with the USEPA-approved OMM plan.

In the area of the TCRA Site, the $TEQ_{DF,M}$ SWAC for soil/sediment following completion of the TCRA is approximately 12 ng/kg dry weight, which is well below the PCL for hypothetical recreational visitors (220 ng/kg). No surface soil/sediment samples under current conditions have a $TEQ_{DF,M}$ concentration exceeding this PCL (Figure 3-1). The only sediment samples outside of the limits of the TCRA cap with $TEQ_{DF,M}$ concentrations exceeding the PCL for hypothetical recreational visitors are two subsurface sediment samples collected north of I-10 from one location near the upland sand separation area, and these samples are buried beneath at least 3 feet of sediment with $TEQ_{DF,M}$ concentrations below the PCL.

For locations within the area of investigation south of I-10, the arithmetic mean of $TEQ_{DF,M}$ concentrations in surface soil is 13.3 ng/kg dry weight, which is well below the PCL for a hypothetical outdoor commercial worker (1,300 ng/kg). The highest $TEQ_{DF,M}$ concentration observed in surface soil, 36.9 ng/kg, is also well below this PCL.

In subsurface soil (6 to 24 inches below grade), the average $TEQ_{DF,M}$ concentration is 16.5 ng/kg. The highest $TEQ_{DF,M}$ concentration observed in subsurface soil is 303 ng/kg. In the

top 10 feet of subsurface soil in the area of investigation south of I-10, 20 samples in 12 cores were found to have $TEQ_{DF,M}$ concentrations greater than the soil PCL, but depth weighted average $TEQ_{DF,M}$ concentration in the upper 10 feet of soils exceeded the PCL for this receptor in four locations. The PCL 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. Therefore, the PCL should be compared to the average soil concentration in the top 10 feet of soil, which is how the data are presented in Figure 3-5.

This alternative includes ongoing OMM of the TCRA cap, which includes inspection and periodic maintenance. The estimated cost of this alternative is $1.3 million (Appendix C).

4.2 Alternative 2 – Institutional Controls and Monitored Natural Recovery

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 (USEPA 2012a).

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

- Restrictions on dredging and anchoring would be established to protect the integrity of the TCRA cap and to limit potential disturbance and resuspension of buried sediment near the upland sand separation area where one location exists with $TEQ_{DF,M}$ concentrations exceeding the sediment PCL.
- Deed restrictions would be applied in the area of investigation south of I-10 where the depth weighted average $TEQ_{DF,M}$ concentrations in upper 10 feet of subsurface soil exceed the soil PCL 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 PCL.
- Public notices and signage around the perimeter of the TCRA Site would be maintained or provided, as appropriate.

A periodic sampling and analytical program would be implemented to monitor the progress of natural recovery. Modeling, presented in Appendix A, projects that ongoing sedimentation will reduce $TEQ_{DF,M}$ concentrations in surface sediment over time. Specifically, natural recovery from sediment inputs within the USEPA's Preliminary Site Perimeter is predicted to further reduce the SWAC for 2,3,7,8-TCDD and 2,3,7,8-TCDF within the USEPA's Preliminary Site Perimeter by a factor of two over a period of 10 to 15 years. The estimated cost for this alternative is $1.6 million (Appendix C).

4.3 Alternative 3 – Permanent Cap, Institutional Controls, and Monitored Natural Recovery

The TCRA cap was constructed to provide immediate containment of the materials in the TCRA 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 TCRA cap, that would involve flattening the slopes of the existing TCRA cap by adding additional armor rock material to enhance the effectiveness and permanence of the armored cap remedy by increasing the degree of safety for the armor rock design, to create a permanent cap.

The TCRA cap was originally designed with a robust armor layer to provide reliable containment of materials exceeding PCLs in the Northern Impoundments. As described in Appendix B, armor materials were sized using a factor of safety of 1.3, which is greater than the suggested minimum of factor of safety of 1.1 to provide additional protection of the Northern Impoundments against catastrophic failure.

The Permanent Cap adds further robustness to the TCRA 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 3 horizontal to 1 vertical (3H:1V) and flattening the slopes in the surf zone from 2H:1V to 5 horizontal to 1 vertical (5H:1V). In addition, the Permanent Cap uses rock sized for the "No Displacement" design scenario, which is more conservative than the "Minor Displacement" scenario used for the TCRA cap design, as well as other CERCLA caps, such as Onondaga Lake and Fox River (Appendix B).

The anticipated extent of the additional rock that would be placed during construction of a permanent cap is shown on 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 TCRA construction, the duration of construction for this alternative is estimated to be 2 months (Table 4-1). During construction of the TCRA, obtaining access to the work area from the uplands was a demonstrated implementability challenge; construction of Alternative 3 will require access from the uplands be obtained, and obtaining such access could be a challenge. This alternative is estimated to require 750 hours of heavy equipment operations, resulting in greenhouse gas, PM, and ozone-generating emissions, and more than 250 truck trips causing greenhouse gas, PM, and ozone-generating emissions, as well as traffic impacts (Table 4-2). 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 partical 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 3 is estimated to result in nearly 0.15 lost time injuries, and more than 0.0005 fatalities as a result of construction (Table 4-3). 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. The cost of this alternative is estimated to be $2.9 million (Appendix C).

Surface flow and wave break modeling was performed to evaluate potential erosive forces to support the selection of cap materials to resist those forces (Appendix B). The modeling considers wind and vessel generated waves breaking in the surf zone, as well as river currents under a variety of design storm and flood scenarios. This modeling is described in more detail in Appendix B. ICs and MNR, as described in Section 4.2, are also included in this remedial alternative.

4.4 Alternative 4 – Partial Solidification/Stabilization, Permanent Cap, Institutional Controls, and Monitored Natural Recovery

This remedial alternative is included per the direction of USEPA Region 6 to address material that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter. The extent of the area for partial solidification/stabilization (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 of the TCRA Site that is currently covered by the TCRA cap. The maximum depth of S/S in the Western Cell would be approximately 10 feet based on the analysis of sediment core samples presented in Figure 2-4. A permanent cap, ICs, and MNR, as described in Sections 4.2 and 4.3, are also included in this remedial alternative.

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 TCRA 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—which could include Portland cement, lime, fly or bottom ash, or a combination of these materials—would be delivered to the project work area, stockpiled, and mixed with sediment, as needed, to treat the sediment in situ. Following treatment, the treated sediment would be re-capped with a permanent cap as described in Alternative 3. Submerged areas that would be stabilized would need to be isolated from the surface water with sheetpiling and mostly dewatered prior to mixing with treatment reagents. Following completion of the S/S operation, the existing protective cover (including the armor cap, geotextile and geomembrane barriers) would be replaced and then the permanent cap, as described in Alternative 3, would be constructed.

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 53,300 cy of soil and sediment would be treated. Following treatment,

replaced permanent cap would be constructed in the areas of treatment. Using production rates similar to that achieved during the TCRA, this alternative has an estimated construction duration of 15 months (Table 4-1). As with Alternative 3, access to the work area from the uplands will be required and could be a challenge. This alternative is estimated to require almost 6,000 hours of heavy equipment operations, and more than 1,500 truck trips causing higher greenhouse gas, PM, and ozone-generating emissions and traffic impacts (Table 4-2) than the previous three Alternatives. Alternative 4 is estimated to result in more than one lost time injury, and nearly 0.005 fatalities as a result of construction (Table 4-3). The cost of this alternative is estimated to be $11.2 million (Appendix C).

4.5 Alternative 5 – Partial Removal, Permanent Cap, Institutional Controls, and Monitored Natural Recovery

This remedial alternative is also included as directed by USEPA Region 6 and involves removing sediments/soils that exceed 13,000 ng/kg $TEQ_{DF,M}$ from areas of the TCRA Site that are currently contained by the TCRA cap. The lateral and vertical extent and volume of sediment removed under the action is the same as the sediment to be treated as described in the previous section for Remedial Alternative 4 and is depicted on Figures 4-5 and 4-6. Under this alternative, submerged areas would need to be isolated using a turbidity barrier/silt curtain prior to excavating sediment. Construction of a permanent cap, ICs, and MNR, as described in Sections 4.2 and 4.3, are also included in this remedial alternative.

As documented in the RAM (Anchor QEA 2012b), all dredging projects result in some degree of resuspension, release, and residuals (NRC 2007). The need to address residual contamination following dredging depends upon the concentrations and thicknesses of residuals remaining. However, empirical data from numerous sediment remediation projects indicate that residual contamination is a common occurrence and that sites with high concentrations are unlikely to achieve RALs with dredge technology alone (Patmont and Palermo 2007; NRC 2007). Further, case studies have shown that engineering controls used to control impacts from dredging such as sheetpiles may have limited effectiveness (Anchor Environmental 2005; Anchor QEA and Arcadis 2010) and can pose unintended consequences, such as concentration of dissolved-phase chemicals, localized scour adjacent to

the barrier, and/or the spread of contaminants during their removal (Anchor QEA and Arcadis 2010; Konechne et al. 2010; Ecology 1995).

Upland areas would not need to be isolated with sheetpiling, 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. Depending on the availability of a suitable disposal facility and their acceptance of the waste, some portion of the excavated material could require incineration as part of the disposal process. Following completion of the excavation, the work area would be backfilled to replace the excavated sediment, the existing protective cover (including the armor cap, geotextile and geomembrane barriers) would be replaced and then the permanent cap, as described in Alternative 3, would be constructed.

The construction duration for this alternative is estimated to be 12 months (Table 4-1). This alternative is estimated to require almost 7,000 hours of heavy equipment operations and more than 9,000 truck trips causing higher greenhouse gas and PM emissions, ozone generation, and traffic impacts (Table 4-2) as compared to the previous four alternatives. As with Alternatives 3 and 4, access to the work area from the uplands will be required and could be a challenge. 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 5 is estimated to result in more than one non-fatal lost time injury, and more than 0.005 fatalities as a result of construction (Table 4-3). The cost of this alternative is estimated to range from $24 to $118 million, depending on the need for incineration as part of the disposal process (Appendix C).

4.6 Alternative 6 – Full Removal of Materials Exceeding the PCL, Institutional Controls, and Monitored Natural Recovery

For the full removal alternative, the hypothetical recreational visitor exposure scenario was considered for the area within the TCRA cap. The PCL for protection of the hypothetical recreational visitor is a $TEQ_{DF,M}$ concentration of 220 ng/kg.

The lateral and vertical extents of the removal under this remedial alternative are presented in Figures 4-7 and 4-8. As with the partial removal alternative, cap rock and geotextile would need to be removed prior to beginning excavation within the TCRA footprint, upland excavation could require dewatering to allow excavation of impacted sediment in relatively dry conditions, and excavation of submerged sediment would require isolation of the work area with a turbidity barrier/silt curtain. Excavated sediment would be further dewatered and stabilized at the 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 sediment. This alternative also includes ICs, which would be implemented for specific areas south of I-10, and continuing natural recovery of sediments within the river.

This alternative entails removal of approximately 208,300 cy of sediment from the TCRA footprint and the area near the upland sand separation area, which would require a relatively large offloading and sediment processing facility to efficiently accomplish the work. Alternative 6 is estimated to have a construction duration of 16 months (Table 4-1). Locating an adjacent facility with sufficient space and availability for more than a year of use for staging, offloading, and sediment processing is considered to be a significant challenge to the implementability of Alternative 6. This alternative is estimated to require over 15,000 hours of heavy equipment operations, and over 18,000 truck trips causing significantly higher greenhouse gas and PM emissions, ozone generation, and traffic impacts (Table 4-2) as compared to the previous five alternatives. Off-site transport of materials for disposal presents a significantly higher risk for spills and accidents compared to Alternative 5, which could result in exposure of these materials to the general public. Dewatering by using additive drying amendments such as lime or Portland cement could result in significant fugitive dust emissions at the offloading/processing area.

Alternative 6 is estimated to result in more than three lost time non-fatal injuries, and more than 0.01 fatalities as a result of construction (Table 4-3). The cost of this alternative is estimated to range from $104 to $636 million, depending on the need for incineration as part of the disposal process (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 protection
2. Compliance with ARARs
3. Long-term effectiveness
4. Reduction of TMV
5. Short-term effectiveness
6. Implementability
7. Cost
8. State acceptance
9. Community acceptance

The first two criteria, overall protection 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 are 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 protection* 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.

- *Long-term effectiveness* is an evaluation of the ability of the remedial alternative to reliably maintain protection of receptors.
- *Reduction of TMV* is an evaluation of the degree to which treatment or recycling of affected media is used to reduce the toxicity, mobility, or volume 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. 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 factors that may impede the implementation of the remedy, considering technical and administrative factors. 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.

This section describes the individual analyses for each of the alternatives. Table 5-1 summarizes the key discussion points from this section for each of the evaluation criteria.

5.1 Alternative 1 – No Further Action

5.1.1 Threshold Criteria

The No Further Action remedial alternative would be protective of human health and the environment. As discussed in Section 2.6, other than locations capped during the TCRA, the only sediment samples with $TEQ_{DF,M}$ concentrations exceeding the applicable PCLs are located within a small area of subsurface sediment near the upland sand separation area. The subsurface sediment near the upland sand separation area is isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the PCL for hypothetical recreational visitors. Model predictions presented in Appendix A indicate that net erosion depths during extreme flood events will be limited to less than 15 centimeters in this area, and that over the long-term, ongoing deposition will result in declines in surface sediment concentrations in this area. However, disturbance from propeller wash, for example, due to activities from the adjacent SJRF operations, could cause locally greater erosion that that modeled for extreme flood events depending on the water depth, the size of the vessel, and the duration of vessel operations. Sediment in the footprint of the TCRA cap is also isolated from exposure at the surface by layers of geotextile, geomembrane, and cap rock. Soil from areas of investigation south of I-10 that exceeds the PCL for hypothetical future construction workers is isolated from the surface by several feet of soil with $TEQ_{DF,M}$ concentrations below this PCL.

Alternative 1 would not result in construction impacts or other changes to baseline conditions that would trigger any action or location-specific ARARs identified in Table 3-1. The fate and transport model described in Appendix A predicts significant improvements in water quality within the USEPA's Preliminary Site Perimeter as a result of the TCRA cap. 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, even though there are ongoing external sources from atmospheric deposition, upstream sediment loads, stormwater runoff and point source discharges. Therefore, the continuation of post-TCRA conditions is expected to result in ongoing water quality compliance.

5.1.2 Balancing Criteria

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 applicable PCLs. The sediment transport modeling (Appendix A) results indicate that sediment in the vicinity of the upland 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 associated with the SJRF operations could disturb these sediments. While the TCRA cap effectively isolates sediment in the TCRA Site from potential receptors and has been designed to resist erosive forces during extreme events in the San Jacinto River, this remedial alternative does not include alerting future landowners of the TCRA Site 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 TCRA Site. Similarly, this remedial alternative does not alert landowners to the potential risks associated with certain locations in the subsurface soil in the area south of I-10.

There are no short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative. The continued protection by the TCRA cap would be ensured through long-term monitoring and maintenance. There are not anticipated to be technical or administrative implementability issues associated with this remedial alternative. The estimated cost associated with this remedial alternative is $1.3 million (Appendix C) for maintaining the existing OMM plan for the TCRA cap, signs, buoys and fencing. Costs assume 20 TCRA cap monitoring events and three TCRA cap maintenance events, assuming available access to the TCRA Site from the river and through the Texas Department of Transportation (TxDOT) right-of-way (ROW). It is understood that the number of monitoring events is subject to further discussion with and approval by USEPA.

5.2 Alternative 2 – Institutional Controls and Monitored Natural Recovery

5.2.1 Threshold Criteria

This remedial alternative would achieve the RAOs through a combination of ICs, MNR, and existing engineering controls. As noted in Section 5.1, the current conditions within the

USEPA's Preliminary Site Perimeter are protective of human health and the environment. Sediment and soil with $TEQ_{DF,M}$ concentrations exceeding the applicable PCLs are isolated from potential receptors by the TCRA cap or by sediment or soil with $TEQ_{DF,M}$ concentrations below the PCLs. ICs 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 in the TCRA footprint or specific areas south of I-10
- Describe requirements for the management of any excavated soil or sediment exceeding PCLs
- 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 permanent cap

Affected sediment near the upland sand separation area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the PCL, would be further isolated by deposition of additional sediment through ongoing natural recovery processes as described in Section 2.6 and Appendix A. 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 PCL for hypothetical recreational visitors.

Alternative 2 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. For the same reasons presented in the ARAR compliance discussion under Alternative 1 (Section 5.1), due to the minimal amount of active construction involved, Alternative 2 is also expected to generally meet the substantive requirements of the ARARs presented in Section 3.4.

5.2.2 Balancing Criteria

The long-term effectiveness of this remedial alternative is primarily derived from the ICs that would protect the integrity of the TCRA cap. Long-term effectiveness is also provided by the layers of surface soil and sediments with concentrations below PCLs and the monitoring that would confirm the continued deposition of clean sediment isolating the affected sediment outside of the footprint of the TCRA 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 two over an approximate 10- to 15-year time period (see Appendix A); monitoring would be conducted to verify actual reductions in sediment concentrations. The highest $TEQ_{DF,M}$ concentrations within the USEPA's Preliminary Site Perimeter—in the footprint of the TCRA cap and in specific areas of subsurface soil south of I-10—are isolated from potential receptors by the TCRA cap and, in the area of investigation south of I-10, by a surface layer of soil with $TEQ_{DF,M}$ concentrations well below the PCL for hypothetical construction workers.

Other than at sample locations SJSB023 and SJSB025, the highest $TEQ_{DF,M}$ concentration in the upper 2 feet of soil in the area south of I-10 is 59.3 ng/kg (Figure 2-3), which is well below the PCL of 450 ng/kg. There is no potential risk associated with the area south of I-10 other than to hypothetical future construction workers exposed to excavated soil as the $TEQ_{DF,M}$ concentrations in surface soil at all locations in the area south of I-10 are well below the PCL. The ICs would provide long-term protection against anthropogenic disturbance of the isolating barriers, cap, and clean surface soil.

There is no additional reduction of TMV due to treatment or recycling associated with this remedial alternative beyond that which was achieved during the TCRA. Risk reduction is achieved by the TCRA cap and the clean soil and sediment layers interrupting potential exposure pathways and by the use of ICs and monitoring to verify that the isolation layers remain effective.

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 TCRA Site and the area of investigation south of I-10 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 would continue to decline and the buried sediment near the upland sand separation area with $TEQ_{DF,M}$ concentrations exceeding the PCL would be further isolated from potential receptors.

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

The estimated present worth cost associated with this remedial alternative is $1.6 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 the MNR, and future monitoring and maintenance of the TCRA cap. The cost estimate for this alternative assumes 20 TCRA cap monitoring events, five natural recovery monitoring events, and three TCRA cap maintenance events, and also assumes available access to the TCRA Site by water from a location along the river and by land through the TxDOT ROW. It is understood that the actual number of monitoring events will be subject to further discussion with and approval by USEPA.

5.3 Alternative 3 – Permanent Cap, Institutional Controls, and Monitored Natural Recovery

5.3.1 Threshold Criteria

This remedial alternative would achieve the RAOs through a combination of ICs, MNR, and existing engineering controls, which would be enhanced to provide greater long-term reliability and create a permanent cap. ICs would be used:

- 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 in the TCRA footprint or specific areas south of

I-10

- Describe requirements for the management of any excavated soil or sediment exceeding PCLs
- 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 permanent cap

Affected sediment near the upland sand separation area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the PCL, would be further isolated by deposition of additional clean sediment as described in Section 2.6 and Appendix A. 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 PCL for protection of hypothetical recreational visitors.

Implementation of Alternative 3 would also involve the placement of fill material (the additional armor rock) into the San Jacinto River to create the permanent 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 3 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 permanent cap would require the placement of approximately 3,400 cy of additional cap armor rock material.

5.3.2 Balancing Criteria

The long-term effectiveness of the existing TCRA cap in this alternative is enhanced by adding additional armor rock to the cap. Flattening the slopes to create the permanent cap, as shown on Figures 4-1 and 4-2, would further enhance the structural integrity and long-term reliability of the cap. Surface flow and wave break modeling, described in more detail in Appendix B, was performed to evaluate potential erosive forces associated with a variety of storms and extreme flow events. The results of the modeling were used to confirm that the rock selected for the cap would further resist movement and provide reliable, and

enhanced long-term containment of material beneath the permanent cap. 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. As described in Section 5.2, ICs would protect the integrity of the TCRA cap and the layer of clean surface soil. Monitoring would confirm the continued deposition of new sediment isolating the affected sediment outside of the footprint of the TCRA cap.

There is no reduction of TMV due to treatment or recycling associated with this remedial alternative beyond that achieved during the TCRA. Risk reduction is achieved by the construction of the permanent cap and the clean soil and sediment layers interrupting potential exposure pathways and by the use of ICs and monitoring to verify that the isolation layers remain effective.

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 permanent cap, air emissions from construction equipment, and truck traffic in the community. Because of the limited duration of construction under this alternative (2 months), these risks are considered to be low: the short duration of construction is correlated with relatively low greenhouse gas, PM, and ozone-generating emissions from the construction equipment (Table 4-2). 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. 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 (Table 4-3). The remedy, like Alternatives 1 and 2, would achieve full protection in the TCRA Site and the area of investigation south of I-10 and would also occur immediately 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 upland sand separation area with $TEQ_{DF,M}$ concentrations exceeding the PCL would be further isolated from potential receptors.

There are limited implementability concerns associated with this remedial alternative. Construction of the permanent cap will require the placement of additional cap material on underwater slopes. While precise placement of material underwater is technically challenging, the feasibility of this construction technique was successfully demonstrated during the TCRA construction and experienced local contractors are available to complete this work. Monitoring would involve collecting and analyzing sediment samples and evaluating the data, which are routine procedures for qualified environmental consultants and laboratories. Although owners might object to land use restrictions, establishing ICs is routinely done, so there are not anticipated to be administrative implementability issues 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 fact that low clearance under the I-10 Bridge limits the size of marine-based equipment that can access the project work area from the water.

The estimated present worth cost associated with this remedial alternative is $2.9 million (Appendix C). The capital costs for this remedial alternative are primarily associated with the construction of the permanent cap. The costs of preparing sampling plans, deed restrictions and notices, and a soil management plan are the same as those for Alternative 2. The long-term costs are for monitoring and maintenance of the TCRA cap, collecting and analyzing environmental samples, evaluating the data, and preparing reports to document the MNR. The cost estimate for this alternative assumes 20 TCRA cap monitoring events, five natural recovery monitoring events, and three TCRA cap maintenance events, and also assumes available access to the TCRA 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.

5.4 Alternative 4 – Partial Solidification/Stabilization, Permanent Cap, Institutional Controls, and Monitored Natural Recovery

5.4.1 Threshold Criteria

This remedial alternative would achieve the RAOs through a combination of treatment, existing engineering controls, ICs, and MNR. S/S would be used to immobilize soil/sediment

in the TCRA Site with $TEQ_{DF,M}$ concentrations above the USEPA-designated level of 13,000 ng/kg. S/S may add another level of protection to the already environmentally-protective TCRA cap. A permanent cap meeting the requirements of Alternative 3 would be re-constructed following the S/S process. ICs 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 in the TCRA footprint or specific areas south of I-10
- Describe requirements for the management of any excavated soil or sediment exceeding PCLs
- 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 permanent cap

Affected sediment near the upland sand separation area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the PCL, would be further isolated by deposition of additional sediment as described in Section 2.6 and Appendix A. 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 PCL for hypothetical recreational visitors. Implementation of Alternative 4 would trigger additional compliance requirements beyond those discussed in Section 5.3 due to the removal and replacement of the existing TCRA 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 50,000 to 55,000 cy of sediment is estimated to result in 60,000 to 66,000 cy of amended sediment and this increase in volume could trigger a need to review flood storage impacts in accordance with Federal Emergency Management Agency (FEMA) and Harris County requirements. It is anticipated that Alternative 4, through implementation of the BMPs and the agency coordination actions

outlined in Section 3.4, would generally meet the substantive requirements of the ARARs in Table 3-1.

5.4.2 Balancing Criteria

The long-term effectiveness of this remedial alternative is primarily derived from the construction of the permanent cap and treating approximately 53,300 cy of sediment by S/S, combined with the natural recovery processes described previously. Flattening the slopes, where appropriate, as shown on Figures 4-3 and 4-4, would further increase the stability and long-term reliability of the containment as described in Section 5.3. The stabilization of sediment with $TEQ_{DF,M}$ concentrations exceeding the USEPA-designated level of 13,000 ng/kg would provide marginal additional enhancement of the reliability of the containment. 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. As described in Section 5.2, ICs would protect the integrity of the TCRA 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 TCRA cap.

This remedial alternative may reduce the potential mobility of soil/sediment exceeding PCLs using S/S treatment; however, those wastes are already adequately contained within the TCRA cap, and the mobility of these materials is already very low. Approximately 53,300 cy of soil/sediment in the TCRA Site would be treated in situ.

Treatment of the soil/sediment within the TCRA Site would require first removing the existing TCRA cap in the affected area. This would increase the potential risk of a release of the most impacted in situ soil/sediment at the TCRA Site during construction while the cap is removed, and from sediment that may have adhered to the cap materials, which results 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 sheetpile barrier may be a necessary to manage the risk of exposure mentioned above, and to facilitate effective solidification in relatively dry conditions. Successful in situ solidification of wet soil/sediments below surface water has not been documented 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., Manitowac River, Renholds 1998; Kita and Kubo 1983). The use of a sheetpile barrier does little to enhance the short-term effectiveness of this alternative because of documented effectiveness issues (Anchor Environmental 2005; Anchor QEA and Arcadis 2010; and USACE 2008) with engineered barriers, 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

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. In addition to these environmental risks, the construction duration (15 months) would have higher greenhouse gas, PM, and ozone impacts associated with construction emissions from equipment (Table 4-2) as compared to the previous alternatives. From a worker safety perspective, there is also a moderate risk of accidental injury (Table 4-3) to workers during construction. The remedy, like Alternatives 1 through 3, would achieve protection in the TCRA Site and the area south of I-10 immediately upon implementation; however, protection would not be greater than Alternatives 2 and 3 because the mobility of dioxins/furans is already very low, and the material that would be stabilized is already currently immobilized by the TCRA cap. As with the previous alternatives, additional clean sediment would 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 would continue to decline, and the buried sediment near the upland sand separation area with $TEQ_{DF,M}$ concentrations exceeding the PCL would be further isolated from potential receptors.

The implementation of this remedial alternative, particularly the treatment of soil/sediment after removal of the TCRA cap, would be significantly more challenging than implementation of Alternative 3. Stabilization of soil/sediment in the floodplain and subtidal areas will require precautions, such as the use of a sheetpile barrier wall to minimize potential releases of materials once the TCRA cap is removed. Even with those precautions,

because of the disturbance of sediments caused by removing the TCRA 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 TCRA cap may be unavoidable, particularly if a storm or high water levels were to occur during construction. The results from chemical fate model simulations of Alternative 4 presented in Appendix A, indicate that short-term increases in surface water concentrations could occur, with such increases being significant at localized scales during the construction. In addition, stabilization in areas that are normally below surface water increases the difficulty in successful implementation of this alternative. Replacement of the TCRA cap following S/S would be implementable with challenges as noted in Section 5.3. 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. As with Alternative 3, 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 fact that low clearance under the I-10 Bridge limits the size of marine-based equipment that can access the project work area from the water.

The estimated present worth cost associated with this remedial alternative is $11.2 million (Appendix C). The capital costs for this remedial alternative are primarily associated with the soil/sediment treatment and construction of the permanent cap. The costs of preparing sampling plans, deed restrictions and notices, and a soil management plan are the same as those for remedial Alternative 2. The long-term costs are for monitoring the condition of the permanent cap, collecting and analyzing environmental samples, evaluating the data, preparing reports to document the MNR, and monitoring and maintenance of the TCRA cap. The estimated cost of this alternative assumes 20 TCRA cap monitoring events, five natural recovery monitoring events, and three TCRA cap maintenance events, and also assumes available access to the TCRA Site by water from a location along the river and by land through the TxDOT ROW. The actual number of monitoring events is subject to approval by USEPA.

5.5 Alternative 5– Partial Removal

5.5.1 Threshold Criteria

This remedial alternative achieves the RAOs through a combination of soil/sediment removal, existing engineering controls, ICs, and MNR. Soil and sediment in the TCRA Site 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. A permanent cap meeting the requirements of Alternative 3 would be re-constructed following removal of the soil/sediment. ICs would be used to:

- Alert property owners of the presence of remaining subsurface material exceeding PCLs
- Describe the need for protective equipment and training to limit exposure to contaminants if future additional excavation is required in the TCRA footprint or specific areas south of I-10
- 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 permanent cap

Affected sediment near the upland sand separation area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the PCL, would be further isolated by deposition of additional sediment as described in Section 2.6 and Appendix A. 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 below the PCL for protection of hypothetical recreational visitors.

Implementation of Alternative 5 would include the removal of portions of the existing TCRA cap, removal of underlying soil/sediment, and transportation of sediment to an upland disposal facility. The removal of the TCRA cap and placement of rock for permanent 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 5 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 placement of clean residual cover material. The removal of sediment would require the construction of a transload 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 transload facility will require substantial compliance with relevant requirements. Although land for the transload facility may not be available within the USEPA's Preliminary Site Perimeter, the NCP (40 CFR 300.430(e)) defines on-site for this purpose as "the areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the response action." Alternative 5 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.

5.5.2 Balancing Criteria

The long-term effectiveness of this remedial alternative is primarily derived from the construction of the permanent cap and removing approximately 53,300 cy of sediment from the TCRA Site, combined with natural recovery as described previously. Long-term effectiveness is reduced by the fact that this alternative will generate dredge residuals from the resuspension of dioxin-impacted sediments that have been documented on other projects as discussed in the RAM (Anchor QEA 2012b). These dredge residuals would likely have concentrations that are similar to the concentrations of the materials that are dredged (e.g., greater than 13,000 ng/kg $TEQ_{DF,M}$). Flattening the slopes, where appropriate, as shown on Figures 4-3 and 4-4, would further increase the stability and long-term reliability of the containment as described in Section 5.3. The removal of sediment with $TEQ_{DF,M}$ concentrations exceeding 13,000 ng/kg may marginally enhance the reliability of the containment, however, it may degrade the reliability of the existing containment at the interface between the backfill and the existing cap where scour could undermine the edges of the permanent cap. 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. As described in Section 5.2, ICs would protect the integrity of the remaining TCRA 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 TCRA cap.

This remedial alternative would reduce the volume of sediment exceeding PCLs within the USEPA's Preliminary Site Perimeter. Approximately 53,300 cy of sediment in the TCRA Site would be removed for disposal; however, these sediments are already effectively contained by the TCRA cap and dioxins and furans within the USEPA's Preliminary Site Perimeter have been shown to have very low solubility and are highly immobile. Sediment dewatering by amendment prior to transporting for disposal may reduce the potential mobility of COCs during transportation and at the disposal facility.

Removal of sediment from the TCRA Site would require first removing the existing TCRA cap in the affected area. This would increase the potential risk of a release of soil/sediment with concentrations exceeding 13,000 $TEQ_{DF,M}$ during construction. Releases would be expected during dredging with potential sediments impacted by releases of dioxins and furans (both dredge residuals, as well as dissolved phase), potentially settling onto areas of the TCRA cap and other areas within the USEPA's Preliminary Site Perimeter, and potentially causing temporary increases in surface water and tissue concentrations for various COCs. For example, results from chemical fate model simulations presented in Appendix A, indicate that short-term increases in surface water concentrations could occur, with such increases being significant at localized scales during the construction (e.g., an order of magnitude). To mitigate the potential impacts from resuspended sediments, the work area would need to be isolated with a turbidity barrier/silt curtain or other engineered barrier, although there are documented limitations in the effectiveness of these types of engineered controls (Anchor Environmental 2005; Anchor QEA and Arcadis 2010; and USACE 2008). Project experience at other sediment remediation sites demonstrates that even with the use of engineered controls, sediment resuspension beyond the work area would occur. Sheetpile or some other barrier would be required to dewater the project work area, if excavation is performed using land-based earth-moving equipment rather than a dredge. Even with those precautions, it would be very difficult to avoid releasing some of these materials exceeding PCLs into the river or onto the surface of the undisturbed parts of the TCRA cap if a storm or high water levels occur during construction.

Additional environmental risks include the possibility of spills during transportation to the disposal facility, potential emissions associated with incineration, and possible releases from the off-site landfill itself. In addition to these environmental risks, as compared to the previous four alternatives, the construction duration (12 months, Table 4-1) for this alternative would have higher greenhouse gas and PM emission impacts and ozone generation 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 (Table 4-2). From a worker safety perspective, there is a low to moderate risk of accidental injury to workers during construction (Table 4-3). The remedy, like Alternatives 1 through 4, would achieve full protection in the TCRA Site and the area south of I-10 immediately upon completion of construction, although with no greater degree of protection than the other alternatives. As with the other alternatives, additional clean sediment continues to be deposited throughout the USEPA's Preliminary Site Perimeter, $TEQ_{DF,M}$ concentrations in surface sediments would continue to decline and the buried sediment near the upland sand separation area with $TEQ_{DF,M}$ concentrations exceeding the PCL would be further isolated from potential receptors.

There are several significant implementability concerns associated with this remedial alternative. As discussed above, removal of sediment in the floodplain would require the use of extensive engineering controls to minimize any releases of highly contaminated sediment during construction and some releases to the surrounding environment could occur (Anchor Environmental 2005; Anchor QEA and Arcadis 2010; and USACE 2008). The modeling of Alternative 5 presented in Appendix A shows that these releases could impact surface water and surface sediment concentrations on both short and long timescales. Further, space is very limited to accommodate contractor access, staging, stockpiling materials, and managing excavated sediment for transportation to an off-site disposal site. Replacement of the cap following sediment removal and backfilling would be implementable with challenges as noted in Section 5.3. 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.

The estimated present worth cost associated with this remedial alternative ranges from $24 million to over $118 million (Appendix C) depending on whether the material is landfilled or incinerated. The capital costs for this remedial alternative are primarily associated with the sediment removal and disposal and construction of the permanent cap. The costs of preparing sampling plans, deed restrictions and notices, and a soil management plan are the same as those for remedial Alternative 2. The long-term costs are for monitoring the condition of the permanent cap, collecting and analyzing environmental samples, evaluating the data, preparing reports to document the MNR, and monitoring and maintenance of the TCRA cap. The estimated cost of this alternative assumes 20 TCRA cap monitoring events, five natural recovery monitoring events, and three TCRA cap maintenance events, and also assumes available access to the TCRA Site by water from a location along the river and by land through the TxDOT ROW. The actual number of monitoring events will be subject to approval by USEPA.

5.6 Alternative 6 – Full Removal of Materials Exceeding the Protective Concentration Level

5.6.1 Threshold Criteria

This remedial alternative would provide achieve the RAOs through a combination of soil/sediment removal, ICs, and MNR. Soil/sediment in the TCRA Site and near the upland sand separation area with $TEQ_{DF,M}$ concentrations exceeding the hypothetical recreational visitor PCL (220 ng/kg) would be removed, dewatered, and transported to a permitted incinerator or landfill for disposal. This PCL is very conservative for the area within the TCRA footprint considering the anticipated future industrial or commercial use of the property but could allow for potentially less restricted future use. ICs would be used to:

- Alert property owners of the presence of remaining subsurface material exceeding PCLs
- Describe the need for protective equipment and training to limit exposure to contaminants if future excavation is required in specific areas south of I-10
- 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.

Implementation of Alternative 6 would generally trigger the same compliance requirements as Alternative 5. Were Alternative 6 to be 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.

5.6.2 Balancing Criteria

The long-term effectiveness of this remedial alternative is primarily derived from the removal of soil and sediment, although soils and sediments are already effectively contained by the existing TCRA cap. Approximately 208,300 cy of soil and sediment would be removed from the TCRA Site and from the area near the upland sand separation area. The anticipated limits of the excavation are shown on Figures 4-5 and 4-6. The dredging activity would reduce the volume of soil/sediment with concentrations above 220 mg/kg $TEQ_{DF,M}$; however, it is expected that a residual layer of contaminated materials would remain at the bottom of the excavated surfaces. The concentration of those residual materials would be similar to the removed materials and would likely require a clean sediment residuals cover across the dredge footprint.

A long-term fate and transport model simulation was conducted for Alternative 6 to evaluate the comparative long-term effectiveness of this alternative and quantify potential water and sediment quality impacts during dredging (see Section 4.2 of Appendix A). Results from this simulation indicate that surface sediment concentrations averaged over the USEPA's Preliminary Site Perimeter increase by nearly a factor of three for the 21-year duration of the simulation period compared to natural recovery scenarios; these predicted increases are a result of releases of sediment and dissolved phase dioxins and furans during dredging and sediment residuals within the TCRA Site, even with the use of a post-dredge residuals management cover. However, ongoing deposition would also act to reduce concentrations impacted by dredge residuals and releases within the USEPA's Preliminary Site Perimeter over the long term, but not to the same levels as predicted for the other alternatives. Under this alternative, the material exceeding PCLs south of I-10 would be considered to be

effectively isolated from potential receptors, and ICs would address unacceptable risks to excavation workers.

This remedial alternative would remove sediment exceeding PCLs from within the USEPA's Preliminary Site Perimeter. Approximately 208,300 cy of sediment would be removed from within the USEPA's Preliminary Site Perimeter for disposal; however, these sediments are already effectively contained by the TCRA cap and dioxins and furans within the USEPA's Preliminary Site Perimeter have been shown to have very low solubility and are highly immobile. Sediment dewatering by amendment prior to transporting the sediment to a landfill or incinerator for disposal would reduce the potential mobility of COCs 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.

Removal of sediment from the TCRA Site would require first removing the existing TCRA cap in the affected area. This would increase the potential risk of a release of sediment with the highest concentrations within the USEPA's Preliminary Site Perimeter during construction. In addition, short-term water quality impacts would occur due to dredging operation releases (Appendix A). For example, the model simulation of Alternative 6 indicates that for an assumed dredge release rate of 3 percent[4] (based on experience from other dredging projects; see Table 5-2), average surface water 2,3,7,8-TCDD concentrations within the USEPA's Preliminary Site Perimeter would be predicted to increase by more than an order of magnitude during dredging. 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 (Appendix A). To minimize the potential for release of impacted sediment during construction, the work area would need to be protected with a turbidity barrier/silt curtain. As mentioned previously, however, there are documented limitations on the effectiveness of these types of controls. In addition to these environmental risks, the construction duration (15 months) would have high greenhouse gas, PM, and ozone impacts associated with construction emissions from equipment operating in the work areas (Table 4-2), as well as from equipment required for

[4] As discussed in Appendix A, this percentage applies to the contaminant mass within the dredge prism, and is simulated as a dissolved phase release in the model.

off-site transportation and disposal of excavated sediments. From a worker safety perspective, there is a moderate to high risk of accidental injury to workers during construction (Table 4-3). The remedy would be intended to achieve full protection upon completion of construction; however, it is likely there would be potentially significant 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.

There are several significant implementability concerns associated with this remedial alternative. As discussed above, removal of sediment in the floodplain would require the use of extensive engineering controls to minimize the release of highly contaminated sediment during construction; nevertheless some loss is expected based on documented case histories and published guidance (e.g., USACE 2008) even with the use of those controls. It would be extremely difficult to avoid releasing contaminated materials into the river, particularly if a storm or high water levels occur during construction. Further, space is very limited to accommodate access, staging and stockpiling materials and excavated sediment for transportation to an off-site disposal site. This logistical concern would be much more significant for this remedial alternative than for the partial removal (Section 5.5) because of the longer duration of the project, the greater extent of the removal area, which would leave less upland space for managing materials, as well as the greater volume of material removed which would have significantly greater community impacts (traffic, noise, air emissions, etc.) during implementation. 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, which adds additional complexity to this alternative. Finally, the volume of material removed could have a significant impact on the capacity of available landfills, and the availably of incineration facilities to handle this volume is uncertain; 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.

The estimated present worth cost associated with this remedial alternative is over $100 million to over $600 million if incineration were to be required by the disposal facility. The

capital costs for this remedial alternative are primarily associated with the sediment removal and disposal. The costs of preparing sampling plans, deed restrictions and notices, and a soil management plan are the same as those for remedial Alternative 2. The estimated cost of this alternative assumes five natural recovery monitoring events, although the actual number of such events would be subject to approval by USEPA.

6 COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section compares the alternatives relative to each of the FS evaluation criteria listed under the NCP. Table 5-1 summarizes the criteria for each alternative and provides the basis for the comparative evaluation discussion in this section.

6.1 Threshold Criteria

All of the remedial alternatives evaluated in this FS satisfy the threshold criteria of protecting human health and the environment and addressing ARARs. As noted in the RAM, the surface weighted average $TEQ_{DF,M}$ concentration in surface sediments was reduced by more than 80 percent by the implementation of the TCRA. Based on the fate and transport modeling, this reduction in sediment concentration translates to improvements in water quality throughout the USEPA's Preliminary Site Perimeter (see Table 3-2 in Appendix A), even though there are ongoing inputs of dioxins and furans from external sources, as discussed previously. The current (post-TCRA) condition within the USEPA's Preliminary Site Perimeter is such that there is little potential for exposure to $TEQ_{DF,M}$ concentrations exceeding the applicable soil and sediment PCLs.

- In the area south of I-10, isolated pockets of subsurface soil with $TEQ_{DF,M}$ concentrations exceeding the hypothetical future construction worker PCL are isolated from the surface by several feet of clean soil. Potential exposure to soil exceeding the PCL in this area is limited to circumstances involving excavation into the affected depth zone or contact with excavated soil left at the surface. The hypothetical future construction worker PCL is based on exposure to soil from zero to 10 feet below the surface.
- In the footprint of the TCRA cap, sediment with $TEQ_{DF,M}$ concentrations exceeding the hypothetical future commercial worker PCL is isolated from the surface by the cap. In part of the area, the affected sediment has already been treated with S/S, which further limits exposure potential. Potential exposure to sediment exceeding the PCL in this area is limited to a scenario in which the TCRA cap is compromised by excavation or a catastrophic erosion event, both of which are unlikely due to security fencing around the TCRA Site, the robust nature of the TCRA cap design and ongoing OMM of the cap.
- For the rest of the USEPA's Preliminary Site Perimeter, the sediment PCL is for the

hypothetical recreational visitor exposure scenario. The only sediment with $TEQ_{DF,M}$ concentrations exceeding this PCL is at one sampling location (SJNE032) near the upland sand separation area, and this sediment is overlain by 3 feet of sediment with $TEQ_{DF,M}$ concentrations below the PCL. This location is part of a secured industrial facility with limitations on access. Model predictions presented in Appendix A indicate that net erosion depths during extreme flood events will be limited to less than 15 centimeters in this area, and that over the long term, ongoing deposition will result in declines in surface sediment concentrations in this area.

6.2 Long-Term Effectiveness

The long-term effectiveness evaluation of MNR-based remedies (Appendix A) projects that the SWAC $TEQ_{DF,M}$ will decrease by approximately a factor of two in a 10 to 15-year time frame within the USEPA's Preliminary Site Perimeter (Appendix A) due to natural sedimentation processes in the river. Construction of the TCRA reduced SWAC $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter by approximately 80 percent, and 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.

Alternative 1 does not include ICs and MNR is not measured over time, so the long-term effectiveness of this alternative ranks lower than Alternatives 2 and 3. The existing TCRA cap slope armor is not enhanced in Alternative 2 compared to Alternative 3, which could increase the need for future long-term monitoring and maintenance under Alternative 2.

Although material is treated or removed under Alternatives 4, 5, and 6, disturbance of the TCRA cap to facilitate construction, as well as potential releases during construction, will reduce the long-term effectiveness of these alternatives compared to Alternative 3. There will also be a requirement for a residuals management cover or backfill over the excavated areas for Alternatives 5 and 6.

Alternative 6 has comparatively lower long term effectiveness: As demonstrated by the modeling (Appendix A), the modeled long-term $TEQ_{DF,M}$ concentration in sediment under this alternative is expected to be more than double that of the MNR-based remedies due to

dredging-related releases and dredging residuals. Similar increases were also predicted for Alternatives 4 and 5, but they were at lower concentrations and on more localized scales.

Figures 6-1a and 6-1b compare model-predicted surface sediment TCDD[5] concentrations at the end of the long-term fate model simulation for all six alternatives; results were averaged over the USEPA's Preliminary Site Perimeter and within the TCRA Site (Figure 6-1a), and by river mile in the vicinity of the TCRA Site (Figure 6-1b). These graphics illustrate the comparatively lower long-term effectiveness of Alternative 4, 5, and 6 relative to Alternatives 1 through 3, due to residuals and releases associated with the excavation/stabilization under these alternatives. The long-term impacts of dredge residuals and releases during construction are also evident in the model-predicted water column concentrations at the end of the long-term simulation (see Figure 6-2, which shows model-predicted annual average water column TCDD concentrations at the end of the long-term model simulation for all six alternatives, averaged over the USEPA's Preliminary Site Perimeter and the TCRA Site). These predictions include several sources of dioxins and furans, including atmospheric deposition, upstream sources, and point sources, such as releases from waste-water treatment plant outfalls, in addition to the dioxin-impacted materials potentially released during dredging and S/S activities.

6.3 Reduction of Toxicity, Mobility, or Volume

Alternatives 1 and 2 do not include additional measures to reduce TMV. However, a portion of the soils in the Western Cell were previously solidified during the TCRA as shown on Figures 4-1, 4-3, 4-5 and 4-7. Thus, these alternatives are comparable in reduction of TMV. Alternative 3 further reduces potential mobility within the TCRA Site by increasing the protection of the armored slopes, and thus ranks more favorably than Alternatives 1 and 2. Alternatives 4 and 5 take additional measures through S/S (Alternative 4) or removal (Alternative 5) of approximately 53,300 cy of sediments and soils, and are comparatively better than Alternative 3 for reduction of TMV; however, the potential mobility of the highest concentration materials addressed in these alternatives is increased during remedy

[5] Although the FS focuses on SWAC $TEQ_{DF,M}$ as a metric of sediment quality, the TCDD results from Appendix A provide a reasonable surrogate for $TEQ_{DF,M}$ because TCDD represents the majority of the potential risk in the calculation of $TEQ_{DF,M}$.

implementation, somewhat offsetting this reduction. Alternative 6 has the greatest volume of removal – however, this is offset by significant dredge water column and residual releases and thus this is considered comparable to Alternatives 4 and 5 in terms of reduction of TMV.

6.4 Short-Term Effectiveness

Alternatives 1 and 2 do not entail any construction, and thus have no short-term impacts. Alternative 3 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 3 does not disturb the TCRA cap or require handling of sediments. Compared to Alternatives 4, 5, and 6, which have significantly longer durations, Alternative 3 ranks significantly more favorably for short-term effectiveness.

Alternative 4 has a longer construction duration than Alternative 5 and both entail removing portions of the TCRA cap and managing approximately 53,300 cy of sediments. Thus, compared to Alternative 3, there is higher risk to worker safety (8 to 9 times the number of injuries and fatalities, Table 4-3) and higher environmental impacts (8 to 9 times the number of hours of operation and truck trips, Table 4-2) due to releases that would be expected during construction. Alternative 4 is considered similar to Alternative 5 for emissions of ozone precursors, PM (smog-forming) and greenhouse gases; under Alternative 4, 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 5.

Alternative 6 is the least favorable for short-term effectiveness. The significantly greater number of work hours has attendant higher worker safety risk (20 times the number of injuries and fatalities compared to Alternative 3, Table 4-3) 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 3, Table 4-2), and the time required for Alternative 6 to achieve protection is also longer. Alternative 6 also has the most significant short-term environmental impact due to water column releases during dredging,

and the expected localized increase in tissue concentrations from these releases, as well as generated dredge residuals, that the model predicts may increase the overall SWAC $TEQ_{DF,M}$ immediately following dredging.

Figure 6-3 compares model-predicted annual average water column TCDD concentrations during Year 1 of the model simulation (i.e., water column concentrations that are predicted during construction) for all six alternatives averaged over the USEPA's Preliminary Site Perimeter and within the TCRA Site. As described above, Alternatives 4 through 6 exhibit higher short-term impacts relative to Alternatives 1 through 3 as a result of water column releases that are assumed to occur during removal/stabilization.

6.5 Implementability

Alternatives 1 and 2 do not have any implementability issues because they do not entail construction. Both are more favorable from an implementability standpoint compared to Alternatives 3, 4, 5, and 6. Alternative 3 is a short-duration project that entails proven technology (i.e., the same activities were demonstrated during construction of the TCRA cap) that can be deployed with readily-available materials and local, experienced contractors. Implementability concerns, such as TCRA Site access, limited staging areas, restrictions on equipment size are substantially greater for Alternatives 4, 5, and 6 compared to Alternative 3 because of the much larger scope and scale of these alternatives. Based on these factors, Alternative 3 is less favorable than Alternatives 1 and 2, but more favorable than the remaining alternatives.

Alternative 4 requires the removal of the TCRA cap, which is considered a technical challenge, 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 another technical challenge. Engineering controls for Alternative 4 would not be adequate to prevent the release of sediments exceeding PCLs to the surrounding environment; this would be especially true during potential high flow events that could occur during construction. Alternative 4 is considered to be unfavorable for implementability.

Alternatives 5 and 6 also require removal of the TCRA cap, and management of a significant volume of sediment and soil for off-site disposal, including the need to potentially treat some portion of the material through incineration. Similar to Alternative 4, engineering controls would not be adequate to prevent the release of sediments exceeding PCLs to the surrounding environment; this would be especially true during potential high flow events that could occur during construction. Thus, both of these alternatives are considered equally as unfavorable as Alternative 4 for implementability.

6.6 Cost

Table 5-1 includes a summary of estimated costs for each alternative. Appendix C provides the detailed estimates that were developed for this FS. Costs range from lowest to highest in order from Alternative 1 to Alternative 6: Alternative 1 is estimated to cost $1.3 million; Alternative 2 is estimated to cost $1.6 million; Alternatives 3 and 4 differ by a factor of four, with estimated costs of $2.9 and $11.2 million, respectively; Alternative 5 is estimated to range from over $20 to over $100 million depending on whether incineration were to be required as part of disposal; Alternative 6 is estimated to range from over $100 to over $600 million, also depending on whether incineration were to be required.

6.7 Summary of Comparative Benefits and Risks

The comparative benefits of each alternative have been assessed using the modeling described in Appendix A to predict the TCDD sediment and water column concentrations within the USEPA's Preliminary Site Perimeter at the end of construction, and at the end of the long-term simulation period. As is shown in Figures 6-1a, 6-1b, 6-2 and 6-3, there is no demonstration that removal of materials or additional S/S provides any benefit; in contrast, there is less benefit associated with implementing Alternatives 4, 5, or 6 compared to Alternatives 1, 2, and 3.

Conversely, there is significant hazard to implementation associated with Alternatives 4, 5, and 6 as discussed under Short-Term Effectiveness. Risks from environmental impacts during and following construction (water column, sediment, and localized tissue impacts) and worker safety (estimated injury and fatality rates) are significantly (8 to 20 times; Table 4-2 and Table 4-3) higher for Alternatives 4, 5, and 6 than for Alternatives 1, 2, or 3. Finally,

Alternatives 4, 5, and 6 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 more than 70 times the number of truck trips; Table 4-2).

Finally, the costs of Alternatives 4, 5, and 6 are significantly higher than for Alternatives 1, 2, and 3 (by factors ranging from 4 times higher to more than 2 orders of magnitude higher). Alternatives 4, 5, and 6 provide no predicted benefit, at significantly increased risk, and significantly increased cost when compared to Alternatives 1, 2, and 3.

6.8 Recommended Remedy

Based on the comparative analysis of remedial alternatives, considerations related to the risk/benefit of the various alternatives presented in this section and as summarized by the considerations described in Table 5-1, the recommended remedy is Alternative 3, which includes a permanent cap, ICs, and MNR. The TCRA cap currently addresses the RAOs pertinent to the TCRA Site by effectively containing the soil/sediment that exceeds the hypothetical future commercial worker PCL for that area. The construction of the permanent cap would reduce the need for long-term maintenance of the existing cap, as demonstrated by the modeling described in Appendix B. The permanent cap would reliably provide permanent containment and isolation of the affected soil/sediment. This remedial alternative could be readily implemented using technologies demonstrated during the construction of the TCRA without increasing risks to workers, the surrounding community, or the environment by exposing the already contained soil/sediment.

By comparison, the treatment and removal alternatives (Alternatives 4, 5, and 6) would require removing the protective cap during construction, increasing the short-term risk of releasing the contaminated sediment and adding significant risk related to releases, generated residuals, water column impacts, and localized temporary increases in tissue COC concentrations during and immediately after S/S or dredging. These alternatives also have substantially greater construction-related impacts, including risks to worker safety, ozone-generating emissions, greenhouse gas emissions, PM emissions, construction traffic, and

greater risks to the public from accidents and off-site spills compared to Alternative 3. Alternatives 4, 5, and 6 all have significant implementability challenges associated with treating or removing contaminated sediment in a floodplain. These alternatives, particularly the full removal (Alternative 6), would require the use of a significant amount of land off-site and water access to prepare contaminated sediment for transportation and disposal.

For all of the remedial alternatives, the soil and sediment with $TEQ_{DF,M}$ concentrations exceeding the pertinent PCLs is already isolated by overlying cleaner soil or sediment, or the TCRA cap. ICs will address the RAOs in the area south of I-10 and protect the integrity of the cap in the TCRA Site from human disturbance. Natural recovery will continue to reduce $TEQ_{DF,M}$ concentrations in surface sediment, including in the area near the upland sand separation area where sediment with $TEQ_{DF,M}$ concentrations exceeding the PCL is already isolated from the biologically active zone by several feet of cleaner sediment and additional net sedimentation is predicted to continually occur.

The construction of Alternative 3 could be fully implemented in approximately 2 months from mobilization of a construction contractor. The estimated cost to implement this remedy is $2.9 million.

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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.
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.
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.

[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
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 roposed 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.
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).
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.

Table 3-1
Applicable or Relevant and Appropriate Requirements Summary

Potential ARARs	Citation	Summary	Comment
State of Texas Threatened and Endangered 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 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 CZMP (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.
Local			
Harris County Floodplain Management Permit[6]	Regulations of Harris County, Texas for Flood Plain Management	All development occurring within the floodplain of unincorporated Harris County requires a permit from Harris County; provide land use controls necessary to qualify unincorporated areas of Harris County for flood insurance under requirements of the National Flood Insurance Act of 1968, as amended, to protect human life and health (Harris County 2007).	Floodplain management is addressed under the Federal requirements for floodplains.

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

[6] Harris County authorization is based upon Texas Local Government Code Section 240.901, as amended; Texas Transportation Code Sections 251.001 - 251.059 and Sections 254.001 - 254.019, as amended; the Harris County Road Law, as amended; and the Flood Control and Insurance Act, Subchapter I of Chapter 16 of the Texas Water Code, as amended. This is included here for discussion without admitting that these local requirements constitute ARARs since local requirements are not included within the definition of ARARs in the NCP. See 40 CFR Section 300.5.

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Table 4-1
Summary of Quantities and Durations

	Alternative 1 No Further Action	Alternative 2 Institutional Controls (IC) and Monitored Natural Recovery (MNR)	Alternative 3 IC, MNR, and Permanent Cap	Alternative 4 IC, MNR, Permanent Cap, and Partial S/S Treatment	Alernative 5 IC, MNR, Permanent Cap, and Partial Removal	Alernative 6 IC, MNR, and Full Removal
Site Preparation						
TCRA Armor Rock Removal (cy)	N/A	N/A	0	6,900	6,900	24,000
Duration (days)	N/A	N/A	0	12	12	40
Sheetpile Install/Remove (lf)	N/A	N/A	0	1,400	0	0
Duration (days)	N/A	N/A	0	70	0	0
Construction of a Permanent Cap						
Armor Rock Placement (cy)	N/A	N/A	3,400	3,400	3,400	0
Duration (days)	N/A	N/A	23	23	23	0
Treatment						
Sediment Solidification (cy)	N/A	N/A	0	53,300	0	0
Duration (days)	N/A	N/A	0	178	0	0
Removal						
Dredging (cy)	N/A	N/A	0	0	53,300	208,300
Residuals Cover/Backfill (cy)	N/A	N/A	0	0	53,300	15,900
Duration (days)	N/A	N/A	0	0	173	292
Capping						
TCRA Armor Rock Replacement (cy)	N/A	N/A	0	6,900	6,900	0
Duration (days)	N/A	N/A	0	46	46	0
TOTAL DURATION (months)	**N/A**	**N/A**	**2**	**15**	**12**	**16**

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. Solidification - 300 cy/day
   e. Dredging - 800 cy/day
   f. Residuals Cover/Backfill - 500 cy/day

Table 4-2
Summary of Construction Emissions Factors

	Alternative 1 No Further Action	Alternative 2 Institutional Controls (IC) and Monitored Natural Recovery (MNR)	Alternative 3 IC, MNR, and Permanent Cap	Alternative 4 IC, MNR, Permanent Cap, and Partial S/S Treatment	Alernative 5 IC, MNR, Permanent Cap, and Partial Removal	Alernative 6 IC, MNR, and Full Removal
Site Preparation						
Heavy Equipment Hours	N/A	N/A	0	2,450	350	2,000
Truck Trips	N/A	N/A	0	570	550	1,800
Construction of a Permanent Cap						
Heavy Equipment Hours	N/A	N/A	750	750	750	0
Truck Trips	N/A	N/A	260	260	260	0
Treatment						
Heavy Equipment Hours	N/A	N/A	0	1,800	0	0
Truck Trips	N/A	N/A	0	250	0	0
Removal						
Heavy Equipment Hours	N/A	N/A	0	0	5,050	13,500
Truck Trips	N/A	N/A	0	0	8,000	16,800
Capping						
Heavy Equipment Hours	N/A	N/A	0	800	800	0
Truck Trips	N/A	N/A	0	520	520	0
TOTAL HEAVY EQUIPMENT HOURS	**N/A**	**N/A**	**750**	**5,800**	**6,950**	**15,500**
TOTAL TRUCK TRIPS	**N/A**	**N/A**	**260**	**1,600**	**9,330**	**18,600**
NORMALIZED EQUIPMENT HOURS			**1.0**	**7.7**	**9.3**	**20.7**
NORMALIZED TRUCK TRIPS			**1.0**	**6.2**	**35.9**	**71.5**

Notes:

1. Equipment hours and truck trips based on durations and quantities in Table 4-1
2. Equipment hours assume 10 hour day and 80% up-time for each piece of equipment
3. Truck trips assume a capacity of 20 tons per truck
4. Site preparation includes TCRA cap rock removal and sheet pile installation. Additional site preparation activities would add to equipment hours and truck trips but were not included as a simplifying assumption
5. Removal includes placement of backfill/residuals management cover

Table 4-3
Summary of Worker Risk Factors

	Alternative 1 No Further Action	Alternative 2 Institutional Controls (IC) and Monitored Natural Recovery (MNR)	Alternative 3 IC, MNR, and Permanent Cap	Alternative 4 IC, MNR, Permanent Cap, and Partial S/S Treatment	Alernative 5 IC, MNR, Permanent Cap, and Partial Removal	Alernative 6 IC, MNR, and Full Removal
Site Preparation						
Non Fatal Injuries	N/A	N/A	0.000	0.478	0.068	0.390
Fatal Injuries	N/A	N/A	0.0000	0.0019	0.0003	0.0016
Construction of a Permanent Cap						
Non Fatal Injuries	N/A	N/A	0.146	0.146	0.146	0.000
Fatal Injuries	N/A	N/A	0.0006	0.0006	0.0006	0.0000
Treatment						
Non Fatal Injuries	N/A	N/A	0.000	0.351	0.000	0.000
Fatal Injuries	N/A	N/A	0.0000	0.0014	0.0000	0.0000
Removal						
Non Fatal Injuries	N/A	N/A	0.000	0.000	0.985	2.633
Fatal Injuries	N/A	N/A	0.0000	0.0000	0.0040	0.0106
Capping						
Non Fatal Injuries	N/A	N/A	0.000	0.156	0.156	0.000
Fatal Injuries	N/A	N/A	0.0000	0.0006	0.0006	0.0000
TOTAL NON-FATAL INJURIES	**N/A**	**N/A**	**0.146**	**1.131**	**1.355**	**3.023**
TOTAL FATAL INJURIES	**N/A**	**N/A**	**0.0006**	**0.0046**	**0.0055**	**0.0122**
NORMALIZED INJURY RATE			**1.0**	**7.7**	**9.3**	**20.7**

Notes:

1. Incident Rates based on data from U.S. Department of Labor (USDL), Bureau of Labor Statistics (USDL 2011)
2. Non-fatal injury estimate based on a rate of 3.9 per 200,000 work hours (NAICS code 23 - construction)
3. Fatal injury estimate based on a rate of 15.7 per 200,000,000 work hours (construction laborer)
4. Total employee work hours estimated based on equipment work hours (Table 4-2) and assuming a crew of 10: 5 workers at the staging area and 5 workers at the work site (3 operators + 2 support workers at each location)

USDL 2011. U.S. Department of Labor, Bureau of Labor Statistics, OSHA Recordable Case Rates and Census of Fatal Occupational Injuries, 2011

Table 5-1
Detailed Evaluation of Remedial Alternatives

	Alternative 1 No Further Action	Alternative 2 Institutional Controls (IC) and Monitored Natural Recovery (MNR)	Alternative 3 IC, MNR, and Permanent Cap	Alternative 4 IC, MNR, Permanent Cap, and Partial S/S Treatment	Alternative 5 IC, MNR, Permanent Cap, and Partial Removal	Alternative 6 IC, MNR, and Full Removal
Threshold Criteria						
Overall Protection	Meets	Meets	Meets	Meets	Meets	Meets
Compliance with ARARs	Meets	Meets	Meets	Meets	Meets	Meets
Balancing Criteria						
Long-Term Effectiveness	• TCRA cap has effectively prevented exposure of ecological and human receptors and requires long-term operations, monitoring and maintenance (OMM) • Natural recovery of sediments within the preliminary Site boundary will continue to provide additional reduction in exposure to dioxins and furans in surface sediments	• Same as Alternative 1 plus: • ICs protect the integrity of the TCRA cap, alert potential future property owners about subsurface risk in subsurface sediment, and control exposure to contaminated subsurface soil through use-restrictions on properties south of I-10	• Same as Alternative 2 plus: • Construction of a permanent cap would provide additional reliability for the long-term performance	• Same as Alternative 3 plus: • S/S of selected sediment would provide redundant mobility controls (in addition to cap)	• Same as Alternative 3 plus: • Removal of selected sediment would eliminate the long-term potential of mobilizing COCs adsorbed to these sediments, which are already effectively contained by the TCRA cap	• Same as Alternative 2 plus: • Removal of sediment from footprint of TCRA cap to the PCL for hypothetical recreational visitors would eliminate the long-term potential of mobilizing COCs adsorbed to these sediments, which are already effectively contained by the TCRA cap • Residuals cover would be required to manage sediment left behind as a result of dredging
Reduction of TMV	• Mobility already reduced through treatment during the TCRA • Dioxin and pulp waste are not mobile in the environment • No additional reduction proposed	• Same as Alternative 1	• Mobility already reduced through treatment during TCRA • Dioxin and pulp waste are not mobile in the environment • Additional potential mobility reduction achieved by construction of a permanent cap	• Same as Alternative 3 plus: • Additional mobility reduction through S/S	• Post-removal dewatering would reduce the mobility of COCs through the addition of amendments to facilitate transportation and disposal • Sediment might need to be incinerated as part of the disposal process, which would remove organic COCs	• Same as Alternative 5
Short-Term Effectiveness	• Achieve protection immediately • No water quality impacts associated with implementation • No sediment quality impacts associated with implementation • No tissue impacts associated with implementation	• Same as Alternative 1	• Achieve protection upon completion of implementation • Minimal water quality impacts from turbidity during rock placement for construction of a permanent cap. • No sediment quality impacts associated with implementation	• Achieve protection upon completion of implementation • Water quality impacts during cap removal • Water quality impacts during sheetpile installation and removal • Potential for sheetpile to drive contamination deeper into subgrade	• Achieve protection upon completion of implementation • Water quality impacts during cap removal • Water quality impacts from losses through turbidity barriers • Minimal water quality impacts from turbidity during backfilling and cap	• Achieve protection upon completion of implementation • Water quality impacts during cap removal • Water quality impacts from losses through turbidity barriers • Minimal water quality impacts from turbidity during backfilling and cap

Table 5-1
Detailed Evaluation of Remedial Alternatives

	Alternative 1 No Further Action	Alternative 2 Institutional Controls (IC) and Monitored Natural Recovery (MNR)	Alternative 3 IC, MNR, and Permanent Cap	Alternative 4 IC, MNR, Permanent Cap, and Partial S/S Treatment	Alternative 5 IC, MNR, Permanent Cap, and Partial Removal	Alternative 6 IC, MNR, and Full Removal
	• No worker safety risk • No air emissions from construction • No traffic impacts from construction		• No tissue impacts associated with implementation • 0.15 estimated construction worker injuries • 0.0006 estimated construction worker fatalities • Air emissions, greenhouse gas, particulate matter and ozone generation from 750 hours of equipment operations • Air emissions, greenhouse gas, particulate matter, ozone generation and traffic impacts from 260 truck trips	• Water quality impacts from losses through sheetpile gaps • Minimal water quality impacts from turbidity during backfilling and cap replacement • Minimal water quality impacts from turbidity during rock placement for construction of a permanent cap. • Sediment quality impacts from losses through sheet pile gaps • Tissue impacts from water column releases during construction • 1.1 estimated construction worker injuries • 0.005 estimated construction worker fatalities • Air emissions, greenhouse gas, particulate matter and ozone generation from 5,800 hours of equipment operations • Air emissions, greenhouse gas, particulate matter, ozone generation and traffic impacts from 1,600 truck trips • Potential air emissions of particulate matter during stabilization operations	replacement • Minimal water quality impacts from turbidity during rock placement for construction of a permanent cap. • Sediment quality impacts from dredging residuals • Tissue impacts from water column releases during construction • 1.4 estimated construction worker injuries • 0.006 estimated construction worker fatalities • Air emissions, greenhouse gas, particulate matter and ozone generation from 6,950 hours of equipment operations • Air emissions, greenhouse gas, particulate matter, ozone generation and traffic impacts from 9,330 truck trips • Potential air emissions of particulate matter during sediment dewatering, if amendments are used • Air emissions from incineration operations, if used • Risk of public exposure to Site materials during off-site transport due to accidents or spills	replacement • Minimal water quality impacts from turbidity during rock placement for construction of a permanent cap. • Sediment quality impacts from dredging residuals • Tissue impacts from water column releases during construction • 3.0 estimated construction worker injuries • 0.01 estimated construction worker fatalities • Air emissions, greenhouse gas, particulate matter and ozone generation from 15,500 hours of equipment operations • Air emissions, greenhouse gas, particulate matter, ozone generation and traffic impacts from 18,600 truck trips • Potential air emissions of particulate matter during sediment dewatering, if amendments are used • Air emissions from incineration operations, if used • Risk of public exposure to Site materials during off-site transport due to accidents or spills

Table 5-1
Detailed Evaluation of Remedial Alternatives

	Alternative 1 **No Further Action**	**Alternative 2** **Institutional Controls (IC) and Monitored Natural Recovery (MNR)**	**Alternative 3** **IC, MNR, and Permanent Cap**	**Alternative 4** **IC, MNR, Permanent Cap, and Partial S/S Treatment**	**Alternative 5** **IC, MNR, Permanent Cap, and Partial Removal**	**Alternative 6** **IC, MNR, and Full Removal**
Implementability	• Minor implementability issues associated with ongoing OMM of TCRA cap	• Property owners may object to land-use restrictions	• Same as Alternative 2 plus: • Site access limited as demonstrated during TCRA construction • Equipment size restricted by low bridge clearance on river • On-site staging area limited • Materials and equipment readily available for construction of a permanent cap. • Construction of a permanent cap placement techniques successfully demonstrated during TCRA construction	• Same as Alternative 3 plus: • Requires partial removal of TCRA cap, decontamination of those materials, and possible disposal • Isolation and dewatering of the treatment or removal area is a construction challenge, particularly if elevated water level occurs during construction • S/S treatment of materials with very high water content is more difficult to implement and less certain, particularly if Site is flooded during implementation	• Same as Alternative 3 plus: • Require partial removal of TCRA cap, decontamination of those materials, and possible disposal • Engineering controls such as silt curtains are difficult to implement and maintain in a flowing river, as demonstrated during TCRA construction • Locating a nearby facility that can accommodate staging, offloading and sediment processing needed for the excavated material, and for the expected is considered a challenge	• Same as Alternative 5 plus: • Volume of material is significantly greater, multiplying implementability challenges • Locating a nearby facility that can accommodate staging, offloading and sediment processing needed for the large volume of excavated material, and for the expected duration of the project, is considered a significant challenge • Finding off-site disposal for high volume of dioxin/furan contaminated soil/sediment considered to be a challenge • Constriction of a permanent cap considerations discussed for Alternative 3 are not applicable
Cost	$1.6M	$1.6M	$2.9M	$11.2M	$24 to $118M	$104 to $636M
Modifying Criteria						
State Acceptance	TBD	TBD	TBD	TBD	TBD	TBD
Community Acceptance	TBD	TBD	TBD	TBD	TBD	TBD

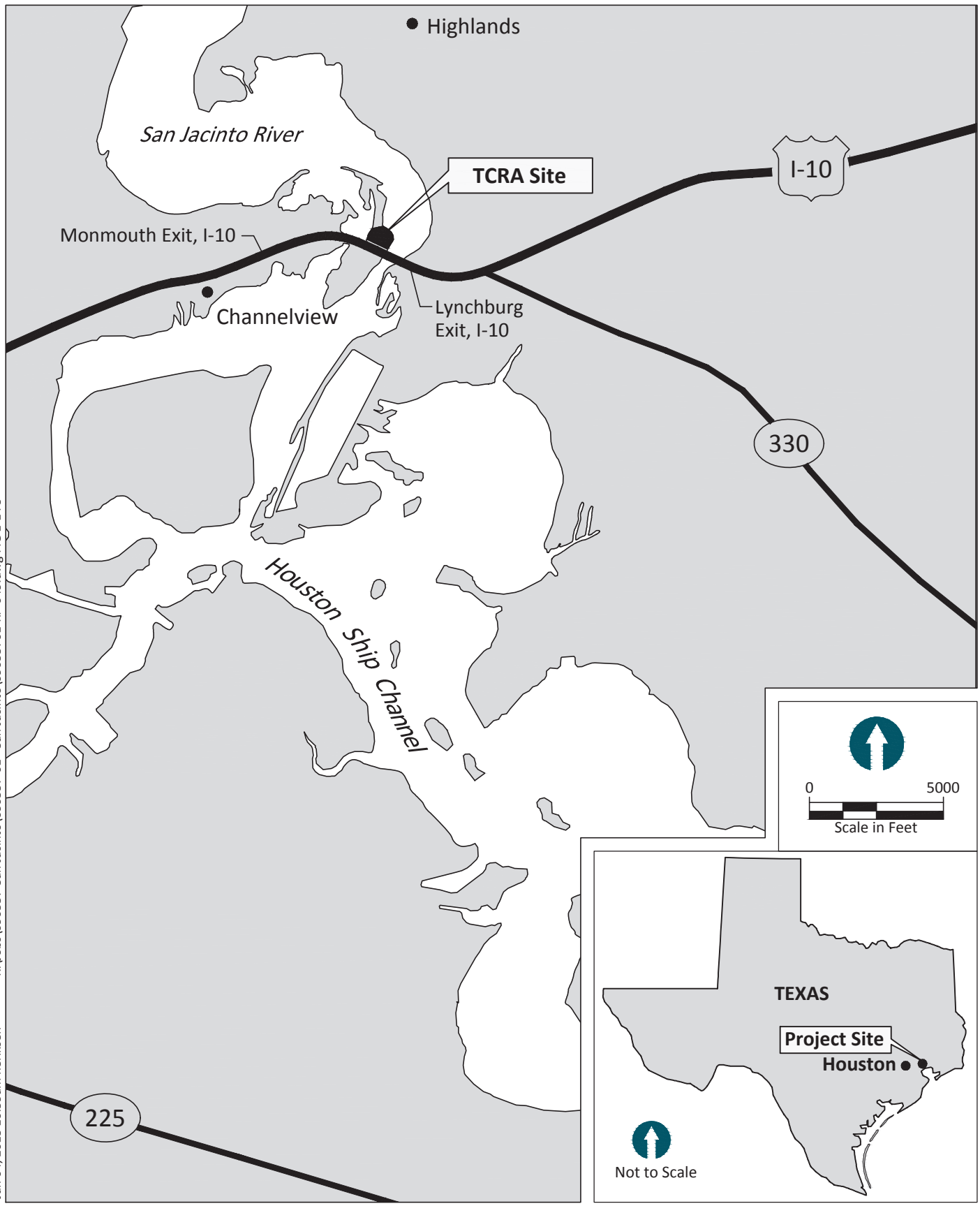
Notes:

ARARs - Applicable or Relevant and Appropriate Requirements
COCs - chemicals of concern
IC - Institutional Controls
MNR - Monitored Natural Recovery
OMM - Operations, Monitoring, and Maintenance
PCL - Protective Concentration Level
S/S - solidification/stabilization
TBD – To Be Determined
TCRA – Time Critical Removal Action
TMV - toxicity, mobility, or volume

Table 5-2
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.

FIGURES



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Jun 04, 2013 10:59am heriksen

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

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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 Upland 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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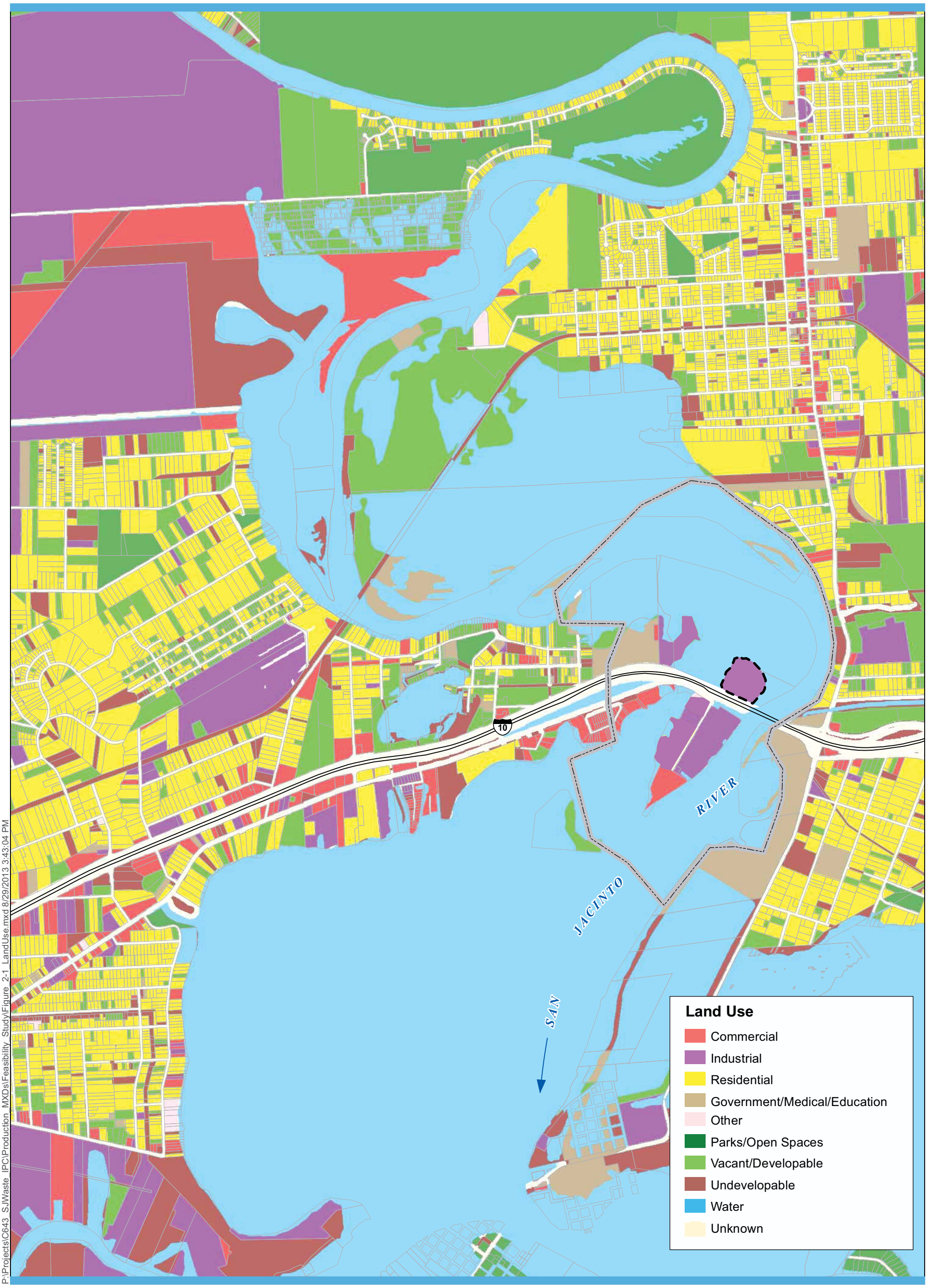
ANCHOR QEA

integral consulting inc

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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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

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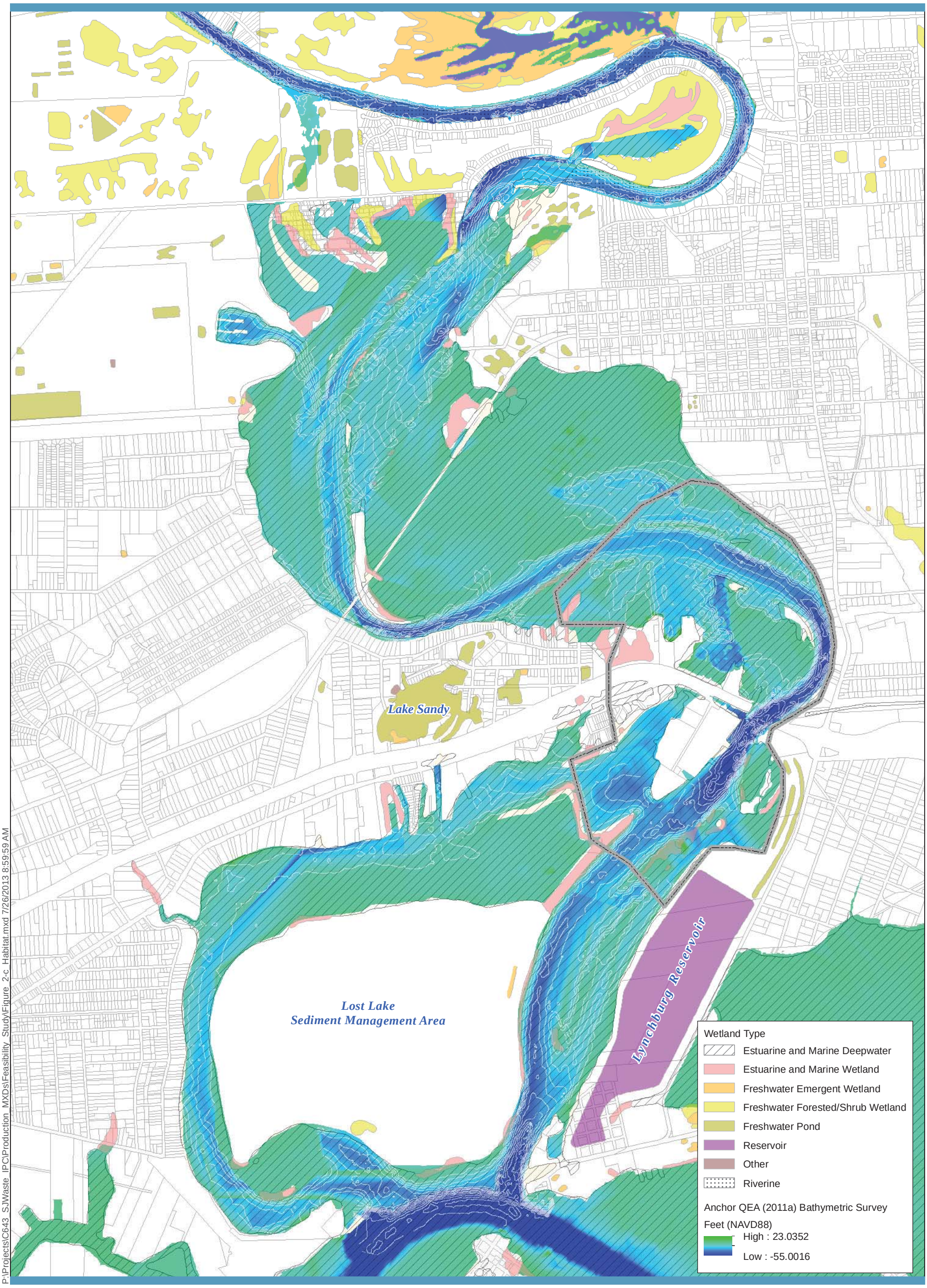

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USEPA's Preliminary Site Perimeter
1-Meter 1995 Bathymetric Contour
Parcel Boundary

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.

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

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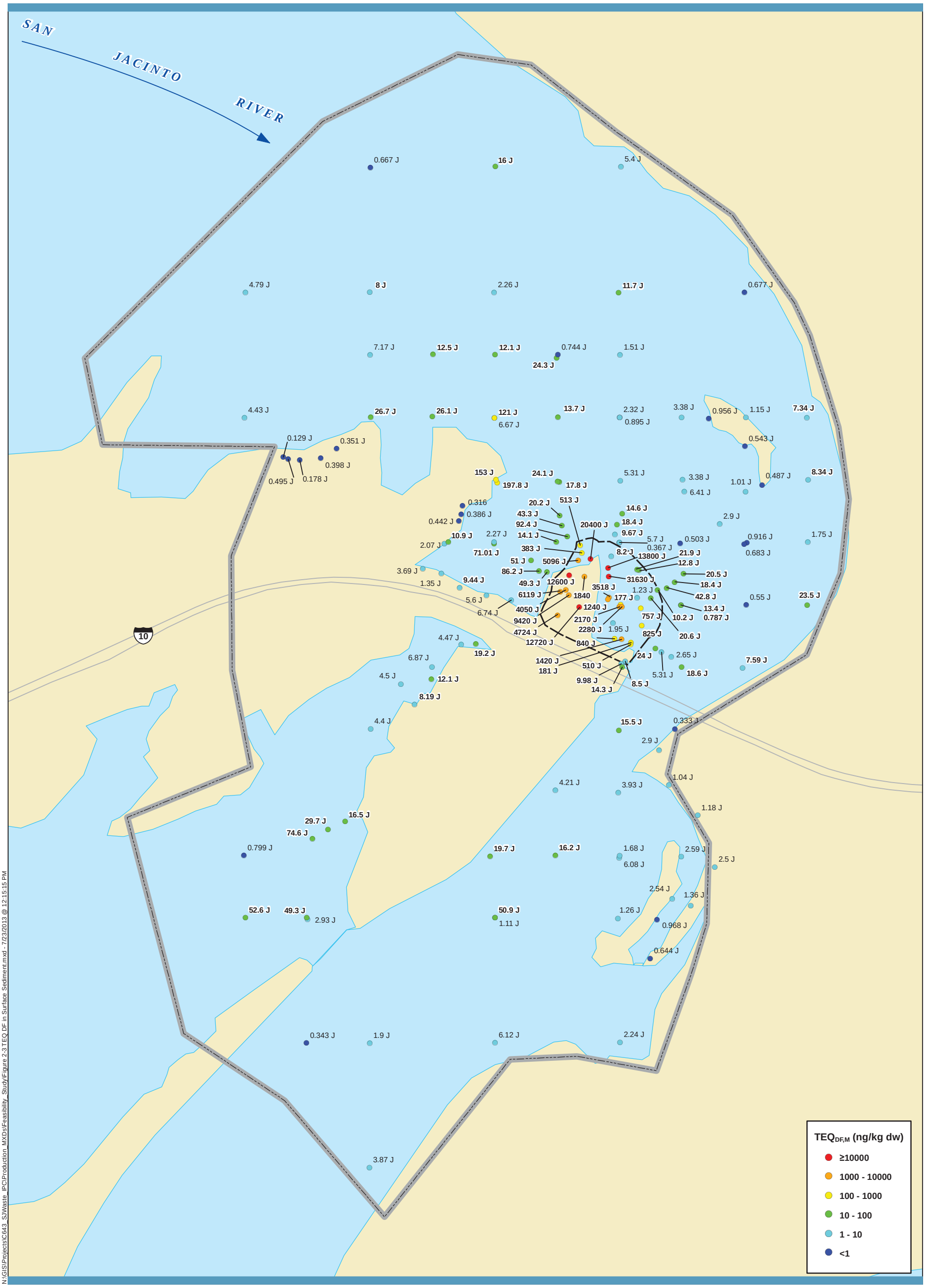

N:\GIS\Projects\C643_SJWaste_IPC\Production_MXDs\Feasibility_Study\Figure 2-3 TEQ DF in Surface Sediment.mxd - 7/23/2013 @ 12:15:15 PM

ANCHOR QEA integral consulting inc

0 800
Feet

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

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
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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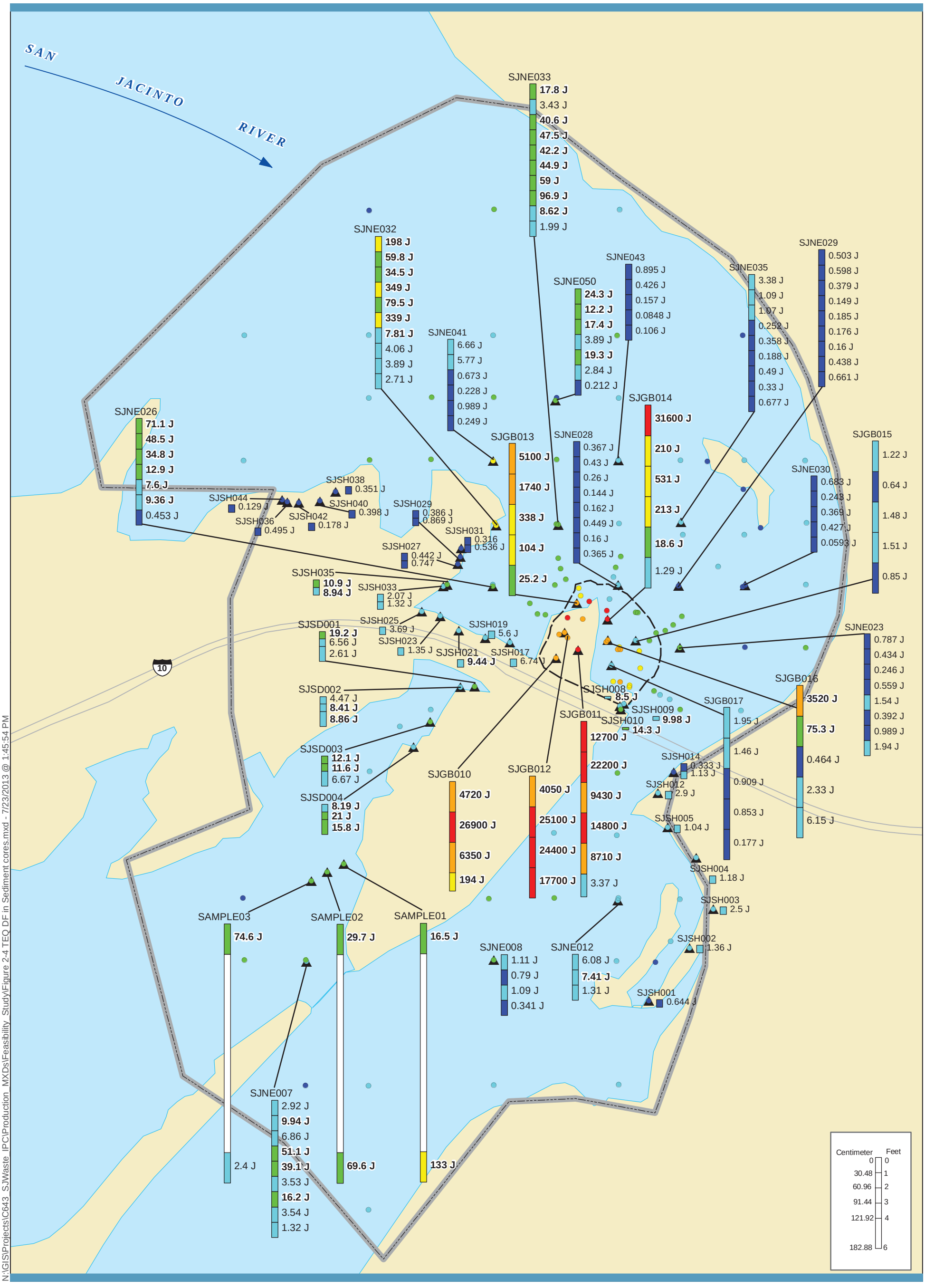

N:\GIS\Projects\C643_SJWaste_IPC\Production_MXDs\Feasibility_Study\Figure 2-4 TEQ DF in Sediment cores.mxd - 7/23/2013 @ 1:45:54 PM

ANCHOR QEA

integral consulting inc

0 800

Scale in Feet

USEPA's Preliminary Site Perimeter

Limit of TCRA 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

Figure 2-4

$TEQ_{DF,M}$ Concentrations in Sediment Cores

Feasibility Study

San Jacinto River Waste Pits Superfund Site

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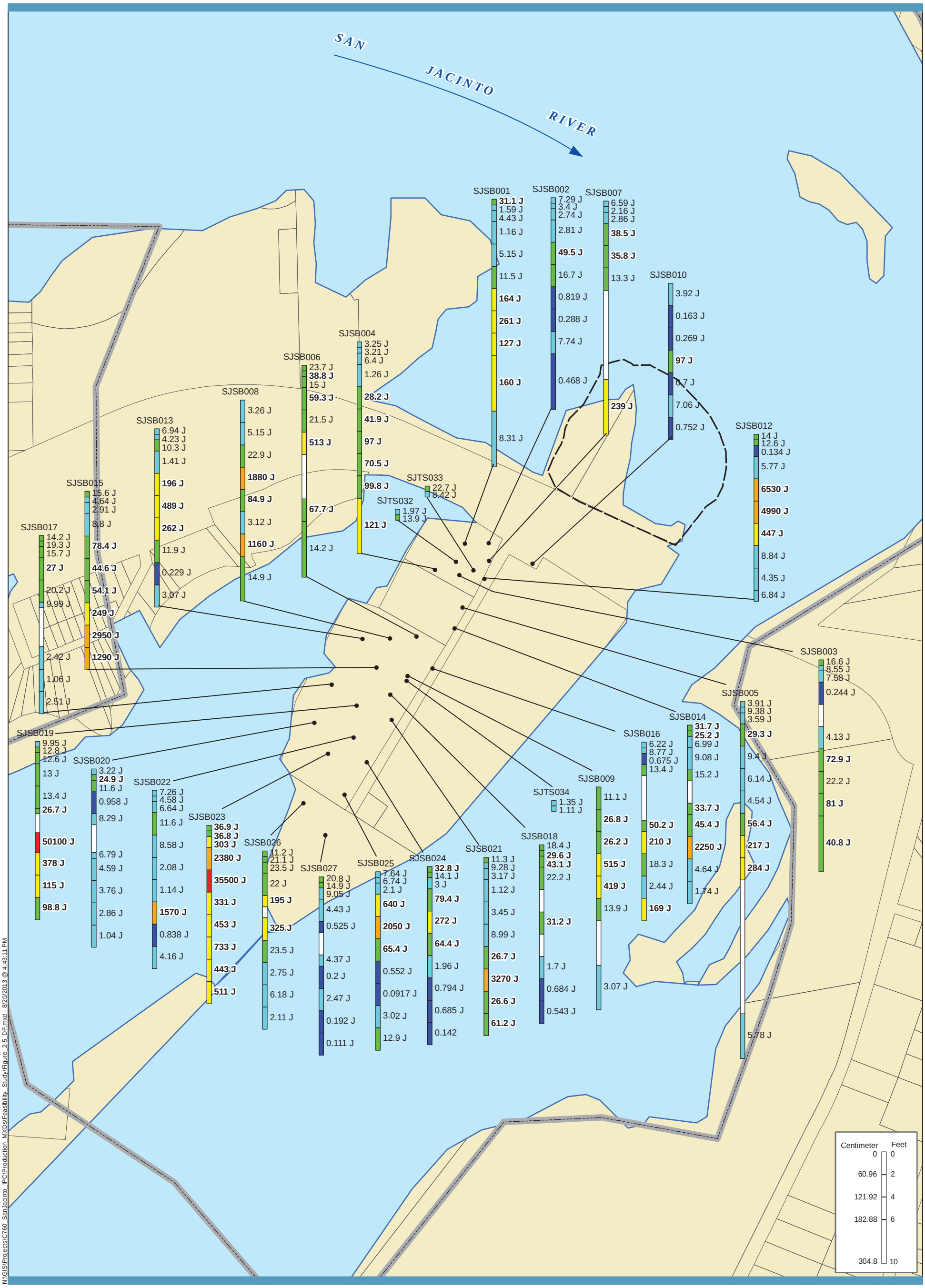

N:\GIS\Projects\C760_SanJacinto_IPC\Production_MXDs\Feasibility_Study\Figure_2-5_DF.mxd - 8/20/2013 @ 4:43:11 PM

ANCHOR QEA integral consulting inc

0 800
Feet

USEPA's Preliminary Site Perimeter
Limit of TCRA 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

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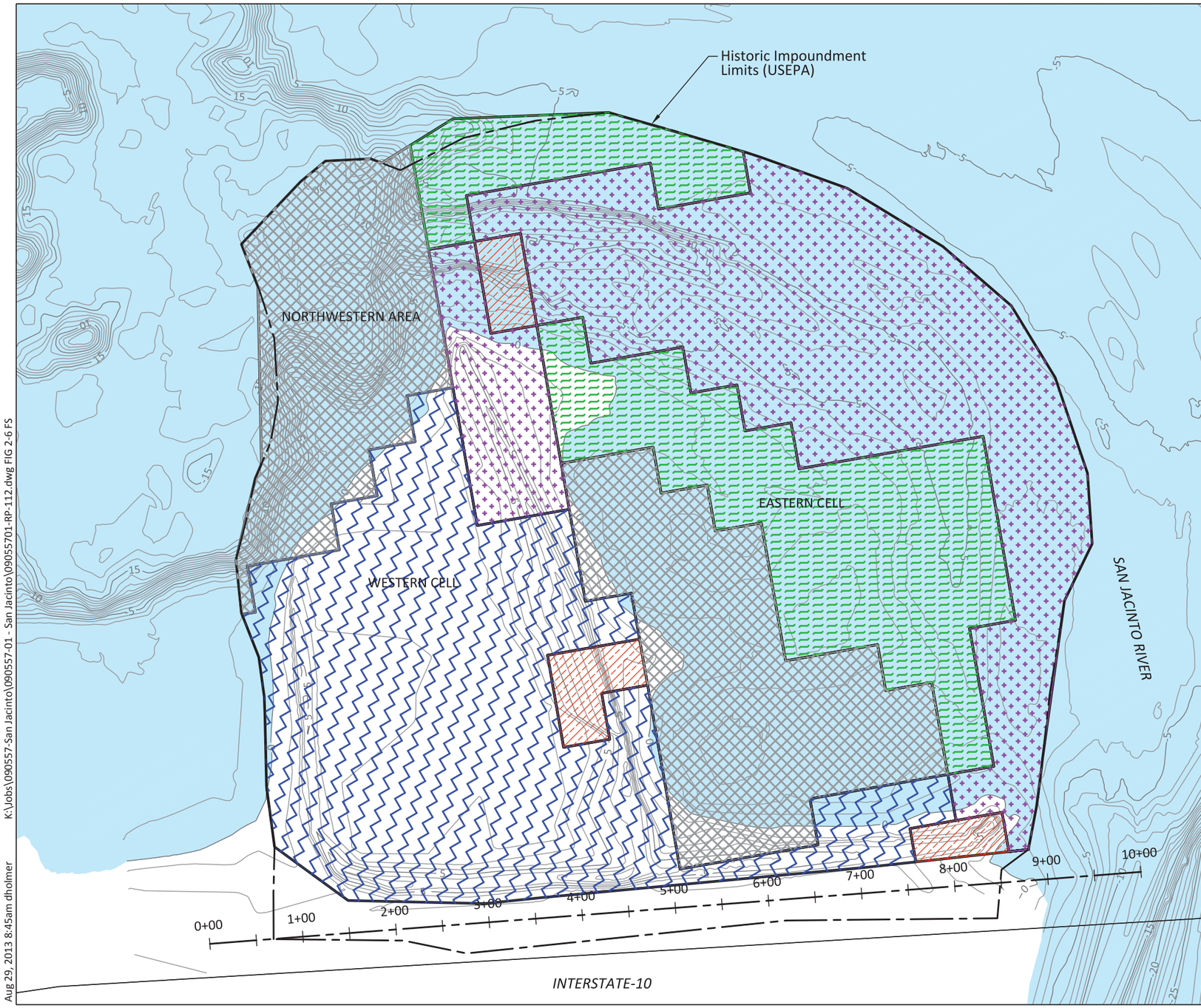

LEGEND:

- Pre-Construction Contour, 6/12/10 (1-foot interval)
- Historic Impoundment Limit (USEPA)
- Armored Cap $A_{(P)}$ (Recycled)
- Armored Cap $B/C_{(P)}$ (Recycled)
- Armored Cap $C_{(N)}$ (Natural)
- Armored Cap $D_{(N)}$ (Natural)
- Armored Cap $D_{(N)}$ (Natural) (24"-Thick)
- Surveyed Extent of Installed Geotextile and Geomembrane in Western Cell
- Approximate Water Surface Elevation (0 feet NAVD88)

HORIZONTAL DATUM: Texas South Central, NAD83. US Survey Feet.

VERTICAL DATUM: NAVD88.

0 120
Scale in Feet

K:\Jobs\090557-San Jacinto\090557-01 - San Jacinto\090557701-RP-112.dwg FIG 2-6 FS

Aug 29, 2013 8:45am dholmer

ANCHOR QEA

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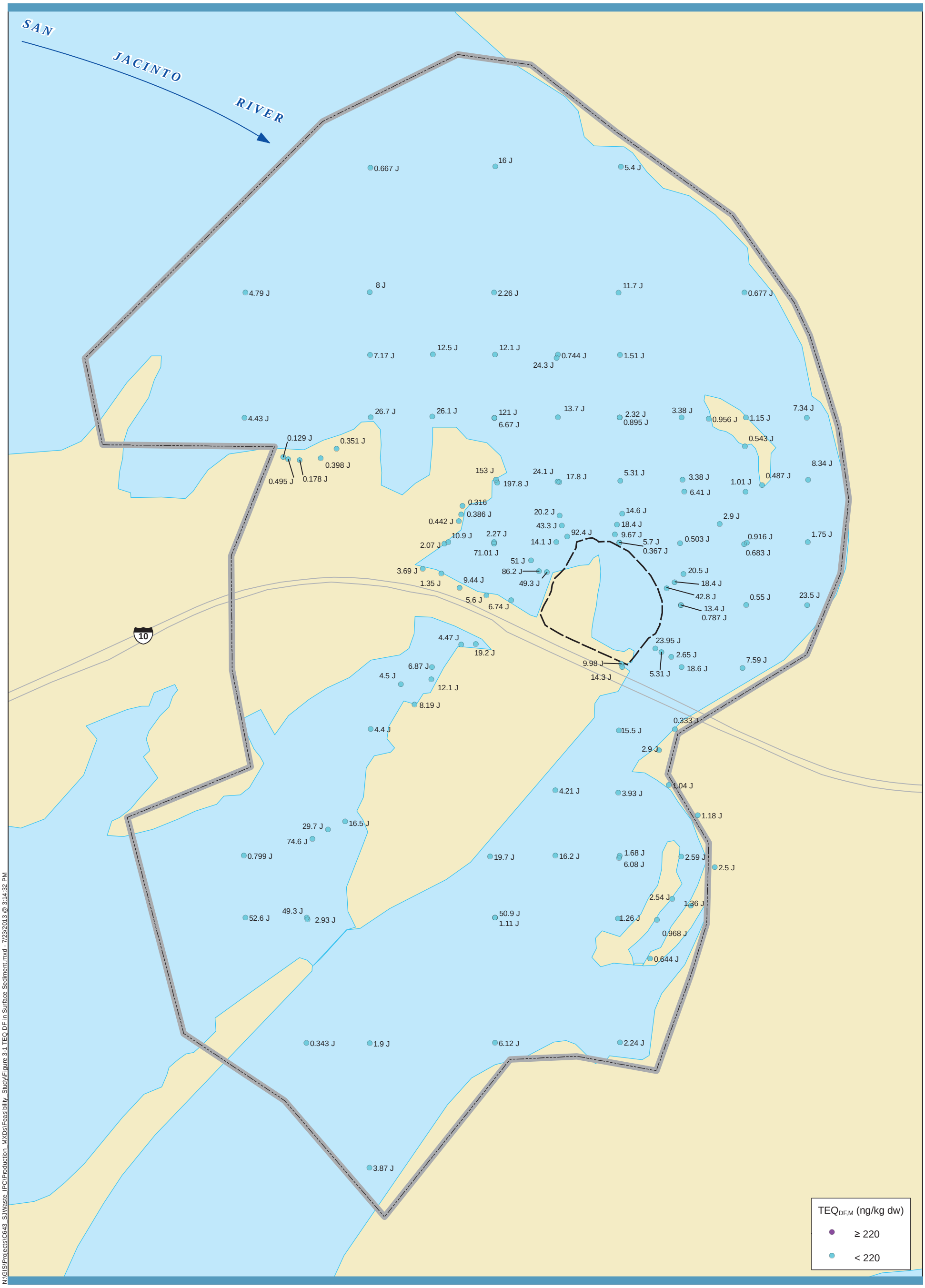
Figure 2-6
TCRA Cap As-Built Drawing
Feasibility Study
San Jacinto River Waste Pits Superfund Site



N:\GIS\Projects\C643_SJWaste_IPC\Production_MXDs\Feasibility_Study\Figure 3-1 TEQ DF in Surface Sediment.mxd - 7/23/2013 @ 3:14:32 PM

ANCHOR QEA

integral consulting inc

0 800
Feet

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

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.

The sediment Protective Concentration Level for a hypothetical recreational visitor for TEQ$_{DF,M}$ is 220 ng/kg dry weight.

Figure 3-1
TEQ$_{DF,M}$ Concentrations in Surface Sediment
Compared to Hypothetical Recreational Visitor PCL
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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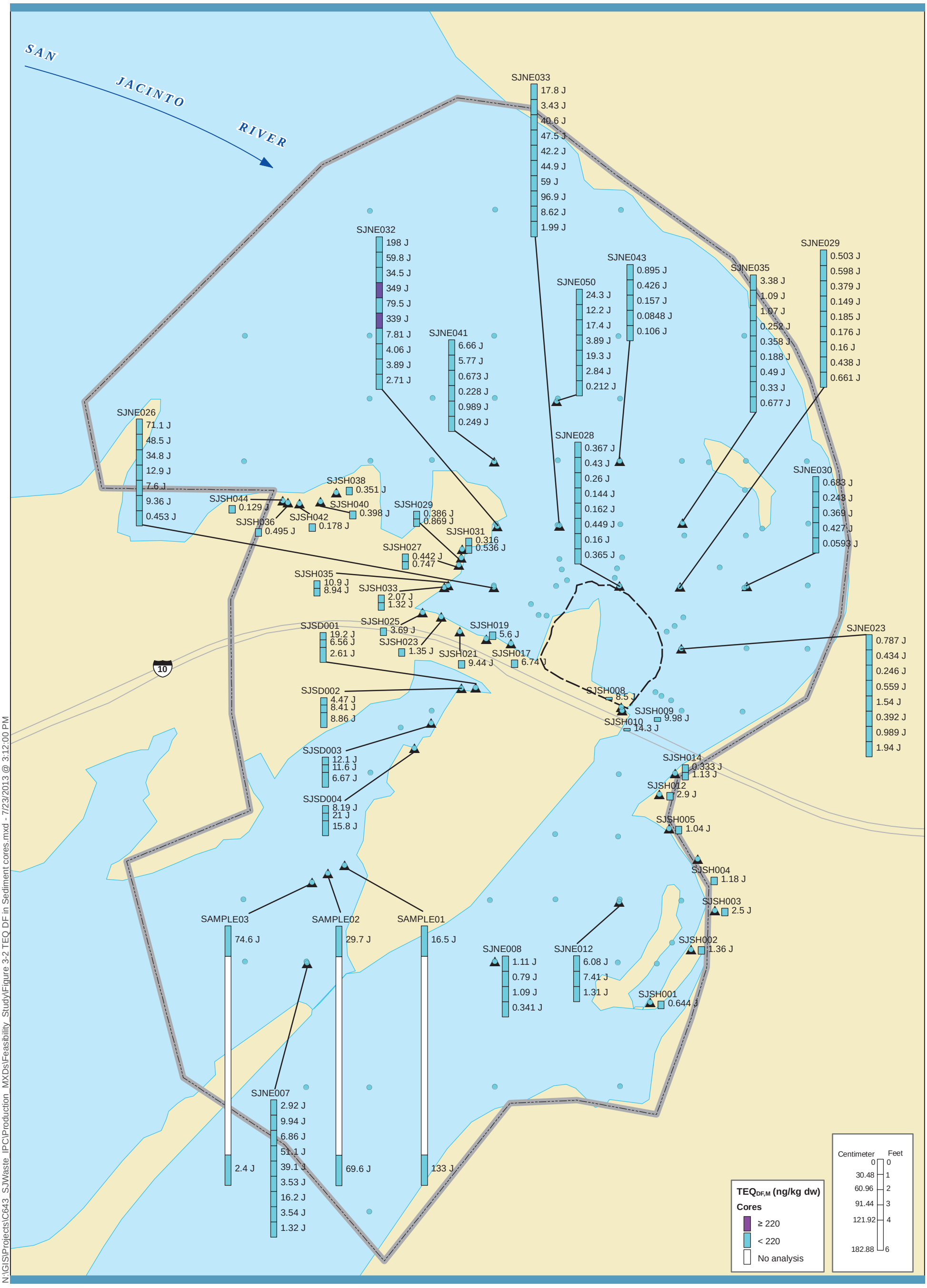

N:\GIS\Projects\C643_SJWaste_IPC\Production_MXDs\Feasibility_Study\Figure 3-2 TEQ DF in Sediment cores.mxd - 7/23/2013 @ 3:12:00 PM

ANCHOR QEA integral consulting inc

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

0 800
Scale in 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.

The sediment Protective Concentration Level for a hypothetical recreational visitor for $TEQ_{DF,M}$ is 220 ng/kg dry weight.

Figure 3-2
$TEQ_{DF,M}$ Concentrations in Sediment Cores
Compared to Hypothetical Recreational Visitor PCL
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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N:\GIS\Projects\C643_SJWaste_IPC\Production_MXDs\Feasibility_Study\Figure 3-3 TEQ DF in Surface Sediment_8202013.mxd - 8/22/2013 @ 4:37:20 PM

ANCHOR QEA integral consulting inc.

0 800
Feet

USEPA's Preliminary Site Perimeter
Limit of TCRA Cap
Soil Investigation Area 4
Surface Soil/Sediment Sample Location

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.

The soil/sediment Protective Concentration Level for a hypothetical future outdoor commercial worker for $TEQ_{DF,M}$ is 1,300 ng/kg dry weight (May 14, 2013, letter to USEPA).

Figure 3-3
$TEQ_{DF,M}$ Concentrations in Surface Soil/Sediment
Compared to Hypothetical Future Outdoor Commercial Worker PCL
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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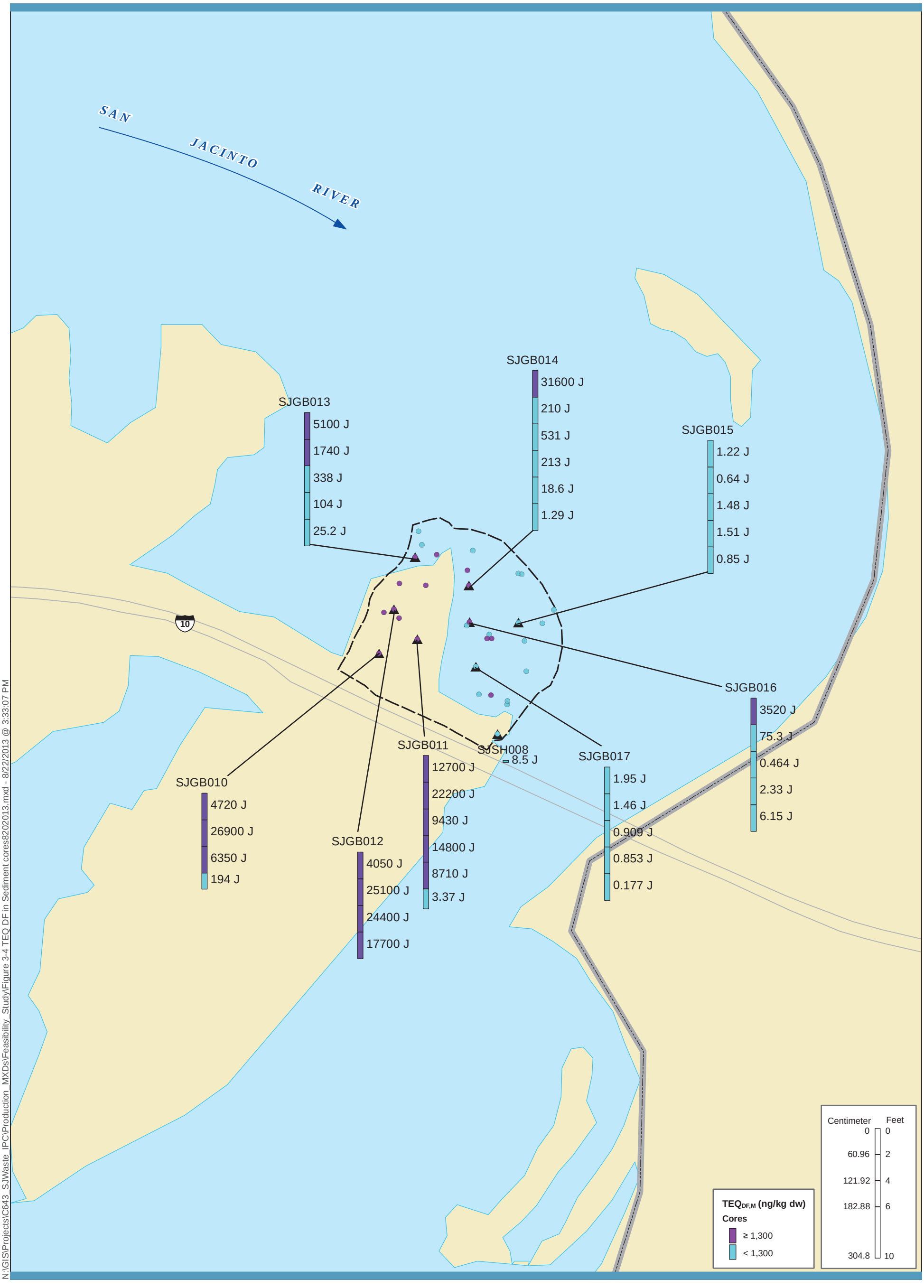

N:\GIS\Projects\C643_SJWaste_IPC\Production_MXDs\Feasibility_Study\Figure 3-4 TEQ DF in Sediment cores8202013.mxd - 8/22/2013 @ 3:33:07 PM

ANCHOR QEA integral consulting inc

USEPA's Preliminary Site Perimeter
Limit of TCRA Cap
Core Location
Surface Soil/Sediment Sample Location

0 800
Scale in 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.

The soil/sediment Protective Concentration Level for a hypothetical future outdoor commercial worker for $TEQ_{DF,M}$ is 1,300 ng/kg dry weight (May 14, 2013, letter to USEPA).

Figure 3-4
$TEQ_{DF,M}$ Concentrations in Soil/Sediment Cores
Compared to Hypothetical Future Outdoor Commercial Worker PCL
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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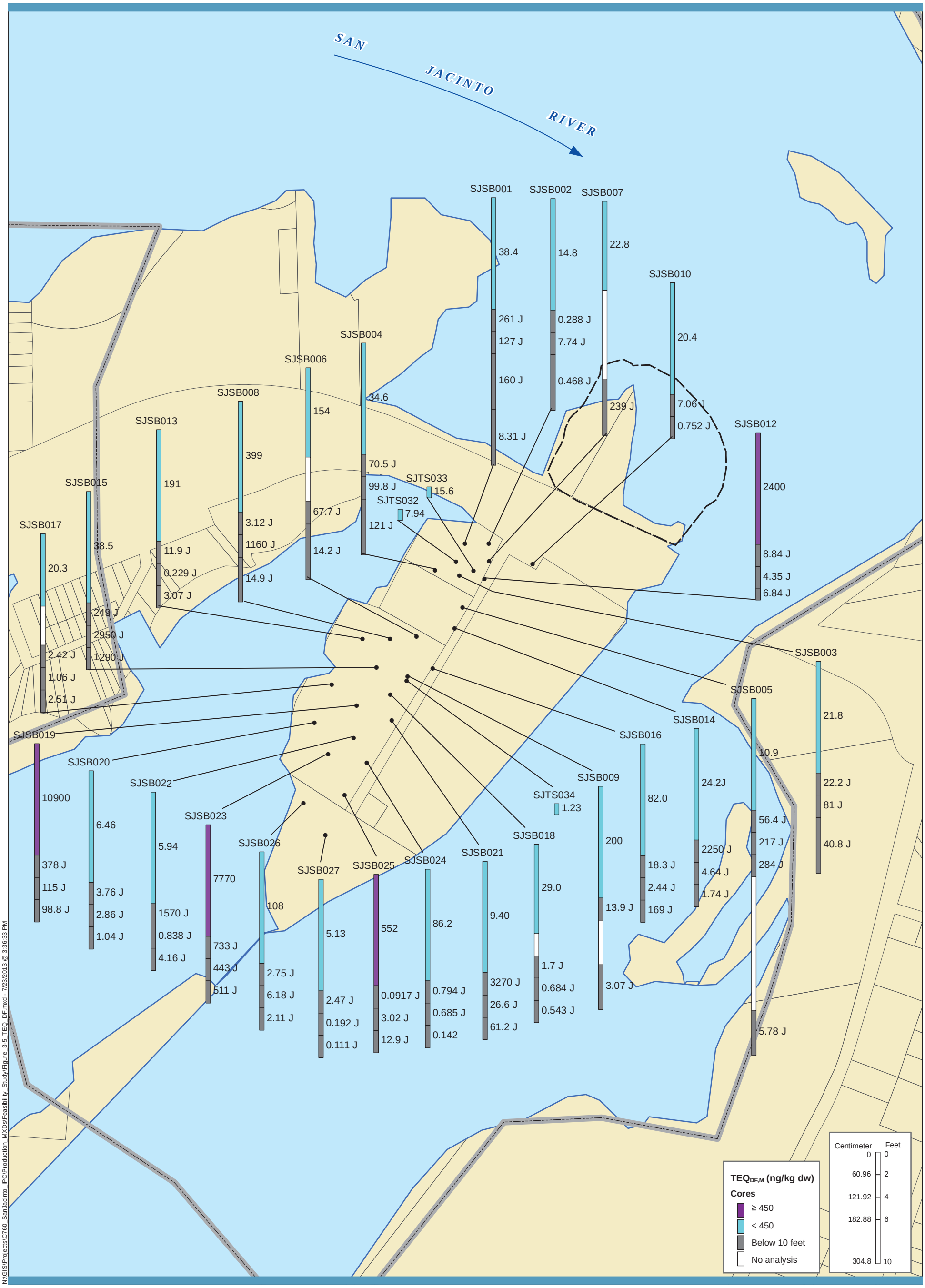

USEPA's Preliminary Site Perimeter

Limit of TCRA Cap

Soil Boring Location

0 400 Feet

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.

The soil Protective Concentration Level for a hypothetical future construction worker for $TEQ_{DF,M}$ is 450 ng/kg dry weight. Concentrations are averaged in the top 10 feet, consistent with risk assessment assumption.

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

Figure 3-5
$TEQ_{DF,M}$ Concentrations in Soil
Compared to Hypothetical Future Construction Worker PCL
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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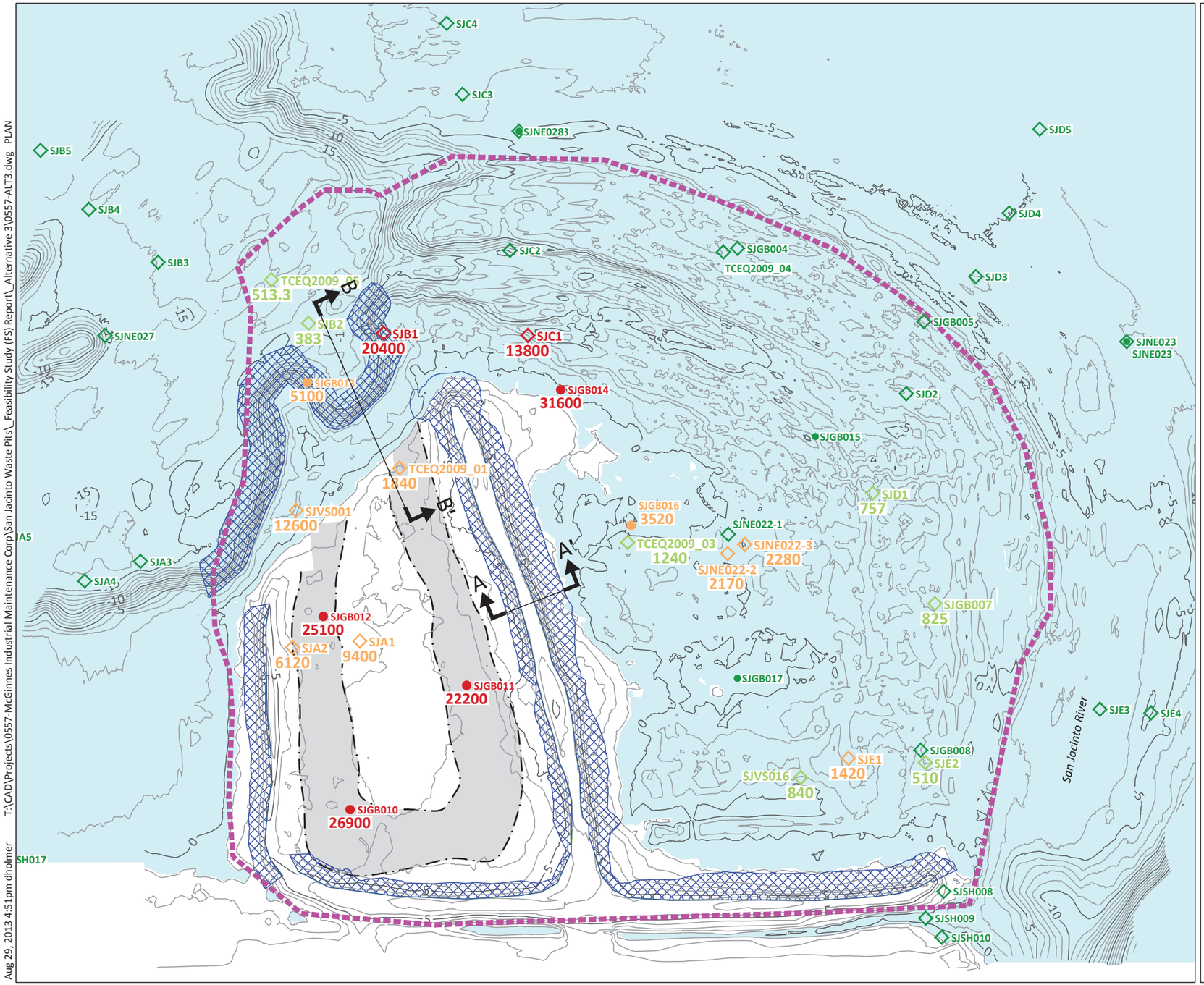
N:\GIS\Projects\C760_SanJacinto_IPC\Production_MXDs\Feasibility_Study\Figure_3-5_TEQ_DF.mxd - 7/23/2013 @ 3:36:33 PM



LEGEND:

- Existing Contour (1 Foot Interval)
- TCRA Cap Limit
- Area of Additional Rock Placement for Flattening Slopes to 5H:1V on berms and 3H:1V in the Northwest Area
- Area Below Mean Tide Level (0.83 Feet NAVD88)
- 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.

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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Aug 29, 2013 4:51pm dholmer

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

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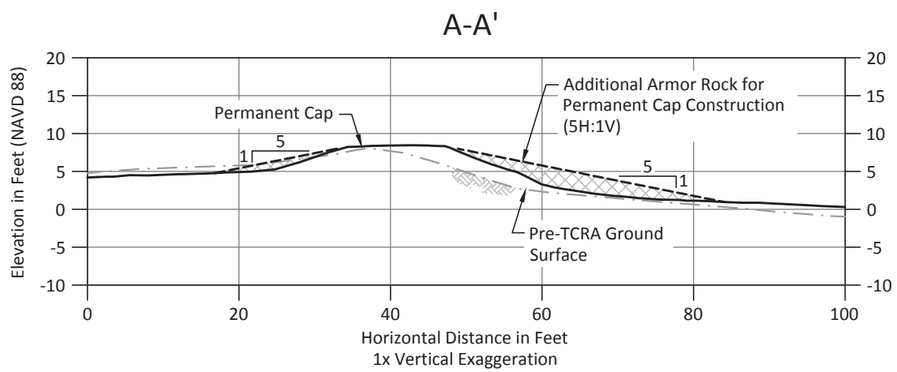

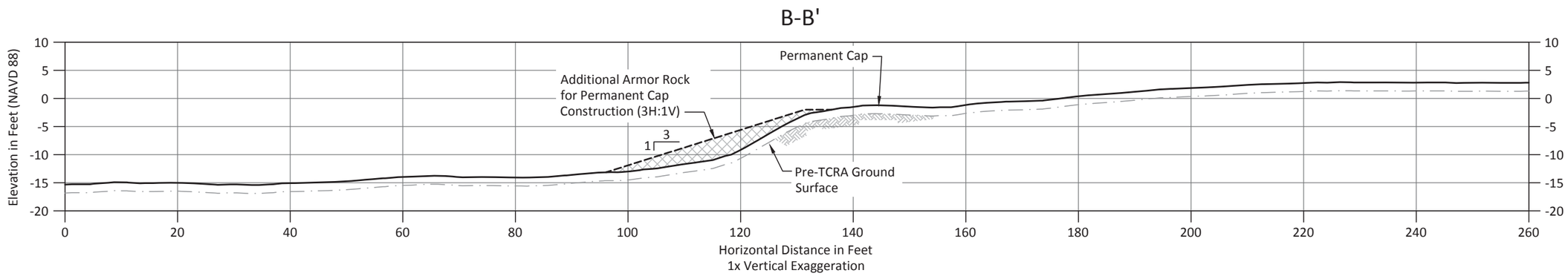

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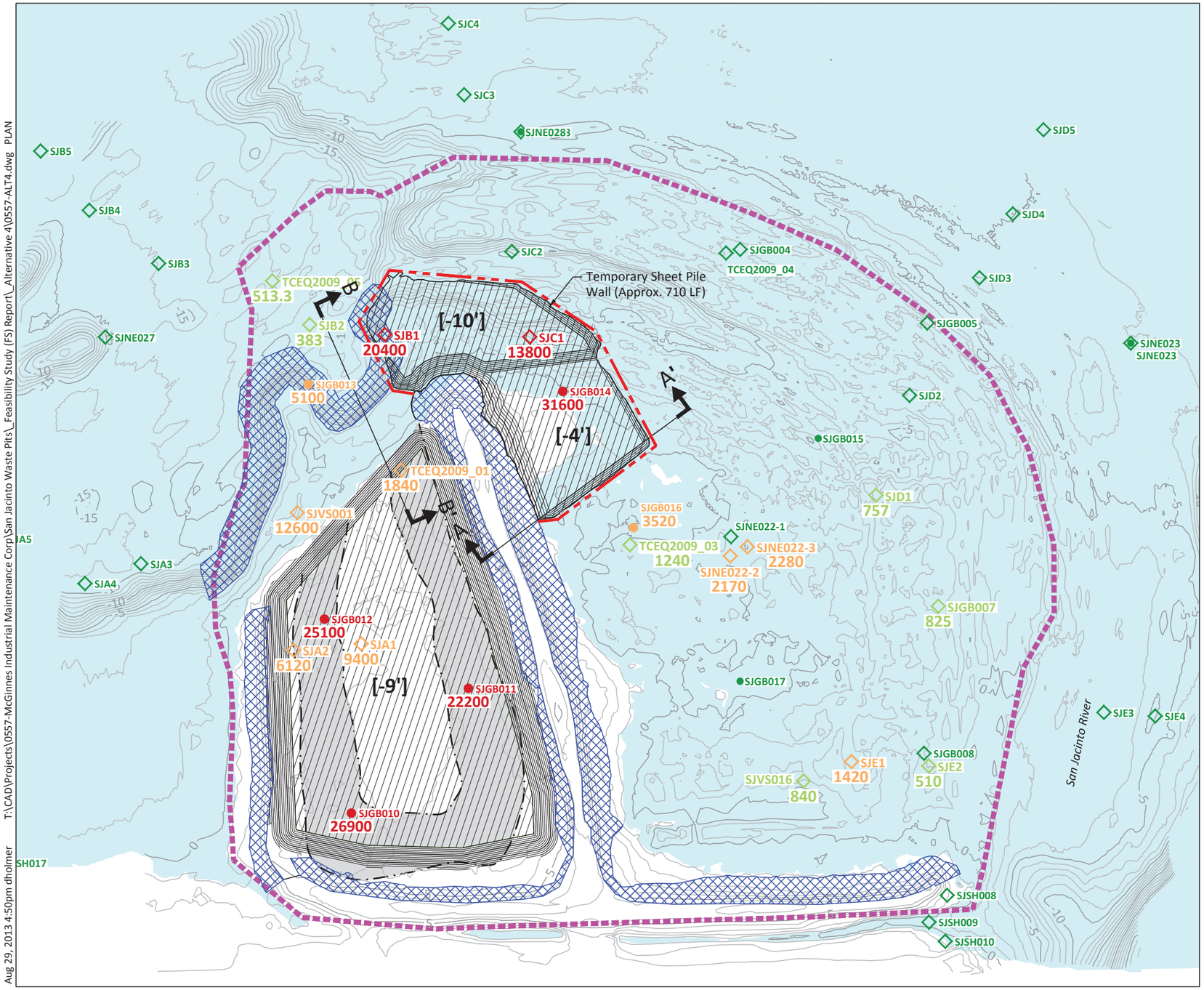
Figure 4-2
Cross Section A-A' - Alternative 3, Permanent Cap
Feasibility Study
San Jacinto River Waste Pits Superfund Site



LEGEND:

- Existing Contour (1 Foot Interval)
- [-4'] Target Solidification Elevation (NAVD 88)
- Solidification Area
- Temporary Sheet Pile Wall
- TCRA Cap Limit
- Area of Additional Rock Placement for Flattening Slopes to 5H:1V on berms and 3H:1V in the Northwest Area
- Area Below Mean Tide Level (0.83 Feet NAVD88)
- 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.

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

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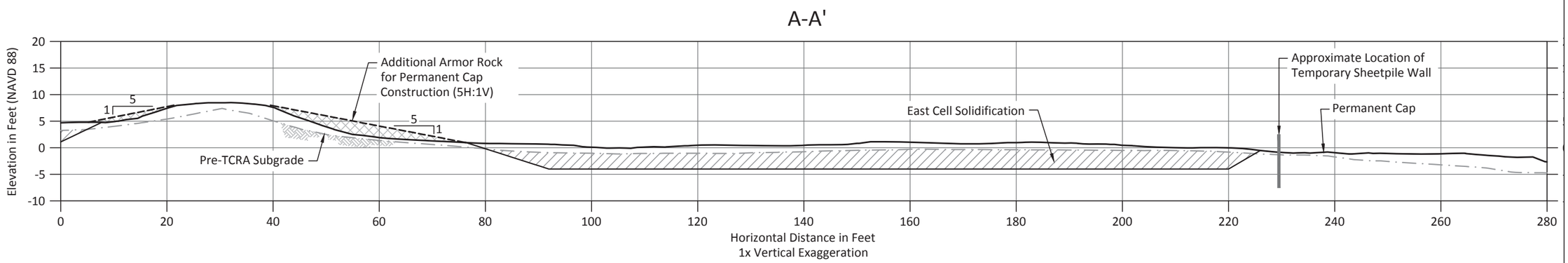

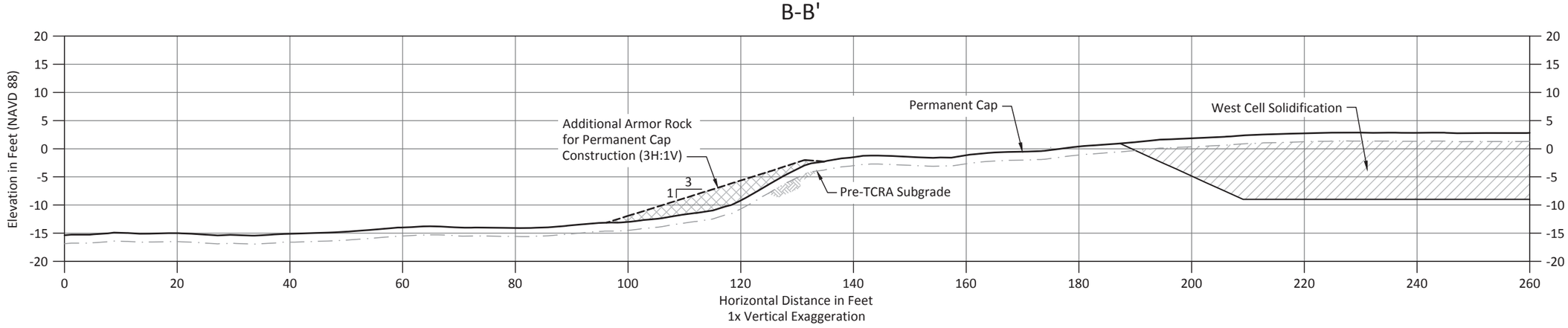

ANCHOR QEA

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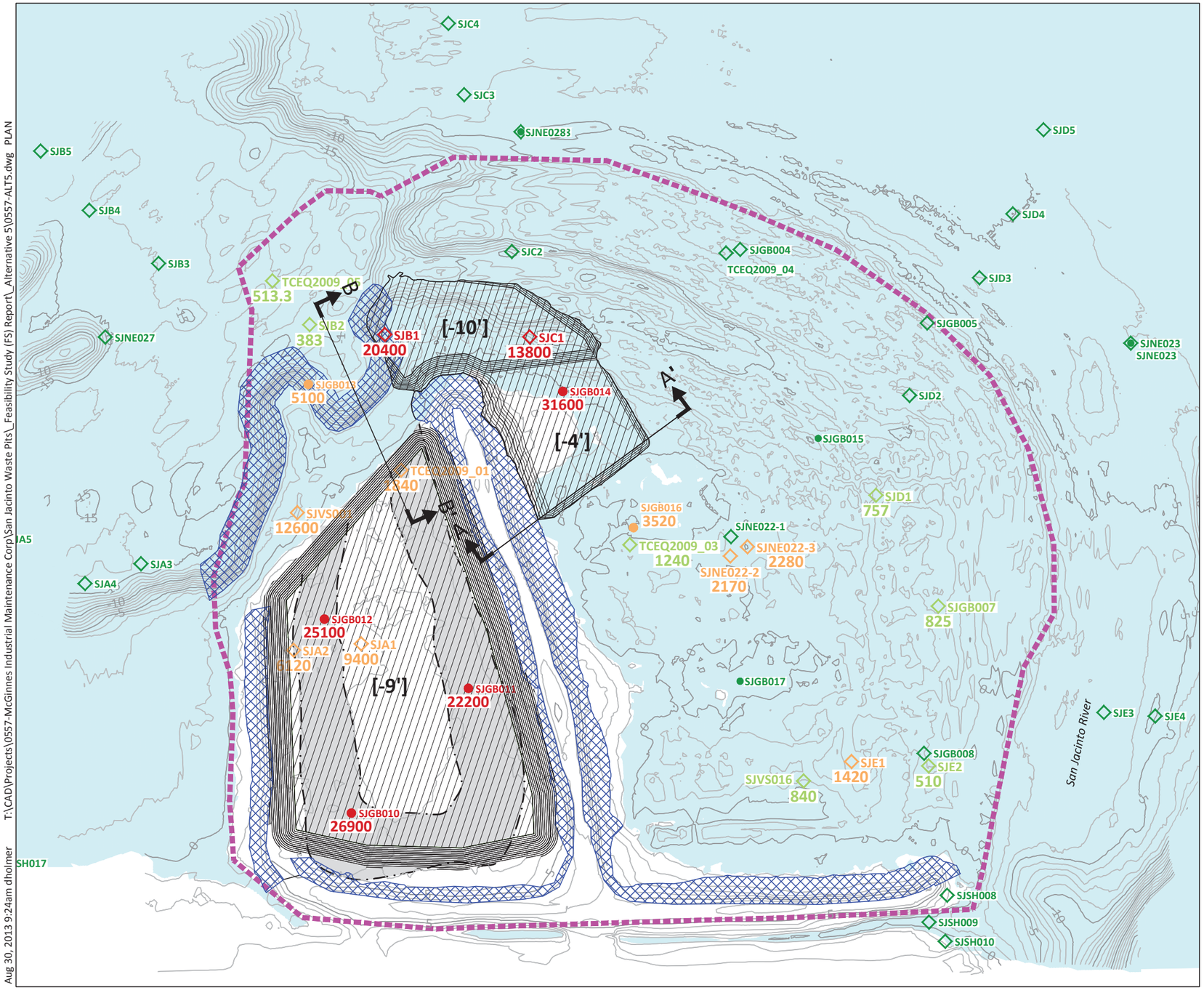
Figure 4-4
Cross Sections A-A' and B-B' - Alternative 4, Partial Solidification
Feasibility Study
San Jacinto River Waste Pits Superfund Site



LEGEND:

- Existing Contour (1 Foot Interval)
- [-4'] Target Cut Elevation (NAVD 88)
- Removal Area
- TCRA Cap Limit
- Area of Additional Rock Placement for Flattening Slopes to 5H:1V on berms and 3H:1V in the Northwest Area
- Area Below Mean Tide Level (0.83 Feet NAVD88)
- 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.

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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Aug 30, 2013 9:24am dholmer

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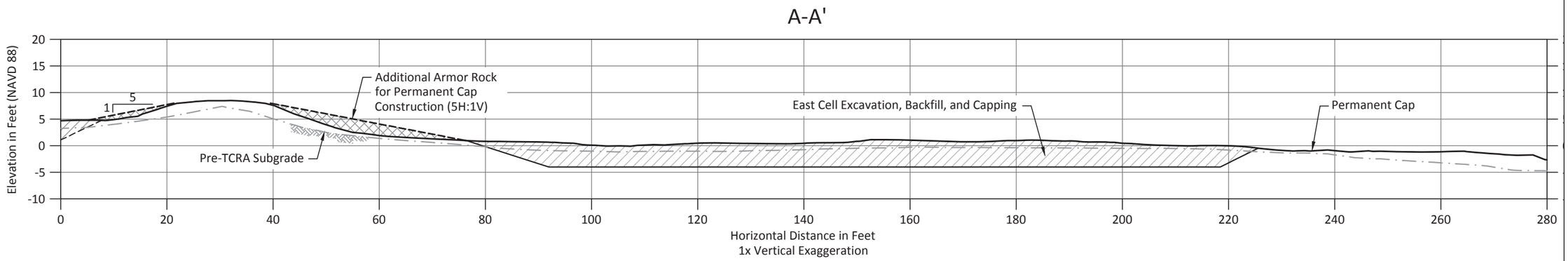
Figure 4-5
Plan View - Alternative 5, Partial Removal
Feasibility Study
San Jacinto River Waste Pits Superfund Site



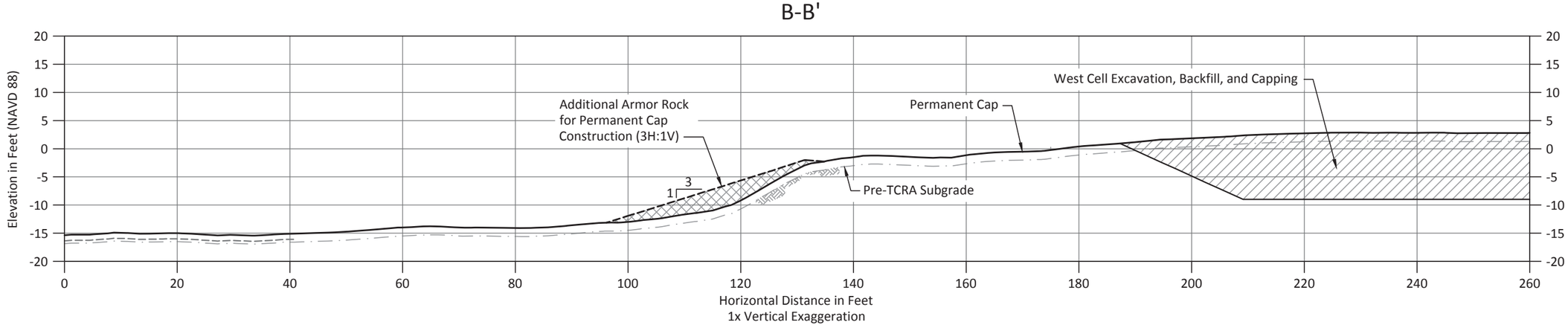


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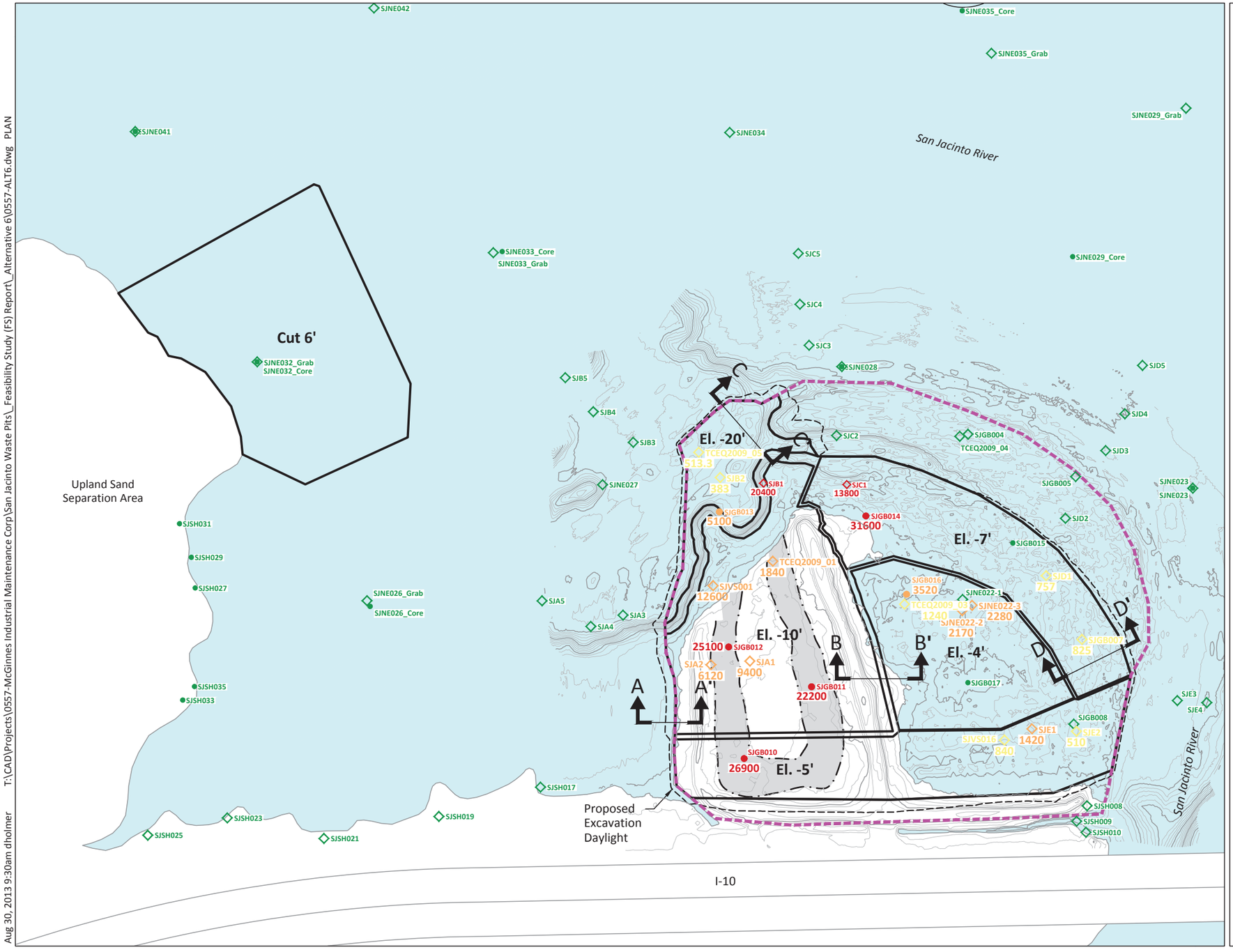
Figure 4-6
Cross Sections A-A' and B-B' - Alternative 5, Partial Removal
Feasibility Study
San Jacinto River Waste Pits Superfund Site



LEGEND:

- Existing Contour (1 Foot Interval)
- El. -10 — Target Cut Elevation (NAVD 88)
- TCRA Cap Limit
- TCRA Footprint of Stabilization
- Area Below Mean Tide Level (0.83 Feet NAVD88)
- 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.

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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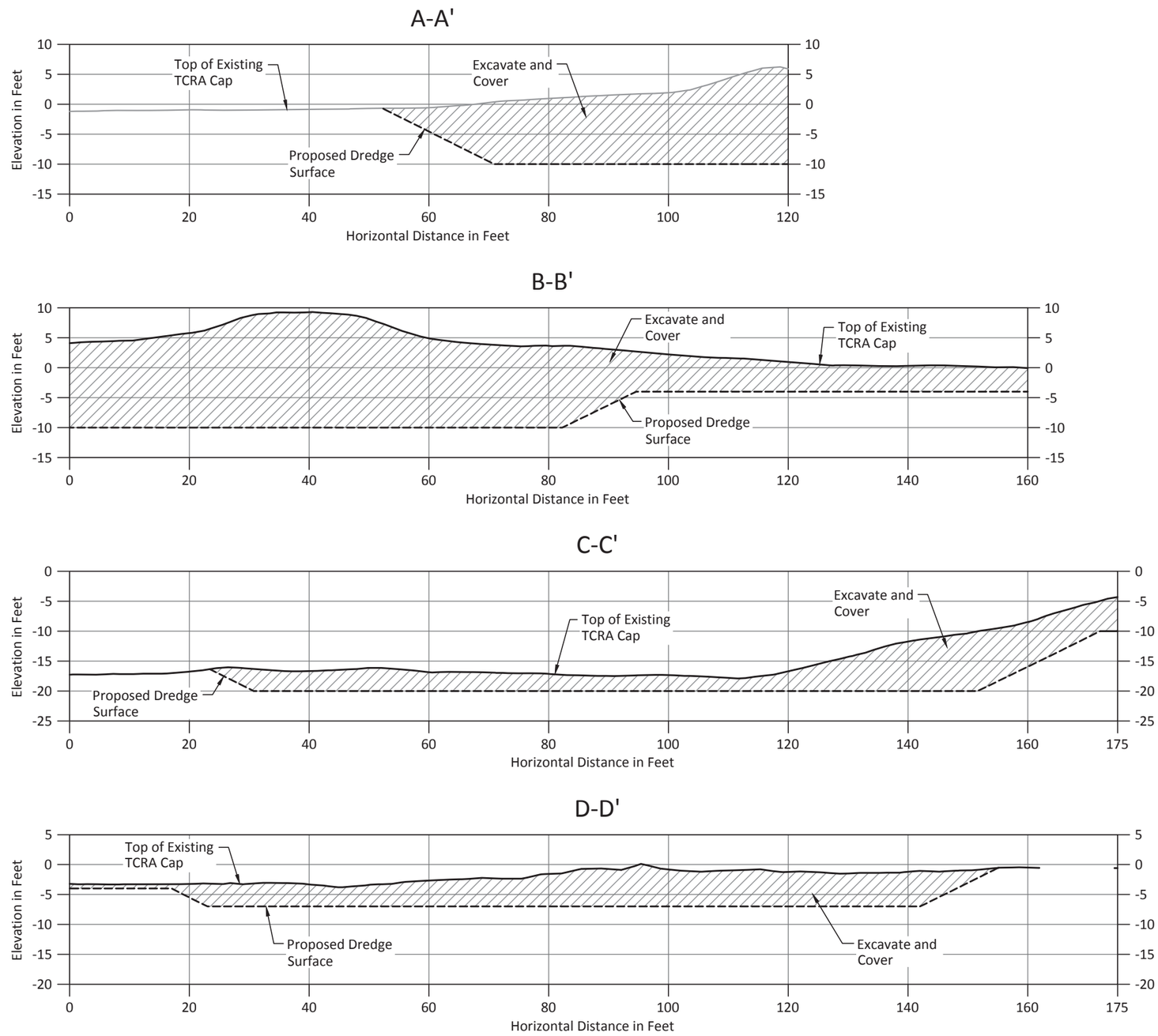
Figure 4-7
Plan View - Alternative 6, Full Removal
Feasibility Study
San Jacinto River Waste Pits Superfund Site



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ANCHOR QEA

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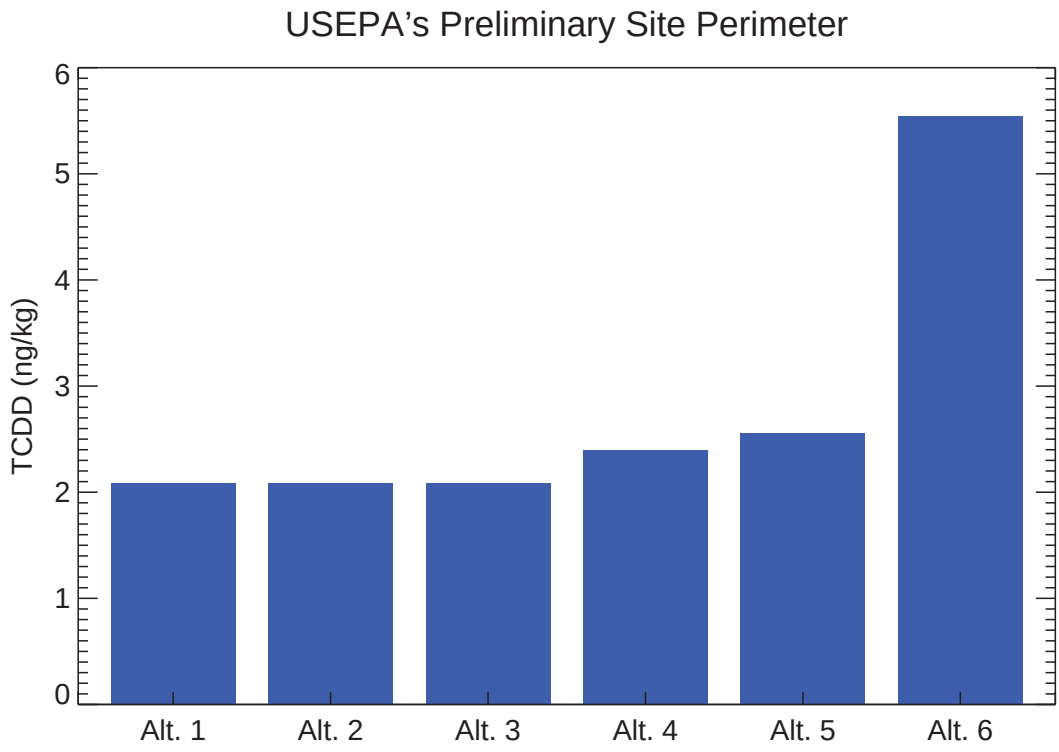
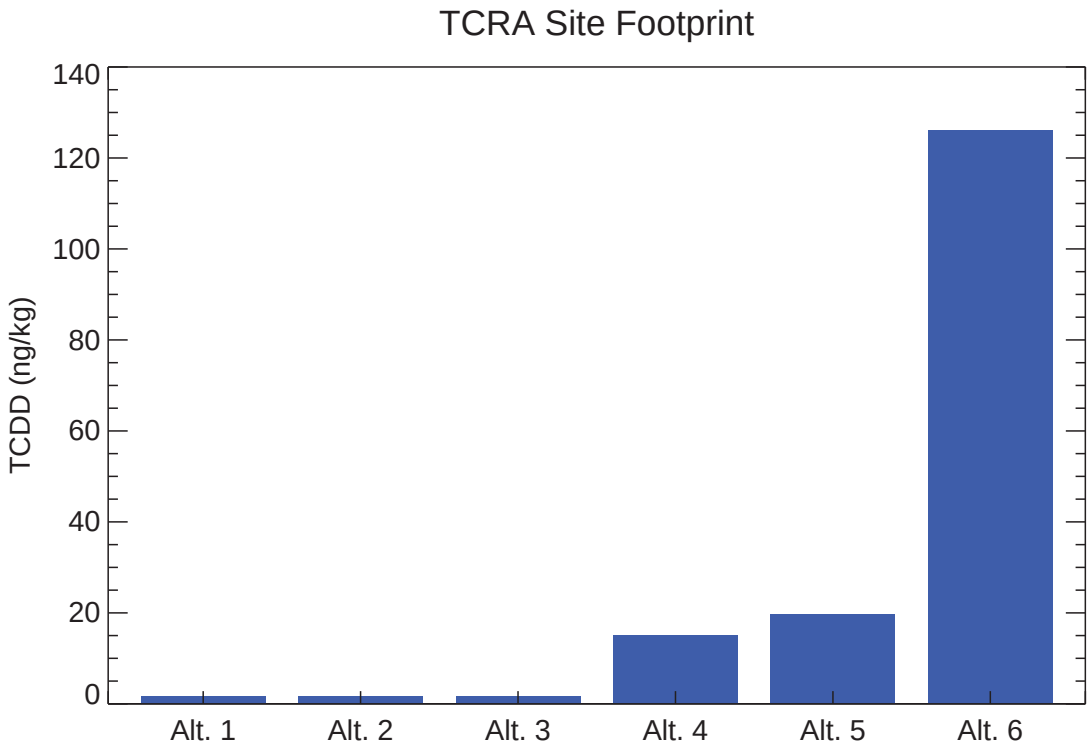
Figure 4-8
Cross Sections A-A', B-B', C-C', and D-D' - Alternative 6, Full Removal
Feasibility Study
San Jacinto River Waste Pits Superfund Site





Model Run: SJR_PROJ2_BC_TCDD_1301-06, SJR_PROJ2_BC_TCDD_1301-06, SJR_PROJ2_BC_TCDD_1301-06, SJR_PROJ3_BC_TCDD_1307-01, SJR_PROJ3_BC_TCDD_1307-02, SJR_PROJ3_BC_TCDD_1307-03

Figure 6-1a

Comparison of Model-Predicted Surface Sediment (top 6 inches) TCDD Concentrations in Year 21, Averaged over USEPA's Preliminary Site Perimeter and TCRA Site Footprint

Feasibility Study

San Jacinto River Waste Pits Superfund Site

ANCHOR QEA

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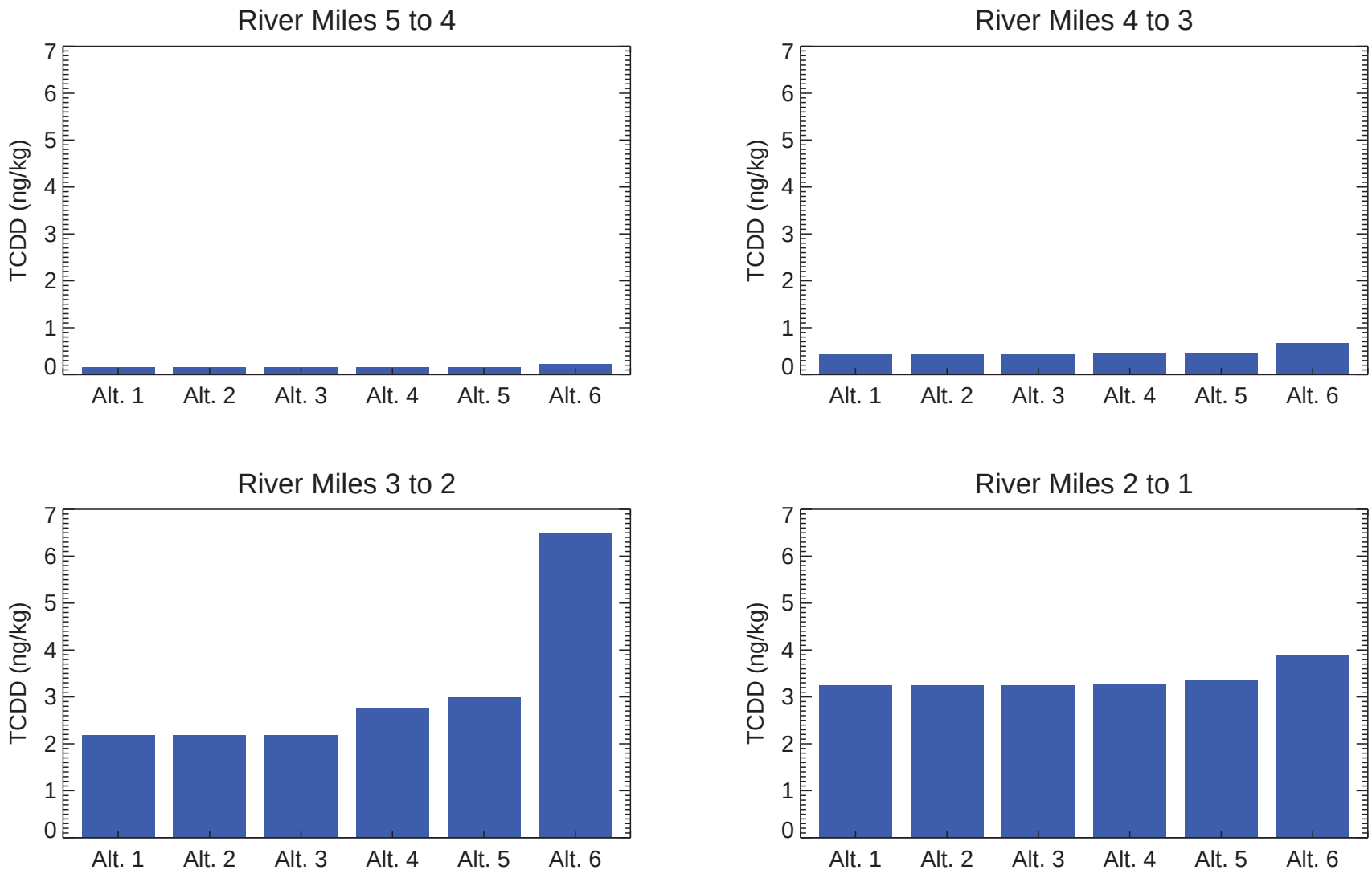

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Figure 6-1b

Comparison of Model-Predicted Surface Sediment (top 6 inches) TCDD Concentrations in Year 21, Averaged by River Mile
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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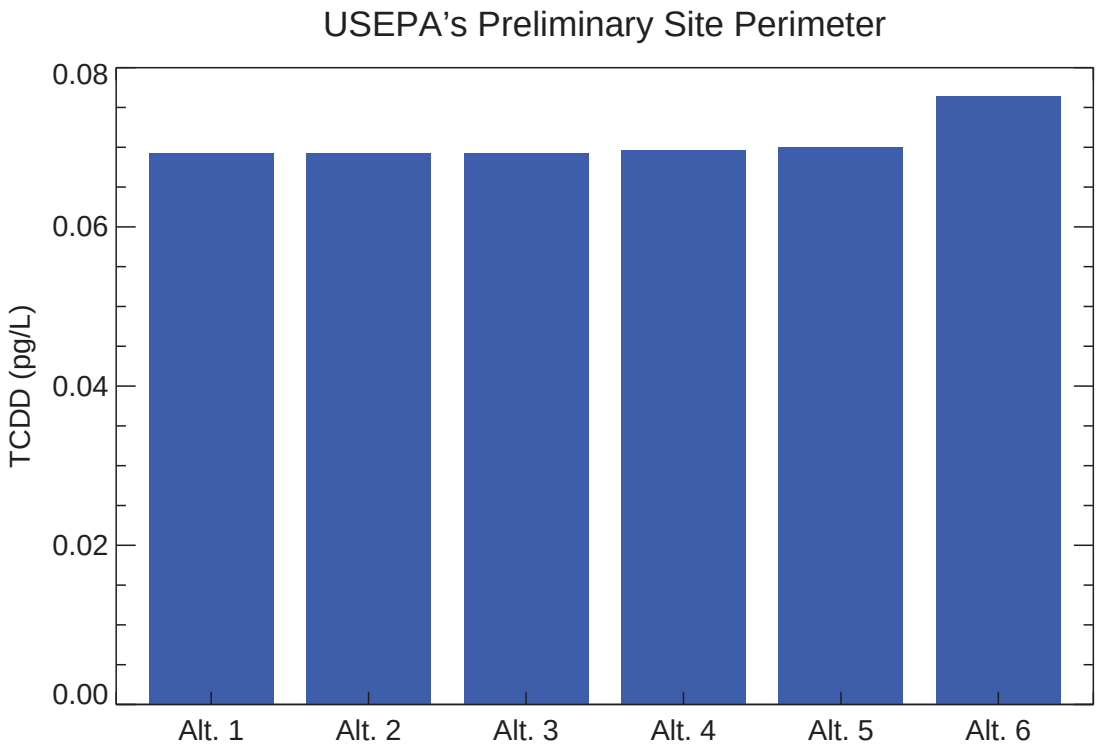

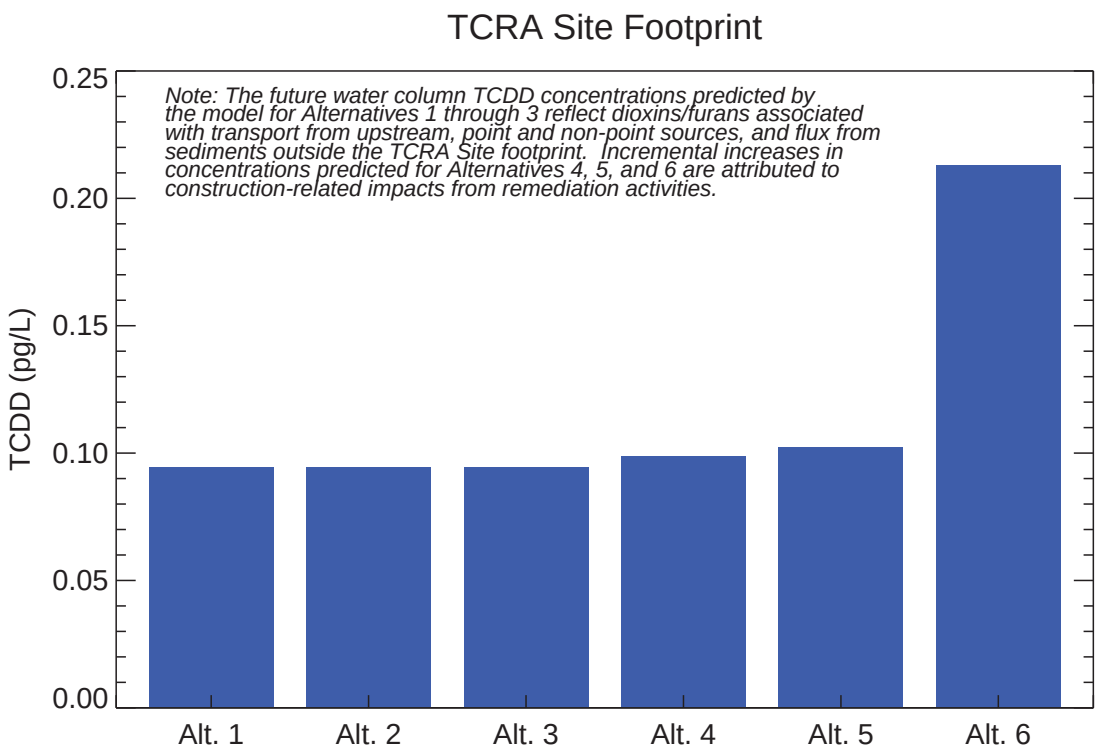

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Figure 6-2

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Feasibility Study

San Jacinto River Waste Pits Superfund Site

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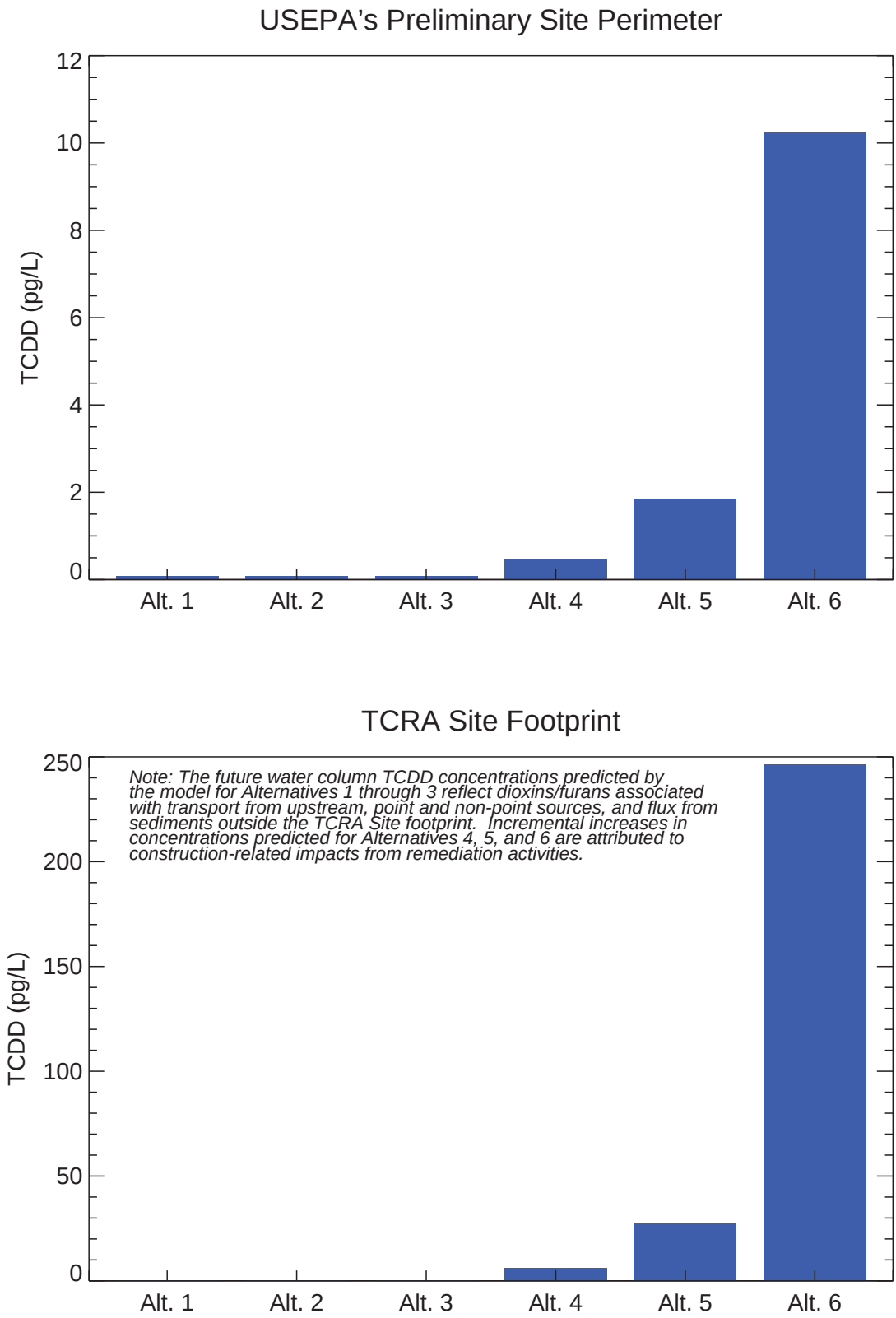

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Figure 6-3

Comparison of Model-Predicted Annual Average Water Column TCDD Concentrations (Year 1) over USEPA's Preliminary Site Perimeter and TCRA Site Footprint

Feasibility Study

San Jacinto River Waste Pits Superfund Site

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APPENDIX A: CHEMICAL FATE AND TRANSPORT MODELING

SAN JACINTO RIVER WASTE PITS SUPERFUND SITE

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Attachment 1 Complete Set of Model Output Graphics for TCDD and TCDF

LIST OF ACRONYMS AND ABBREVIATIONS

Anchor Environmental	Anchor Environmental, LLC
Anchor QEA	Anchor QEA, LLC
cfs	cubic feet per second
cm	centimeter
D_{50}	median particle diameter
FS	Feasibility Study
HSC	Houston Ship Channel
IC	institutional control
Integral	Integral Consulting Inc.
MNR	monitored natural recovery
MT	metric tons
ng/kg	nanograms per kilogram
NOAA	National Oceanic and Atmospheric Administration
NSR	net sedimentation rate
OCDD	octachlorodibenzo-p-dioxin
PCL	Protective Concentration Level
RI	Remedial Investigation
Site	San Jacinto River Waste Pits Superfund Site
SJRF	San Jacinto River Fleet
S/S	solidification/stabilization
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TCDF	2,3,7,8-tetrachlorodibenzofuran
TCEQ	Texas Commission on Environmental Quality
TCRA	Time Critical Removal Action
TEQ	toxicity equivalent
TMDL	total maximum daily load
TOC	total organic carbon
USEPA	U.S. Environmental Protection Agency
WSE	water surface elevation

1 INTRODUCTION

This appendix to the Feasibility Study (FS) for the San Jacinto River Waste Pits Superfund Site (Site) describes chemical fate and transport modeling that was performed in support of the FS. The models used in this effort are summarized in Section 1.1, and the specific evaluations conducted for the FS are introduced in Section 1.2.

1.1 Background on the Chemical Fate and Transport Modeling Study

The Chemical Fate and Transport Modeling Study report (Anchor QEA 2012a) was submitted for U.S. Environmental Protection Agency (USEPA) review in February 2012, and USEPA comments were addressed in a draft final report submitted on July 18, 2012. USEPA approved the report with certain modifications in a letter dated September 12, 2012 (Miller 2012, pers. comm.).[1] The document was modified accordingly, and the final report was submitted to USEPA on October 11, 2012 (Anchor QEA 2012a).

1.1.1 Study Objectives

The primary goal of the Chemical Fate and Transport Modeling Study (Anchor QEA 2012a) was to simulate physical and chemical processes governing chemical fate and transport of selected dioxins and furans in the aquatic environment within the USEPA's Preliminary Site Perimeter, which is shown on Figure 1-1. The primary objectives of the chemical fate and transport analysis were three-fold, as follows:

- Develop conceptual site models for sediment transport and chemical fate and transport
- Develop and apply quantitative methods (i.e., computer models) that can be used to evaluate the effectiveness of various remedial alternatives during the FS
- Address specific questions about sediment transport and chemical fate and transport processes within the USEPA's Preliminary Site Perimeter

Given that any model has some amount of uncertainty associated with its predictions, results from the chemical fate and transport modeling are used in the FS to provide relative comparisons between the outcomes of the various remedial alternatives being evaluated.

[1] In that letter, USEPA also required that additional model sensitivity analyses be performed as part of the FS.

Specific predictions of chemical concentrations in sediment and water do not represent actual measures of sediment or water quality during the time period being modeled.

1.1.2 Model Framework and Model Study Area

The fate and transport modeling is based on three linked models that simulate hydrodynamics, sediment transport, and chemical fate and transport (Figure 1-2). The hydrodynamic model simulates temporal and spatial changes in water depth, current velocity, and bed shear stress in the San Jacinto River. This information is transferred from the hydrodynamic model to the sediment transport model, which is used to simulate the erosion, deposition, and transport of sediment in the San Jacinto River. The sediment transport model is used to simulate temporal and spatial changes in suspended sediment concentrations in the water column and bed elevation changes (i.e., bed scour depth and net sedimentation rate [NSR]). The results from the hydrodynamic and sediment transport models are transferred to the chemical fate and transport model, which calculates spatial and temporal variations of dioxin and furan concentrations in the water column and sediment bed. Specifically, the chemical fate processes represented by the model include the following:

- *Sediment-water interactions* – Particulate-associated dioxins and furans within the sediment bed enter the water column in cases where erosion of the surface layer occurs, and chemicals being transported in the water column can likewise deposit on the bed.
- *Partitioning and dissolved phase flux* – Dioxins and furans within the surface layer of the sediment bed are also present in the dissolved phase due to partitioning processes. In some cases, the resulting porewater concentrations can be greater than those in the overlying water column. Such a concentration gradient, through the process of surface exchange flux (due to diffusion, bioturbation, and tidal pumping), can result in a transfer of dissolved-phase mass to the water column that in turn can affect concentrations in the river under low-flow conditions.
- *Transport in the water column* – Dissolved and particulate phase dioxins and furans that are present in the water column from a variety of sources, including atmospheric deposition, upstream sources, point sources such as waste water treatment outfalls, and sediments within the area, are transported with the currents, which are affected

by freshwater flow in addition to more complex circulation patterns associated with the tides.

- *Inputs from external sources* – As described above, dioxins and furans can enter the aquatic environment from the sediment bed and external sources. The Texas Commission on Environmental Quality's dioxin Total Maximum Daily Load (TMDL) study[2] (University of Houston and Parsons 2006) detected dioxins and furans in samples of outfalls and surface runoff, and in dry and wet atmospheric deposition samples that were collected adjacent to the San Jacinto River and in areas within the USEPA's Preliminary Site Perimeter. These inputs represent external sources to the Model Study Area, and are accounted for and reflected in the results of the fate and transport modeling presented below.

The model's predictions reflect the processes described above using a mass balance approach; as such, its predictions of surface water concentrations reflect sources from upstream, point and non-point sources, flux from sediments, and transport throughout the Model Study Area.

For the purposes of chemical fate and transport modeling, the Model Study Area is defined as the San Jacinto River from the Lake Houston Dam to the Houston Ship Channel (HSC; Figure 1-1). This Model Study Area was selected so that appropriate boundary conditions are utilized in the numerical models, which was needed to produce reliable predictions within the USEPA's Preliminary Site Perimeter.[3] The resolution of model grid cells is spatially variable, with high resolution (i.e., smaller grid cells) in the region near the impoundments north of Interstate 10 (Northern Impoundments), which is the area that underwent a Time Critical Removal Action (TCRA) and is hereafter referred to as the TCRA Site.

1.1.3 Model Development and Calibration

Model development and calibration was described in the Chemical Fate and Transport Modeling Study report (Anchor QEA 2012a). A brief summary is provided below.

[2] http://www.tceq.texas.gov/waterquality/tmdl/26-hscdioxin.html

[3] The hydrodynamic model also simulates a portion of the HSC in order to properly represent tidal exchange at the confluence with the San Jacinto River (see Anchor QEA 2012a for details).

Development of the hydrodynamic model consisted of specifying the following inputs: 1) bathymetry and geometry; 2) freshwater inflow at the upstream boundary at the Lake Houston Dam; 3) freshwater inflow at the various bayous discharging into the simulated portion of the HSC; and 4) water surface elevation (WSE) at the downstream boundary (i.e., near the confluence of the San Jacinto River and the HSC). Data obtained from historical sources or collected as part of this study were used to determine these model inputs. The hydrodynamic model was calibrated using current velocity and WSE data collected at two locations in the Model Study Area during 2010 and 2011. Daily average WSE data collected at the U.S. 90 Bridge during a 14-year period (1997 to 2010) were used for additional validation of model performance over a wide range of flow conditions in the river. Overall, the calibration and validation results demonstrate that the model is able to sufficiently simulate the hydrodynamics within the Model Study Area to meet the objectives of this study.

The sediment transport model was developed based on Model Study Area-specific information on sediment properties (e.g., grain size distribution, bulk density), bed properties (e.g., mapping of cohesive and non-cohesive bed areas), and boundary conditions (e.g., sediment load passing Lake Houston Dam and incoming load during flood tide at the downstream boundary near the confluence of the San Jacinto River and the HSC). The calibration period for the sediment transport model was the 21-year period from 1990 through 2010. The sediment transport model was calibrated to measurements of long-term NSR estimated from radioisotope cores collected at ten locations within the Model Study Area. Overall, the report concluded that the model predicted NSRs with reasonable accuracy. The general pattern of net sedimentation predicted by the model is qualitatively consistent with known characteristics of the Model Study Area. At small spatial scales (e.g., single grid cell), the model uncertainty is higher; however, as the spatial scale increases, the uncertainty in the model's predictive capability decreases. This trend (i.e., decreasing uncertainty in model reliability with increasing spatial scale) is consistent with sediment transport models developed at other sites that have been successfully calibrated and used as a management tool.

The chemical fate and transport model was developed for three dioxin and furan congeners (2,3,7,8-tetrachlorodibenzo-p-dioxin [TCDD], 2,3,7,8-tetrachlorodibenzofuran [TCDF], and

octachlorodibenzo-p-dioxin [OCDD]). Parameters describing the various processes simulated by the fate model (described above) were developed based on available Model Study Area data (e.g., dioxin and furan concentrations in sediment and surface water), information generated as part of the TMDL study (e.g., loads associated with permitted outfalls, atmospheric deposition, and surface runoff), and literature (e.g., depth and rate of sediment bioturbation and surface porewater exchange coefficients). The chemical fate model was developed and calibrated using surface water and sediment bed data collected between 2002 and 2010 prior to the TCRA; the number of samples is summarized in Table 1-1 below.

Table 1-1
Summary of Water Column and Sediment Data Used to Develop and Calibrate Fate and Transport Model

Program	Years	Number of Locations	Number of Samples
TMDL surface water[1]	2002 – 2004	6[2]	34[2]
TCEQ surface water	2009	2[2]	3[2]
TMDL sediment	2002 – 2005	70	70
TCEQ et al. sediment[3]	2009	18	19
RI sediment	2010	162	170

Notes:
[1] Each TMDL water column sample was analyzed separately for dissolved- and particulate-phase dioxins/furans.
[2] Only one of the TMDL surface water sample locations (nine total samples) was located within the USEPA's Preliminary Site Perimeter (outside the perimeter of the Northern Impoundments). The 2009 TCEQ surface water samples were all collected from within the perimeter of the Northern Impoundments. As shown in the table above, the data available for surface water were more limited than those for sediment, especially post-2004.
[3] 2009 sediment data were collected by TCEQ and others
RI – Remedial Investigation
TCEQ – Texas Commission on Environmental Quality
TMDL – total maximum daily load

The chemical fate model was shown to provide a good representation of spatial gradients in water column dioxin and furan concentrations (on a whole-water basis) across the Model Study Area.[4] The model also simulated the spatial patterns and differences between particulate- and dissolved-phase water column concentrations within the Model Study Area.

[4] Model predictions of water concentrations are not equivalent to actual measurements, and verification of model predictions is limited by data availability as noted above.

With respect to surface sediment concentrations, for which much more empirical data are available for comparison (Table 1-1), the chemical fate model predicted a decline in surface sediment concentrations within the area surrounding the USEPA's Preliminary Site Perimeter over the period from 2005 to 2010 that is within a factor of 2.5 of the decline estimated from data-based evaluations presented in the *Chemicals of Potential Concern Technical Memorandum* (Integral 2011); these results are considered consistent when uncertainties associated with both the data and model are taken into account.

Overall, the modeling framework summarized above provides a useful management tool for evaluating remedial alternatives in the FS. It integrates the large body of Model Study Area data into a quantitative, objective framework. The models were calibrated to several datasets covering varying spatial and temporal scales, and were shown to provide a good representation of hydrodynamics, sediment transport, and chemical fate and transport within the Model Study Area, subject to the above-described data limitations.

It should be noted that the model summarized above was developed and calibrated based on data collected prior to implementation of the TCRA in 2010 and 2011. The TCRA was implemented to stabilize soils/sediments within the original 1966 perimeter berm of the TCRA Site to prevent the release of dioxins and furans and other chemicals of potential concern to the environment (Anchor QEA 2011a) by installation of an armor rock cap that in most areas was placed atop a geotextile bedding layer (as well as a geomembrane cover layer in certain portions of the area). The effect of the TCRA on fate and transport of dioxins and furans in the Model Study Area is evaluated by the modeling presented in this appendix.

1.2 Application of the Model in the Feasibility Study

As part of the FS, the model was used to develop estimates of future dioxin and furan concentrations in sediment and surface water within the Model Study Area. The specific FS model applications presented in this appendix included the following:

- Long-term future simulations were first conducted for current (post-TCRA) conditions (i.e., starting from contemporary sediment concentrations within the USEPA's Preliminary Site Perimeter, and reflecting the presence of the cap at the TCRA Site). These simulations served two purposes for the FS. First, the model was

used to provide estimates of the effects of the TCRA on surface water concentrations of select dioxin and furan congeners within the Model Study Area. Second, these simulations also provide estimates of rates of natural recovery (i.e., reductions in surface sediment dioxin and furan concentrations over time) in various portions of the Model Study Area in the absence of any remedial action beyond the current TCRA armored cap. These simulations, therefore, apply to the No Further Action alternative (Alternative 1), as well as two other alternatives evaluated in the FS: Alternative 2 (institutional controls [ICs] and monitored natural recovery [MNR]) and Alternative 3 (ICs and MNR plus construction of a permanent cap). For both of these evaluations (i.e., predictions of the effects of the TCRA on surface water concentrations and predictions of natural recovery rates), simulations were also conducted with alternate sets of model input parameters to develop uncertainty bounds on the predictions.

- Simulations were also conducted of Alternatives 4, 5, and 6, which include active remediation of soil/sediments within the TCRA Site, as well as sediments exceeding Protective Concentration Levels (PCLs) from another area within the USEPA's Preliminary Site Perimeter in the case of Alternative 6. In addition to evaluating general long-term trends for these alternatives, the model's predictions of relative future sediment and water column dioxin and furan concentrations from these simulations were also used to quantify potential short- and long-term impacts associated with the construction activities (i.e., sediment resuspension and release during remediation and effects of dredge residuals).

1.3 Appendix Organization

The remainder of this appendix is organized as follows. Section 2 describes sensitivity analyses that were performed with the hydrodynamic and sediment transport models at the request of USEPA in its letter approving the draft final Chemical Fate and Transport Modeling Study report (Miller 2012, pers. comm.). Section 3 presents long-term simulations of post-TCRA future conditions conducted with the model, including a discussion of the model setup, model results, and uncertainty analyses associated with use of the model to: 1) evaluate the impacts of the TCRA on estimated surface water concentrations; and 2) predict future surface sediment concentrations and estimated rates of natural recovery. Section 4

documents the model simulations used to evaluate the remedial alternatives; it compares the estimated rates of natural recovery from the post-TCRA future simulation, which is representative of Alternatives 1 through 3, with results from model simulations of the active soil/sediment remediation alternatives (Alternatives 4 through 6). A summary of this appendix is presented in Section 5, and reference citations are contained in Section 6.

2 HYDRODYNAMIC AND SEDIMENT TRANSPORT MODEL SENSITIVITY ANALYSES

In response to USEPA's request for additional hydrodynamic and sediment transport model sensitivity analyses in its conditional approval letter for the draft final Chemical Fate and Transport Modeling Study report (Miller 2012, pers. comm.), a series of simulations was conducted to evaluate sediment deposition and erosion during high-flow events and evaluate the sensitivity of model predictions to WSE at the downstream boundary.

2.1 Evaluation of Deposition and Erosion during High-Flow Events

The calibrated hydrodynamic and sediment transport models (Anchor QEA 2012a) were used to simulate sediment transport processes in the San Jacinto River during high-flow events. A range of high-flow conditions, from 2- to 100-year events, were investigated, with the objective of answering the following questions:

- What portions of the Model Study Area are depositional and what areas experience erosion during a given high-flow event?
- What are the depths of net deposition and erosion during a given high-flow event?

High-flow events with return periods of 2, 10, and 100 years were evaluated during this analysis. The probability of a high-flow event occurring in any given year is 50 percent, 10 percent, and 1 percent for return periods of 2, 10, and 100 years, respectively. Peak flow rates at Lake Houston Dam for the three high-flow events evaluated in this analysis are listed in Table 2-1. The peak flow rates for these flood simulations were determined from a flood frequency analysis that was performed using historical flow rate data collected at Lake Houston Dam (see Section 3.3.1 of Anchor QEA 2012a). Incoming sediment loads to the San Jacinto River at the dam during the flood simulations were estimated using the methodology described in Section 4.2.3 of Anchor QEA (2012a).

Table 2-1
Peak Flow Rates and Sediment Loads at Lake Houston Dam for High-Flow Event Simulations

Return Period (years)	Peak Flow Rate (cfs)	Total Sediment Load (MT)
2	38,400	56,600
10	126,000	324,000
100	372,000	1,620,000

Notes:
cfs – cubic feet per second
MT – metric tons

Simulating sediment transport in the San Jacinto River during a high-flow event requires specifying time-variable inflow at both the Lake Houston Dam and the HSC boundary tributaries (i.e., high-flow hydrographs). At the Lake Houston Dam inflow boundary, the hydrograph that occurred during the high-flow event in October 1994 was chosen. This flood had a peak flow rate of approximately 356,000 cubic feet per second (cfs) measured in the San Jacinto River at the U.S. Geological Survey gauging station located at the U.S. 90 Bridge near Sheldon, Texas, representing a return period of between 50 and 100 years. The hydrographs for the specific high-flow events evaluated in this analysis (i.e., 2-, 10-, and 100-year events) were developed by linearly scaling the October 1994 hydrograph so that the peak flow rate corresponded to the appropriate value for each event (i.e., those listed in Table 2-1). For example, the hydrograph for the 100-year event was generated by increasing the peak flow rate during the October 1994 event by 4.5 percent. For the hydrographs of the HSC tributaries, observed time-variable flow rates during the October 1994 flood period were used as model input. This assumption was evaluated in a sensitivity analysis by comparing the results to those using the average flow rates for each of the tributaries.

Temporal variation in WSE at the downstream boundary for these simulations was specified using data collected during the October 1994 high-flow event at the National Oceanic and Atmospheric Administration (NOAA) tidal gauge station at Morgan's Point. Time histories of flow rate at Lake Houston Dam and WSE at the downstream boundary during the high-flow event simulations are shown on Figure 2-1.

Spatial distributions of predicted net erosion and deposition at the end of the 2-year high-flow simulation are shown on Figures 2-2 and 2-3, respectively. During the 2-year high-flow event, net erosion was predicted to occur only in 6 percent of the total bed area in the Model Study Area and over just 8 percent of the area within the USEPA's Preliminary Site Perimeter,[5] with bed scour being predicted to occur primarily in the sub-tidal zone. Predicted net erosion depths in these limited areas were all less than -3 centimeters (cm), with average and maximum predicted net erosion depths of -0.5 and -2.3 cm, respectively, within the USEPA's Preliminary Site Perimeter during the 2-year flood. Within the USEPA's Preliminary Site Perimeter, the average and maximum net deposition values were predicted to be 0.1 and 1.9 cm, respectively, during the 2-year high-flow event (Table 2-2).

During the 10-year high-flow event, net erosion was predicted over a larger area, although most of the net erosion depths were predicted to be less than -5 cm; there were a few isolated areas with erosion depths predicted to range between -5 and -8 cm. Spatial distributions of predicted net erosion and deposition for the 10-year flood simulation are presented on Figures 2-4 and 2-5, respectively. Average values of predicted net erosion and deposition within the corresponding portions of the USEPA's Preliminary Site Perimeter were -2.1 and 0.7 cm, respectively, during the 10-year flood (Table 2-2). Maximum values of bed scour and deposition were -7.7 and 9.9 cm, respectively, within that area. Over the entire Model Study Area, net deposition was predicted to occur in 73 percent of the bed area, with net erosion predicted in 27 percent of the area. The fractions of bed area predicted to experience net deposition and net erosion within the USEPA's Preliminary Site Perimeter during the 10-year event were 54 percent and 46 percent, respectively.

Spatial distributions of predicted net erosion and deposition at the end of the 100-year high-flow simulation are shown on Figures 2-6 and 2-7, respectively. Net erosion was predicted in 45 percent of the bed area in the Model Study Area (with the remaining 55 percent being net depositional) and 56 percent of the area within the USEPA's Preliminary Site Perimeter. During the simulated 100-year flood, the average and maximum values of predicted net deposition within the USEPA's Preliminary Site Perimeter were 2.6 and 26 cm, respectively (Table 2-2). The average and maximum predicted scour depths were -4.5 and -29 cm,

[5] Total area for the Model Study Area and USEPA's Preliminary Site Perimeter is 4,023 acres and 900 acres, respectively.

respectively, within the USEPA's Preliminary Site Perimeter; scour depths greater than 10 cm were predicted to occur in less than 5 percent of that area.

Table 2-2
Predicted Bed Elevation Change within the USEPA's Preliminary Site Perimeter for High-Flow Event Simulations

Return Period (years)	Average Net Deposition (cm)	Maximum Net Deposition (cm)	Average Net Erosion (cm)	Maximum Net Erosion (cm)
2	0.1	1.9	-0.5	-2.3
10	0.7	9.9	-2.1	-7.7
100	2.6	26	-4.5	-29

Notes:
cm – centimeters

Results of the high-flow event simulations described above are representative of conditions immediately after the occurrence of those floods. The post-flood conditions will change with time as sediment is transported into the Model Study Area during lower flow conditions (i.e., deposition will occur in areas that experience bed scour during floods). This type of recovery process after a major flood was incorporated into the long-term 21-year sediment transport calibration simulation (Anchor QEA 2012a). The results from those simulations indicated that the area within the USEPA's Preliminary Site Perimeter is net depositional on a long-term basis (Anchor QEA 2012a).

2.2 Sensitivity Analysis: Water Surface Elevation at Downstream Boundary

Data collected at the Morgan's Point tidal gauge station were used to specify WSE at the downstream boundary of the hydrodynamic model because of gaps in the data records of the Battleship Texas State Park and Lynchburg gauge stations. An analysis of differences between WSE data collected at the Battleship Texas State Park/Lynchburg and Morgan's Point gauge stations was presented in Anchor QEA (2012a). The effects of data source for specifying WSE at the downstream boundary of the model were evaluated by simulating hydrodynamic conditions from 2002 using data collected at the Lynchburg gauge station (Anchor QEA 2012a). USEPA requested that a similar analysis be conducted using WSE data collected during 2001 (Miller 2012, pers. comm.). Comparisons of WSE data collected at the

Morgan's Point and Lynchburg tidal gauge stations during 2001 are shown on Figure 2-8. These data show WSE was very consistent between the two stations in 2001. The only significant differences in WSE between the two locations occurred in early June 2001, during a flood on the San Jacinto River; this flood had a peak flow rate that corresponded to a return period between 2 and 10 years. The WSE measured at Morgan's Point during that event were lower than those measured at the Lynchburg station.

The models were used to simulate hydrodynamics and sediment transport during 2001, with the downstream boundary condition specified using WSE data collected at the Lynchburg tidal gauge station. These results were compared to the original (base case) simulation for 2001, for which the downstream boundary condition was specified using WSE data collected at the Morgan's Point tidal gauge station. Cumulative frequency distributions of predicted bed elevation changes for grid cells within the USEPA's Preliminary Site Perimeter for the base case (Morgan's Point) and sensitivity (Lynchburg) simulations are compared on Figure 2-9. Differences in bed elevation change between the two simulations range between -2 and +1 cm for the grid cells within the USEPA's Preliminary Site Perimeter (Figure 2-9, bottom panel). These results are similar to the previous analysis conducted for 2002 (Anchor QEA 2012a). A one-to-one comparison of bed elevation changes for each model grid cell within the USEPA's Preliminary Site Perimeter is presented on Figure 2-10; this figure also demonstrates the minimal difference between the base case and sensitivity simulations. Overall, the data source for specifying WSE at the downstream boundary of the hydrodynamic model has minimal effect on sediment transport within the USEPA's Preliminary Site Perimeter.

3 SIMULATION OF POST-TCRA FUTURE CONDITIONS

As noted in Section 1.1.3, the calibrated model described in Anchor QEA (2012a) was developed based on data collected prior to placement of the TCRA cap in 2010 and 2011. As such, the model was first updated to reflect current conditions, which include the presence of the armored cap over the TCRA Site. Long-term future simulations under these post-TCRA conditions were then conducted using the updated model. These simulations were used to provide estimates of future rates of natural recovery (i.e., reductions in water column and surface sediment dioxin and furan concentrations over time) in various portions of the Model Study Area. The subsections below describe the methods used to develop these long-term simulations, and the results from the model evaluations of TCRA impacts on relative surface water concentrations and model-predicted rates of natural recovery in sediments.

Because any model has some amount of uncertainty associated with its predictions, it is often desirable to quantify that uncertainty so that it can be factored into the interpretation of model predictions, as well as any decisions that may be made based on the results. Therefore, this section also describes an analysis of uncertainty that involved conducting simulations based on alternate sets of input parameters, for both sediment transport and chemical fate. Specifically, the uncertainty analysis results associated with the sediment transport model, and the chemical fate model's predictions of the effects of the TCRA on surface water dioxin/furan concentrations and future natural recovery rates in sediments are described.

3.1 Hydrodynamic and Sediment Transport Models

3.1.1 Model Setup

3.1.1.1 General Setup of Long-Term Simulation

The long-term, 21-year hydrodynamic and sediment transport simulations used for calibration of the sediment transport model (Anchor QEA 2012a) were updated to represent conditions present in the TCRA Site after implementation of the TCRA for the purposes of future simulations; this period is referred to hereafter as the Future Projection Period. The basis of design for the TCRA cap was the construction of an armored cap designed to withstand a flow event with a return period of 100 years. The area that was affected is

shown on Figure 3-1. Model inputs were revised to reflect physical conditions after construction of the cap, with the following changes made within the TCRA Site:

- Bed elevations were updated to reflect the increase in elevation due to the cap.
- The sediment bed map was revised to reflect the placement of the cap, which is composed of armor stone, and, therefore, represented as non-cohesive sediment in the model.
- The median particle diameter (D_{50}) was updated to represent the armor stone size of the cap.

Updated bed elevation inputs were based on an interpolated surface map created from data collected during October 2012 by Hydrographic Consultants Limited, which was representative of post-TCRA construction conditions. Pre- and post-TCRA bathymetry and topography data are compared on Figure 3-1. Increases in bed elevation due to the cap placement (i.e., post-TCRA construction) are evident within the TCRA Site on this figure.

The sediment bed map for the model grid cells within the TCRA Site was converted from cohesive to non-cohesive sediment, as shown on Figure 3-2. The model's median particle diameter in the TCRA Site was also updated using cover material gradation data provided in the Final Removal Action Work Plan (Anchor QEA 2011b). Each zone within the TCRA Site received a specific cap material type; a summary of those zones is shown in Table 3-1, and a comparison of the changes to the median particle diameter used in the model to reflect these cap types is shown on Figure 3-3.

Table 3-1
Cover Material Gradation of the TCRA Cap

Material Designation Zone	Material Type	Median Particle Diameter: D_{50} (inches)
Cap A	Recycled concrete	3
Cap B/C	Recycled concrete	6
Cap C	Natural stone	6
Cap D	Natural stone	8

3.1.1.2 Uncertainty Analysis

The effects of input uncertainty on the long-term sediment transport model calibration were previously evaluated through a sensitivity analysis, as documented in Section 4.4.1 of Anchor QEA (2012a). Specifically, the effects of varying the following model inputs were evaluated: 1) erosion rate parameters; 2) incoming sediment load at the Lake Houston Dam; and 3) effective bed roughness. To evaluate the effects of possible interactions between the three inputs, a factorial analysis was conducted, which resulted in eight simulations to account for all of the possible combinations of the bounding limits of the three inputs. The parameter sets used in the eight sensitivity simulations are provided in Table 3-2, where "lower" refers to lower-bound value and "upper" refers to upper-bound value. The effects of each sensitivity simulation were evaluated through comparison to the base case simulation results. A more detailed description of this sensitivity analysis is provided in Section 4.4.1 of Anchor QEA (2012a). These same sensitivity analysis simulations were repeated for the post-TCRA conditions model setup.

Table 3-2
Bounding Limits for Sediment Transport Model Sensitivity Analysis

Sensitivity Simulation	Upstream Sediment Load	Effective Bed Roughness	Erosion Rate Parameters
1	Lower	Lower	Lower
2	Lower	Lower	Upper
3	Lower	Upper	Lower
4	Lower	Upper	Upper
5	Upper	Lower	Lower
6	Upper	Lower	Upper
7	Upper	Upper	Lower
8	Upper	Upper	Upper

3.1.2 Results

Spatial distributions of predicted NSRs for the long-term simulation period for pre- (i.e., the sediment transport model calibration) and post-TCRA conditions are shown on Figures 3-4 and 3-5, respectively. Generally, the model predicted slightly more deposition to occur within the TCRA Site for the post-TCRA case; otherwise, differences in NSR between the two cases are minimal. Spatial distributions of predicted net erosion rate for pre- and post-

TCRA conditions are presented on Figures 3-6 and 3-7, respectively. Areas of net erosion are similar for the two cases.

To evaluate the uncertainty of these sediment transport model predictions, comparisons of model-predicted and empirically estimated NSR values are shown on Figure 3-8. On that figure, each cross-hatched box represents the range of NSR values based on lower- and upper-bound estimates of the data, and the whisker bars correspond to the uncertainty range in NSR due to uncertainty in laboratory analytical results. The model-predicted NSR values (shown as different colored circles representing the base case post-TCRA future simulation and the various sensitivity simulations) represent average values during the Future Projection Period. This Future Projection Period included a rare flood (i.e., approximately 100-year return period, as discussed in Section 2.1) that was predicted to have a significant effect on the Model Study Area, which may bias the model predictions of NSR to some extent due to its inclusion in the simulation period (i.e., unrealistic decrease of NSR; see Anchor QEA [2012a]). Thus, model predictions for the 16-year period corresponding to flows from 1995 through 2010 are also compared to the empirically estimated NSR values. Similar comparisons of predicted and estimated NSR for the 16-year period from 1995 through 2010 are shown on Figure 3-9. Overall, these figures show that the range of sensitivity simulations result in predicted values for NSR that are within approximately a factor of 2 of the base case calibration, which in many cases is consistent with the range of uncertainty in the empirical data.

Results of the sensitivity simulations for post-TCRA conditions were also evaluated using a sediment mass balance for the Model Study Area as a metric for quantitative comparison. The sensitivity of the predicted trapping efficiency for the Model Study Area to varying the three model inputs is shown on Figure 3-10. The base case trapping efficiency predicted by the model was 17 percent, with the range of trapping efficiencies for the sensitivity simulations being 6 percent to 24 percent.[6] These results are very similar to the sensitivity analysis results for the pre-TCRA condition (Anchor QEA 2012a).

[6] Simulation 4 was net erosional, so no trapping efficiency was calculated for that simulation.

Rates of gross erosion, gross deposition, and net deposition and erosion for the base case and each of the sensitivity simulations predicted within the USEPA's Preliminary Site Perimeter are compared on Figure 3-11. Gross erosion rate was the total sediment mass eroded from all grid cells that were predicted to be erosional (i.e., bed scour) during the Future Projection Period within the USEPA's Preliminary Site Perimeter. Similarly, gross deposition rate was the total sediment mass deposited in all grid cells that were predicted to be depositional during the Future Projection Period. Rate of net change (i.e., either net deposition or erosion) was the difference between gross deposition and gross erosion (i.e., rate of change equals gross deposition minus gross erosion, with positive values being net deposition and negative values being net erosion). Overall, the sensitivity analyses result in a range in gross erosion and deposition rates that are within a factor of 2 to 3 of the base case.

Based on the results described above, sediment transport Sensitivity Simulations 2 and 7 were selected as lower- and upper-bound parameter sets to be carried forward to the evaluation of fate and transport model uncertainty (described below). The lower-bound parameter set produced the minimum trapping efficiency within the Model Study Area (Figure 3-10), as well as the minimum net deposition rate within the USEPA's Preliminary Site Perimeter (Figure 3-11). In contrast, the upper-bound parameter set produced the second highest values of trapping efficiency within the Model Study Area (Figure 3-10) and net deposition rate within the USEPA's Preliminary Site Perimeter (Figure 3-11). Predicted NSRs within the USEPA's Preliminary Site Perimeter for these lower- and upper-bound parameter sets were in reasonable agreement with the range of measured values (Figures 3-8 and 3-9).

3.2 Chemical Fate and Transport Model

3.2.1 Model Setup

3.2.1.1 General Setup of Long-Term Simulations

As described in Anchor QEA (2012a), the chemical fate and transport model was calibrated over the 6-year period between 2005 and 2010. For the long-term future simulations conducted for the FS, the fate and transport model also used the Future Projection Period (i.e., this forecast was based on the 21-year flow and tide history used for the hydrodynamic and sediment transport models described above). These simulations were developed to

predict future dioxin/furan concentrations for comparison of remedial alternatives; the historical hydrodynamic information used to project conditions during the Future Projection Period was only used as a means of estimating future flow and tide conditions in the river (i.e., this makes the reasonable assumption that flows in the future will be statistically similar to those observed in the past).

In addition, the sediment dioxin/furan concentrations in the model were revised for the simulations of post-TCRA future conditions. As described in Anchor QEA (2012a), the initial sediment concentrations specified in the model for calibration were based on concentrations of dioxins and furans in sediment collected within the Model Study Area in 2002 to 2005. For the future simulations described in this section, the sediment dioxin/furan initial concentrations were updated using the 2010 to 2012 Remedial Investigation (RI) Report sediment dataset (Integral and Anchor QEA 2013). This dataset provides a more detailed characterization of contemporary dioxin/furan sediment concentrations within the USEPA's Preliminary Site Perimeter. The methodology used to develop surface sediment dioxin/furan initial conditions was generally the same as that described in Section 5.2.5.2 of Anchor QEA (2012a)—i.e., Thiessen polygons were generated for all sediment sample locations and mapped onto the model grid. However, in the area of the TCRA Site, the Thiessen polygons were generated consistent with the methodology used in the Remedial Alternatives Memorandum (Anchor QEA 2012b), whereby the polygons were generated separately for the areas within and outside the TCRA Site boundary. To simulate future (i.e., post-TCRA cap) conditions, the sediment dioxin/furan concentrations were set to zero in the grid cells corresponding to the TCRA Site footprint. This setting in the model corresponds to the assumption of no release of dioxins/furans from that area to the overlying water column, consistent with the data collected during the TCRA Cap Porewater Assessment (see Section 5.3 of the RI Report). However, the post-TCRA model simulation results (described below) show that the surface of the TCRA armored cap equilibrates with sediments from the surrounding area over time because of transport and deposition of dioxin-bearing sediments from upstream areas. As discussed above, to evaluate the impacts of the TCRA on relative surface water conditions, a second comparison simulation was conducted based on pre-TCRA sediment conditions; for this simulation, the surface sediment concentrations within the TCRA Site were based on RI samples collected from that area. Figures 3-12a and 3-12b present the Thiessen polygons within the USEPA's Preliminary Site Perimeter developed

based on the 2010 to 2012 RI data used for these two simulations for TCDD and TCDF, respectively.

Similar to the sediment initial conditions, sediment total organic carbon (TOC) in the model was updated based on the 2010 to 2012 RI dataset. A map showing the updated model TOC is provided on Figure 3-13. All other chemical fate model inputs (i.e., boundary conditions, external loads, partition coefficients, mass transfer coefficients) used in the post-TCRA future simulations were the same as those from the calibrated model (Anchor QEA 2012a).

3.2.1.2 Uncertainty Analysis

Similar to the sediment transport model uncertainty analysis described above, the effects of input uncertainty on chemical fate model predictions were previously evaluated through sensitivity analyses (Anchor QEA 2012a). To develop uncertainty analyses for the long-term future modeling for the FS, the two bounding sediment transport simulations described in Section 3.1.1.2 above (i.e., sediment transport Sensitivity Simulations 2 and 7) were propagated through the fate model uncertainty simulations and combined with two bounding chemical fate and transport input parameter sets. The sets of bounding parameters for the fate and transport model used in this uncertainty analysis were those from the combined parameter sensitivity analysis described in Section 5.3.3.2.7 of Anchor QEA (2012a). For that sensitivity analysis, values related to bed mixing (i.e., depth and rate of bioturbation), the downstream boundary condition (i.e., estimated dioxin/furan concentrations in surface water at HSC), and partition coefficients were modified (Anchor QEA 2012a). The goal of these simulations was to produce upper-bound and lower-bound results to quantify the uncertainty range associated with the model's base case future predictions. Because different combinations of chemical fate model parameters, when coupled with the two bounding sediment transport model simulations, could produce differing responses in water column and sediment concentrations, all four possible combinations were simulated (i.e., the two bounding sediment transport simulations and two alternate sets of chemical fate parameters). Table 3-3 lists the combinations of sediment transport and chemical fate model input sets that were used in the uncertainty analysis, and how they are referred to in the discussion of results below.

Table 3-3
Fate Model Uncertainty Simulations

Fate Run Name	Sediment Transport Sensitivity Simulation	Fate Model Parameters		
		Bed Mixing	Downstream Boundary	Partition Coefficient
Fate Uncertainty 1	Simulation 7	None	Decreased	Increased
Fate Uncertainty 2	Simulation 7	Increased	Increased	Decreased
Fate Uncertainty 3	Simulation 2	None	Decreased	Increased
Fate Uncertainty 4	Simulation 2	Increased	Increased	Decreased

3.2.2 Results

3.2.2.1 Water Column

The predicted effects of placement of the TCRA cap on surface water concentrations, including model uncertainty, were evaluated based on a review of pre- and post-TCRA water column concentration estimates for the four fate model uncertainty simulations described above. It was determined that Fate Uncertainty Simulations 1 and 4 produced the largest upper and lower bounds for the water column predictions, respectively. Therefore, all figures discussed in this section include results for six simulations: the base case (shown as solid lines) and Fate Uncertainty Simulations 1 and 4 (shown as dashed lines), each for both pre- and post-TCRA conditions. These model predictions of water quality are useful for comparisons of pre- and post-TCRA conditions, as well as conditions under various remedial alternatives (see Section 4) but are not equivalent to empirical measurements. This is why model uncertainty has been characterized and carried through the discussion of results below and model predictions are most appropriately used for comparative purposes.

As described in Section 1.1.3, the chemical fate and transport model was developed for three dioxin and furan congeners (TCDD, TCDF, and OCDD). Pre- and post-TCRA simulations were conducted for TCDD and TCDF but not OCDD; furthermore, to simplify the discussion presented in this appendix, results below are only discussed for TCDD.[7]

[7] Graphics of model results for TCDF have been included in Attachment 1 to this appendix; TCDF results are not included in the discussion of this appendix because: 1) model results for TCDF were consistent with those for TCDD in all cases; 2) as noted in Anchor QEA (2012a), the fate and transport behavior of TCDF is similar to

A longitudinal profile of annual-average, model-predicted water column TCDD concentration estimates, including the model uncertainty bounds, is presented on Figure 3-14. For this figure, model results were averaged using the same methodology as described in Section 5.3.2.1.1 of Anchor QEA (2012a) and are summarized as follows:

- Model results were averaged only for low-flow days, which was defined as flow less than 4,000 cfs over the Lake Houston Dam.
- In order to be shown on a one-dimensional longitudinal profile, the model results from the two-dimensional model grid used in the San Jacinto River were averaged laterally (i.e., across the channel), as well as longitudinally at increments ranging generally from 0.1 to 0.5 mile.
- The results shown on Figure 3-14 are for 1 year of the simulation (Year 11) that represents a typical flow year near the middle of the model simulation. Annual-average longitudinal profiles of TCDD (and TCDF) for all years of the Future Projection Period have been included in Attachment 1.

The base case and uncertainty simulations all show that the largest differences in predicted water column TCDD concentrations between pre- and post-TCRA conditions are generally within the immediate vicinity of the TCRA Site. For a given set of starting sediment concentrations (i.e., pre- or post-TCRA), the uncertainty simulations produce bounds that are within a factor of 2 to 3 of the base case results. Also, when comparing water column concentration estimates in this area between the two cases, the upper-bound (pre- versus post-TCRA) and lower-bound (pre- versus post-TCRA) simulations both show that the post-TCRA results are lower than the pre-TCRA results (similar to the base case results), with differences up to a factor of 2 to 3. Thus, these results show that although there is uncertainty in the exact magnitude of model-predicted concentrations (e.g., a factor of 2 to 3), there is relatively less uncertainty in the predicted reductions achieved by the TCRA (i.e., the upper and lower bounds from the uncertainty simulations show reductions in water

that of TCDD due to similarities in their chemical characteristics; and 3) TCDF generally contributes to TEQ in smaller proportions than TCDD (Integral and Anchor QEA 2013). Results for OCDD are not presented in this appendix because OCDD was included in the model only to provide added robustness to the calibration (i.e., because OCDD has different chemical characteristics and it exhibits a different spatial pattern across the Model Study Area as compared to TCDD/TCDF [Anchor QEA 2012a]); it is indicative of background dioxin/furan sources within the Model Study Area (Integral and Anchor QEA 2013).

column concentration estimates as a result of the TCRA that are both consistent with the base case).

To further illustrate differences in model-predicted pre- and post-TCRA water column concentrations, time-series plots of laterally averaged concentration estimates were developed. Figure 3-15 shows model-calculated concentration estimates of TCDD (averaged monthly) over the Future Projection Period at the following five locations:

- Lake Houston Dam
- River Mile[8] 12, which is near the U.S. 90 Bridge
- River Mile 4.5, which is just upstream of the northern limit of the USEPA's Preliminary Site Perimeter
- River Mile 2.5, which transects the TCRA Site
- River Mile -0.5, which is at the confluence between the San Jacinto River and HSC

Time-series plots were also developed to show spatially averaged model results within the USEPA's Preliminary Site Perimeter and within the footprint of the TCRA Site (Figure 3-16). The flow rate over the Lake Houston Dam is shown on the top panel of both figures. Similar to the spatial profile, these figures show that the difference between pre- and post-TCRA water column concentration estimates for both the upper-bound and lower-bound simulations are similar to the base case. When comparing the overall uncertainty ranges for the six simulations, these figures show that at some of the larger spatial scales, the differences between the pre- and post-TCRA simulations are likely within the range of model uncertainty, although at smaller spatial scales, the effects of the TCRA are clearly evident because there is little to no overlap of the uncertainty bounds (e.g., bottom panel of Figure 3-16). These results indicate there is a relatively localized effect of the TCRA on model-predicted water column concentrations.

To summarize the effects of the TCRA on water column concentration estimates, average percent reductions in model-predicted, pre- and post-TCRA water column TCDD concentration estimates were calculated. Percent reductions in model-predicted water column TCDD concentrations were averaged over two timescales: 1) during the first year of

[8] River mile locations are shown on Figure 1-1.

the model simulation, and 2) over the entire Future Projection Period. The calculations were made on various spatial scales, consistent with those shown on Figures 3-15 and 3-16 (i.e., spatially averaged over the USEPA's Preliminary Site Perimeter, laterally averaged over the transect at River Mile 2.5 that runs directly through the TCRA Site, spatially averaged over the TCRA Site, and for the grid cell with the peak estimated concentration within the footprint of the TCRA Site). A summary of the predicted improvement in water column concentration (quantified as an estimated percent reduction between the pre- and post-TCRA model simulations) averaged over these various temporal and spatial scales is provided for the base case and Fate Uncertainty Simulations 1 and 4 in Table 3-4 below.

Table 3-4
Summary of Percent Reduction in Water Column TCDD Concentration Estimates

Run	Time Averaging Period	Percent Reduction			
		USEPA's Preliminary Site Perimeter	River Mile 2.5	TCRA Site Footprint	Peak Concentration
Base Case	Year 1	38	74	88	87
Fate Uncertainty 1		43	78	89	87
Fate Uncertainty 4		39	73	87	86
Base Case	Long-term	26	63	86	87
Fate Uncertainty 1		19	49	84	91
Fate Uncertainty 4		38	73	88	89

The base case and uncertainty simulation results all indicate that the model predicts the TCRA achieves significant reductions in water column TCDD concentration estimates. When looking at Year 1 of the simulation, the calculated percent reductions are relatively similar between the base case and the uncertainty bounds for all of the various averaging areas, with the uncertainty of the various percent reductions ranging from less than 1 percent to 5 percent. The following are the model's predicted results over the long term:

- When averaged over the USEPA's Preliminary Site Perimeter, the uncertainty range on the base case-predicted reduction in concentration of 26 percent is from 19 percent to 38 percent.

- Within the model grid cells corresponding to the lateral transect at River Mile 2.5, the long-term average percent reduction predicted by the model is 63 percent, with an uncertainty range of 49 percent to 73 percent.
- Within the footprint of the TCRA Site, long-term average estimated concentration reductions are similar between the base case and the uncertainty simulations (i.e., between 84 percent and 88 percent).
- Finally, at the smallest localized scale (i.e., a single model grid cell corresponding to the maximum predicted concentration in the vicinity of the TCRA Site), the base case model prediction and the uncertainty simulations all resulted in a nearly 90-percent reduction in peak TCDD concentration over the long term.

Overall, the results from these uncertainty analyses show that although there is uncertainty in the exact magnitude of model-predicted water column concentrations, there is relatively less uncertainty in the predicted relative reductions achieved by the TCRA, which average in the range of 30 percent within the USEPA's Preliminary Site Perimeter (uncertainty range of approximately 20 to 40 percent) to 90 percent in the areas of the TCRA Site (with uncertainty range of less than 5 percent). Water column concentrations in the immediate vicinity of the TCRA cap are not reduced completely due to various background sources, and flux from sediments outside the limits of the TCRA Site.

3.2.2.2 Surface Sediment

Model-predicted future rates of natural recovery in surface sediments, including the range of model uncertainty, were evaluated at various spatial scales over the Model Study Area using the long-term future simulation described above (i.e., starting from post-TCRA sediment concentrations and forecasting over the Future Projection Period). With regard to model uncertainty, in some cases, each of the four fate model sensitivity simulations described in Table 3-3 had a different effect on predicted long-term surface sediment concentrations in different portions of the Model Study Area; therefore, the figures described below contain results for all four sensitivity simulations compared with the base case predictions.

Figure 3-17 shows a time series of model-predicted surface (0- to 6-inch) sediment TCDD concentrations averaged over the USEPA's Preliminary Site Perimeter. This figure shows a

base case predicted decrease in TCDD concentration of approximately 75 percent over the Future Projection Period (decreasing from an initial TCDD concentration of approximately 8 nanograms per kilogram [ng/kg] to 2 ng/kg by Year 21). To quantify the rate of decline, an exponential decay curve was fit through the model results, and the rate of decline was calculated (see example for the base case simulation shown as a dotted line on Figure 3-17); the model-predicted decline of TCDD in surface sediment concentrations within the USEPA's Preliminary Site Perimeter corresponds to a half-life of 11 years. Although the model results vary year-to-year due to differences in flow conditions, the nature of the predicted recovery curve (i.e., an exponential decline) exhibits an asymptotic behavior, which is expected because concentrations of dioxins/furans would be expected to approach regional background concentrations associated with remaining sources of dioxins/furans (i.e., point and non-point sources, transport from upstream) in the area. For the uncertainty simulations, this predicted decline ranges from more than 85 percent (Fate Uncertainty 1) to 40 percent (Fate Uncertainty 4), corresponding to half-lives that vary by about a factor of 2 from the base case, ranging from 7 years to 24 years (Figure 3-17). The faster rates of recovery predicted for the Fate Uncertainty 1 simulation are a result of a combination of increased sedimentation rates and decreased mixing within the bed for this simulation. Conversely, the slower rates of recovery predicted for the Fate Uncertainty 4 simulation are a result of lower sedimentation and increased mixing within the bed.

Figure 3-18 shows time-series plots of model-predicted surface (0- to 6-inch) sediment TCDD concentrations averaged over 1-mile reaches in the vicinity of the TCRA Site. Similar to the spatial averages calculated for the USEPA's Preliminary Site Perimeter, the 1-mile reach averages show a trend of decreasing surface sediment concentrations over the model simulation period. The predicted natural recovery in this area can be attributed to ongoing deposition of lower concentration sediments derived from upstream areas of the river. The 1-mile reach that includes the TCRA Site (River Miles 3 to 2) shows a predicted decrease in concentration consistent with that for the USEPA's Preliminary Site Perimeter (i.e., 75-percent decrease corresponding to an 11-year half-life, with an uncertainty range that varies by about a factor of 2 to 3 from the base case). These results also show year-to-year variability, which is a result of varying flow conditions. For example, the model predicts an increase in concentration during Year 5 within River Miles 3 to 2, which is a result of predicted erosion during the highest flow event included in the simulation (corresponding to

a return period between 50 and 100 years, as discussed in Section 2.1), but that increase only has a temporary effect on the long-term average trend predicted within that 1-mile area. Predicted rates of natural recovery in the other 1-mile reaches are similar to that in the reach containing the TCRA Site (i.e., half-lives of approximately 10 years), with estimated uncertainty ranges of approximately a factor of 2 to 3 (i.e., half-life values ranging from approximately 5 to 35 years). In some cases, the year-to-year variability in surface sediment concentrations is greater than others; however, an important finding from these simulations is that, despite the relatively wide ranges in parameter values included in these various uncertainty simulations, the model predicts decreases in concentration in all cases and spatial scales over the long term.

Lastly, as described in Section 3.2.1, the TCRA cap was simulated by setting the sediment bed TCDD/TCDF concentrations to zero within the corresponding model grid cells (which eliminated flux of dioxins/furans from this area to the overlying water column). Figure 3-19 shows a time-series plot of the base case model-predicted surface sediment TCDD concentrations averaged over this area (i.e., the capped area). Because concentrations were initially set to zero in this area, Figure 3-19 can be used to evaluate the model's prediction of sediment re-equilibration levels within the surface of the cap. This figure shows predicted surface sediment TCDD concentrations increasing to approximately 2 ng/kg over the Future Projection Period. This predicted increase is a result of deposition of sediments from the surrounding areas of the river on the surface of the cap, and the concentration is generally consistent with regional background levels in surface sediment (e.g., Table 4-5 of the RI Report indicates TCDD background concentrations range from 0.01 to 5 ng/kg; Integral and Anchor QEA 2013).

4 MODELING TO SUPPORT EVALUATION OF REMEDIAL ALTERNATIVES

As described in Section 3.2.2.2 above, the post-TCRA future chemical fate model simulation was used to evaluate relative changes in surface sediment dioxin/furan concentrations over time (i.e., rates of natural recovery) in the Model Study Area. The results from this simulation apply to Alternatives 1 through 3 evaluated in the FS (as discussed in Section 4.1). Section 4.2 provides a description of additional model simulations that were conducted for FS Alternatives 4, 5, and 6, which include active remediation of sediments within the TCRA Site, as well as one other area within the USEPA's Preliminary Site Perimeter in the case of Alternative 6. In addition to evaluating general long-term trends for these alternatives, the model's predictions of future sediment and water column dioxin/furan concentrations from these simulations were used to quantify potential short- and long-term impacts associated with the construction activities (i.e., sediment resuspension and release during remediation and effects of dredge residuals).

4.1 Simulation of Natural Recovery for FS Alternatives

The predicted rates of natural recovery presented in Section 3.2.2.2 apply to Alternatives 1 through 3 for the FS. For the purposes of chemical fate and transport modeling, these alternatives can all be characterized by the post-TCRA future simulation because Alternatives 1 (No Further Action) and 2 (ICs and MNR) have no additional remedial activities, and Alternative 3 only includes construction of a permanent cap, which would not be expected to create any significant potential for construction-related releases of dioxins/furans. Therefore, there would be no significant differences in future surface water or sediment concentrations among Alternatives 1 through 3; thus, the long-term chemical fate model predictions described in Section 3.2.2 would be the same for all three of these alternatives.

4.2 Simulation of Remediation Alternatives 4, 5, and 6

Additional simulations were conducted using the calibrated fate and transport model for FS Alternatives 4, 5, and 6, because these alternatives include active remediation of sediments that could affect long-term chemical fate and transport within the Model Study Area (due to resuspension and release during remediation and dredge residuals). The remediation components of these alternatives are as follows:

- Alternatives 4 and 5 include the same permanent cap as Alternative 3, as well as partial remediation of sediments from portions of the TCRA Site. For Alternative 4, this would consist of solidification/stabilization (S/S) of soils/sediments beneath the TCRA armored cap that have concentrations exceeding 13,000 ng/kg on a toxicity equivalent (TEQ) basis whereas for Alternative 5, it would involve removal of those same materials, after which the remediated area would be backfilled and the TCRA cap would be replaced/reconstructed.
- Alternative 6 includes full removal of soils/sediments from the TCRA Site, as well as removal of sediments exceeding the PCL in one other area of the USEPA's Preliminary Site Perimeter. A sand cover would be placed following removal to address dredge residuals.

The simulations of these alternatives utilized the same 21-year future simulation length, hydrologic conditions, and boundary loads as described for the simulations of post-TCRA future conditions in Section 3.2.1. However, unlike the simulation of post-TCRA conditions, these simulations account for the effects of sediment remediation on dioxins/furans within the Model Study Area, and as such, required the following:

- "Mapping" of the remediation footprints onto the chemical fate model grid
- Specification of dioxin/furan releases during in-water construction activities associated with the sediment remediation
- Specification of post-remediation concentrations, including simulation of the effects of dredge residuals on sediment concentrations for certain cases

Details regarding the additional model setup required for simulation of these alternatives are provided in the subsection that follows.

4.2.1 Model Setup

4.2.1.1 Mapping of Remediation Areas onto the Model Grid

In order to simulate Alternatives 4, 5, and 6 in the fate model, the footprint of the remediation area for each alternative was first "mapped" onto the fate model grid. As discussed in Section 4 of the FS, the remediation footprints are defined as follows:

- For Alternatives 4 and 5, the footprint was based on the limited portion of the TCRA Site containing dioxin/furan concentrations in excess of 13,000 ng/kg on a TEQ basis. The resulting remediation footprint consists of two areas, termed the eastern and western cells (Figure 4-1). Because remediation of the western cell would be performed from land, releases during remediation would be expected to be minimal from that area; therefore, only the eastern cell was represented in the model simulations for these two alternatives.
- The Alternative 6 dredging footprint was delineated to encompass all areas containing sediment samples with concentrations exceeding a PCL of 220 ng/kg TEQ. These areas included a large portion of the TCRA Site footprint, as well as one sample polygon offshore of the San Jacinto River Fleet (SJRF) property (Figure 4-1).

These remediation areas were mapped onto the chemical fate model grid as shown on Figure 4-1.

4.2.1.2 Releases during Sediment Remediation

The model's simulation of sediment remediation accounts for releases of dioxins/furans during construction by specifying a fraction of the chemical mass present in the remediated sediment (i.e., sediment that is removed in the case of Alternatives 5 and 6, or that which undergoes S/S in the case of Alternative 4) that could be released to the water column under the simulated conditions. Details on how this potential release was represented in the model are discussed below.

Potential releases of chemical mass during remediation activities were simulated in the fate model as a dissolved phase flux of dioxins/furans to the water column within each remediated grid cell. The magnitude of that release flux was determined based on the average concentration and depth of sediments removed (or subject to S/S in the case of Alternative 4), an assumed fraction of dioxin/furan mass released, and the construction schedule associated with the removal or S/S activities (i.e., time it takes to remediate that grid cell based on the specified production rate for the alternative). For each remediation footprint, an average depth of remediation and volume-weighted average concentration within the remediation prism were calculated. These values were used in conjunction with

each grid cell's surface area and bulk density to calculate the mass of dioxins/furans remediated for the purposes of the model's release calculation. The depths and concentrations used in these calculations are listed in Table 4-1.

Table 4-1
Average Remediation Depth and Volume-Weighted Average Sediment Concentration Used for Calculating Potential Releases during Construction

Alternative / Remediation Area	Average Depth of Remediated Sediment (feet)	Volume-Weighted Average Concentration in Remediation Prism	
		TCDD (ng/kg)	TCDF (ng/kg)
Alternatives 4 and 5 / eastern cell of footprint within TCRA Site	7	5,600	23,800
Alternative 6 / TCRA Site	6.75	4,300	13,100
Alternative 6 / Polygon adjacent to SJRF property	6	120	500

The dioxin/furan mass release fractions applied in the calculations are as follows:

- For simulation of S/S under Alternative 4 (eastern cell only), a release rate of 0.85 percent was assumed. This value was based on the midpoint of the range of release values estimated from areas of the Hudson River in which sediment removal was performed within sheet pile walls (Anchor QEA and Arcadis 2010). This value is in the low end of the range observed from sites where dredge release has been measured, and was assumed to be representative of releases that could occur due to disturbance of the sediments during S/S activities for the purposes of this model simulation.
- Simulation of release during sediment removal under Alternatives 5 (eastern cell only) and 6 assumed the fraction of dioxins/furans released during removal was 3 percent of the chemical mass removed. This value is based on case studies of dredging release at various contaminated sediment sites across the country, as summarized in Section 5.4.2 of the FS (see FS Table 5-2).

The mass of dioxin/furan released (calculated in each grid cell based on the average depth and concentration of remediated sediment and the assumed release rates as described above) was specified in the model to occur uniformly over the time needed to complete the in-water remediation activities of a given alternative. These times were estimated to be 1.5 months and 0.5 month for Alternatives 4 and 5, respectively (eastern cell only), and 13 months for Alternative 6; the start of remediation was specified to begin in the first year of the projection period for each alternative.

4.2.1.3 Sediment Bed Concentrations Following Remediation

Because the remediation activities for Alternatives 4 and 5 would include backfilling followed by replacement/reconstruction of the TCRA cap, it was assumed for the purposes of modeling that the surface sediment concentration within the remediated grid cells would be zero following construction, consistent with the method used to simulate the TCRA cap in the post-TCRA future simulation. However, due to the extensive removal under Alternative 6, the remediation would be conducted through in-water construction techniques (dredging), followed by placement of a sand cover to manage residuals. Thus, an analysis of post-remediation sediment concentrations was needed for accurate simulation of that alternative in the model. The methods used for specifying post-remediation bed concentrations in the model to account for the Alternative 6 dredging is described below.

Sediment removal under Alternative 6 was simulated in the fate model by resetting the simulated sediment bed to reflect post-dredging conditions within the two removal areas. The corresponding post-remediation sediment concentrations were specified to account for three factors: 1) sediment residuals that would be generated following dredging; 2) the observed concentration of the (un-dredged) sediment present beneath the neatline elevation of the last dredge pass; and 3) the placement of a sand cover following dredging.

The potential for generating residuals during dredging is well documented (e.g., Patmont and Palermo 2007; U.S. Army Corps of Engineers 2008a, 2008b; Bridges et al. 2010). Based on information regarding residuals generated at other sites where environmental dredging has been performed (e.g., Patmont and Palermo 2007; Bridges et al. 2010; Anchor Environmental

2007; Alcoa 2006), post-remediation sediment bed concentrations in areas subject to dredging were specified in the model as follows:

- Deep sediments (i.e., the bottom 39 inches of the simulated 48-inch sediment bed) were set to un-dredged sediment concentrations that were specified based on sampling data. Given the relatively small size of the two dredge areas (relative to the size of the overall model grid), these concentrations were defined as a single average concentration over each area.
- A 3-inch layer of dredge residuals was assumed to be generated above the deeper un-dredged sediments;[9] 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). 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; 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).

Table 4-2 provides a summary of the concentrations of TCDD and TCDF specified for the various model bed layers described above under Alternative 6. These concentrations were calculated based on the same surface and subsurface sediment core data used to determine the horizontal and vertical extents of removal as described in Section 4 of the FS.

[9] The 3-inch residual layer thickness was specified based on an assumed average 6-foot dredge cut plus 1-foot over-dredge, with 5-percent sediment loss (i.e., [6 feet + 1 foot] * 0.05 = 4.2 inches); this thickness was rounded down to 3 inches, which is the thickness of a single model sediment bed layer.

Table 4-2
Summary of Post-Remediation Sediment Bed Concentrations for Alternative 6

Alternative 6 Remediation Area	Model Bed Layer	TCDD (ng/kg)	TCDF (ng/kg)
TCRA Site	Top 6 inches (residual cover)	*(3,956 * 0.05)* = 198	*(9,979 * 0.05)* = 499
	Next 3 inches (residual layer)	3,956	9,979
	Bottom-most 39 inches (un-dredged sediment)	37	107
Polygon adjacent to SJRF property	Top 6 inches (residual cover)	*(224 * 0.05)* = 11	*(1,050 * 0.05)* = 53
	Next 3 inches (residual layer)	224	1,050
	Bottom-most 39 inches (un-dredged sediment)	6	17

4.2.2 Results

This subsection presents the results from the fate and transport model long-term (21-year) simulations of Alternatives 4, 5, and 6 for TCDD (results for TCDF are contained in Attachment 1). For comparison purposes, the water column and sediment TCDD concentration estimates predicted for these three alternatives are presented together on overlay plots, along with those from the simulation of post-TCRA future conditions (representative of Alternatives 1 through 3) described in Sections 3.2.2. Hereafter in this appendix, the post-TCRA future simulation is referred to as "Alternatives 1 through 3."

4.2.2.1 Water Column

Longitudinal profiles of predicted water column TCDD concentration estimates during the first year of the simulation are shown on Figure 4-2a. As shown on this figure, predicted lateral average water column concentration estimates for Alternatives 4, 5, and 6 all exhibit substantial increases in the vicinity of the TCRA Site relative to the simulation for Alternatives 1 through 3. These predicted increases are a result of simulated releases of TCDD during remediation within the TCRA Site for these alternatives (which is simulated to occur over the first month or two for Alternatives 4 and 5 and the first 13 months of the simulation for Alternative 6). The magnitude of these predicted increases is proportional to the volume of remediated sediment and the assumed release rate associated with the construction techniques (discussed in Section 4.2.1.2 above). Relative to Alternatives 1 through 3, the Year 1 average concentrations in the area of the TCRA Site are predicted to

increase by approximately 10-, 50-, and more than 100-fold for Alternatives 4, 5, and 6, respectively, as a result of the simulated TCDD releases during remediation. Several years following the simulated remediation, as represented by model results from simulation Year 11 (Figure 4-2b), differences in predicted water column concentration estimates between the Alternatives 1 through 3 simulation and results for Alternatives 4, 5, and 6 are much smaller. Concentration estimates throughout the USEPA's Preliminary Site Perimeter predicted for Alternatives 4 and 5 in Year 11 are indistinguishable from those predicted for Alternatives 1 through 3, and those for Alternative 6 are only slightly higher than Alternatives 1 through 3 (i.e., increases of 50 percent or less), due to elevated flux from sediments (discussed more below).

Figure 4-3 shows time-series plots of model-predicted monthly average water column TCDD concentration estimates averaged over the USEPA's Preliminary Site Perimeter and within the footprint of the TCRA Site for the various alternatives (i.e., Alternatives 4, 5, 6, and Alternatives 1 through 3). This figure also shows the large predicted increases in water column concentration estimates during Year 1 of the simulations for Alternatives 4, 5, and 6 (relative to Alternatives 1 through 3), within both averaging areas; the timing of these increases corresponds directly to the simulated remediation durations associated with these alternatives. After the simulated remediation is complete, the results for Alternatives 4/5 and 6 exhibit differing behavior, as follows:

- Average water column concentration estimates within the USEPA's Preliminary Site Perimeter for Alternatives 4 and 5 are predicted to decrease to levels consistent with those predicted under Alternatives 1 through 3 following the simulated remediation (Figure 4-3, middle panel). Similar results are predicted for average water column concentrations within the footprint of the TCRA Site (Figure 4-3, bottom panel), although the Alternative 4/5 results are predicted to be slightly elevated as compared to Alternatives 1 through 3.
- For Alternative 6, the average water column concentration estimates predicted within the USEPA's Preliminary Site Perimeter generally track those predicted for the Alternatives 1 through 3 simulation following remediation (i.e., after Year 1), but the Alternative 6 results are approximately double those of Alternatives 1 through 3 for approximately 5 years after completion of the simulated dredging, which indicates a long-term impact in some areas. Longer term, water column concentration estimates

within the USEPA's Preliminary Site Perimeter predicted for Alternative 6 approach those of Alternatives 1 through 3 (i.e., after approximately 11 years), as lower concentration sediments are deposited in that area. Average concentrations within the TCRA Site footprint for Alternative 6 are also predicted to decrease after the simulated dredging but remain approximately three to four times higher than those predicted under Alternatives 1 through 3 for the next 10 years, with the difference diminishing slightly, to approximately a factor of two, by the end of the Future Projection Period (Figure 4-3; bottom panel). This predicted difference is due to a combination of sediment residuals generated during dredging within the TCRA Site (i.e., higher concentration sediments at depth are brought to the surface as residuals during removal and subsequently simulated to be entrained within the residual cover) and TCDD that is redistributed following release during dredging; these two factors are discussed further below.

4.2.2.2 Surface Sediment

Time series of model-predicted surface sediment TCDD concentrations averaged over the USEPA's Preliminary Site Perimeter for Alternatives 1 through 3 and Alternatives 4, 5, and 6 are shown on Figure 4-4. This figure shows that the average surface sediment concentrations within this area are predicted to increase in Year 1 under Alternatives 4, 5, and 6, as compared to Alternatives 1 through 3. The magnitudes of these increases differ for each alternative, with those for Alternatives 4 and 5 being 1 and 2 ng/kg (approximate increases of 12 percent and 25 percent), respectively, whereas the concentrations predicted for Alternative 6 at the end of Year 1 represent an approximate three-fold increase relative to Alternatives 1 through 3. This large predicted increase for Alternative 6 is due in part to high sediment residuals that are generated during the simulated dredging within the TCRA Site. The predicted increases for Alternatives 4 and 5, as well as a majority of that predicted for Alternative 6, are due to fluxes of dissolved dioxins/furans simulated to be released during remediation that partition onto suspended sediments and are subsequently re-deposited both within and outside of the TCRA Site footprint. Following these initial increases, the surface sediment concentrations predicted for Alternatives 4, 5, and 6 generally track those of the Alternatives 1 through 3 simulation, declining at an average half-life of about 10 years (albeit at higher concentrations, especially for Alternative 6).

Figure 4-5 shows time-series plots of surface sediment TCDD concentrations averaged over 1-mile reaches within the vicinity of the TCRA Site. The river mile that includes the TCRA Site (River Miles 3 to 2) shows initial increases in sediment concentration for Alternatives 4, 5, and 6 that are similar to those shown on Figure 4-4 (i.e., approximately 10 to 20 percent for Alternatives 4 and 5, and almost three-fold for Alternative 6). For the remaining three 1-mile reaches, the predicted sediment concentrations under Alternatives 4 and 5 are similar to or slightly higher in some cases (e.g., Alternative 5 in River Miles 4 to 3) than those predicted under Alternatives 1 through 3. However, the results for Alternative 6 show noticeable predicted increases in concentration relative to Alternatives 1 through 3 in all three one-mile reaches (although the absolute magnitude of these increases is small in some cases; e.g., 1 to 2 ng/kg in River Miles 5 to 4). These increases are due to dissolved TCDD that was simulated to be released during remediation within the TCRA Site, and was predicted to partition onto suspended sediments that were being transported in the area and subsequently deposited outside of the TCRA Site footprint. The larger increase predicted for River Miles 3 to 2 under Alternative 6 is also due in part to the simulated sediment residuals generated during dredging within the TCRA Site. The effects of dredge release and subsequent redistribution for Alternative 6 are further explored through the graphics described below.

The effects of redistribution of TCDD following release during remediation, as predicted by the model, are further evident when surface sediment concentrations are viewed on a model grid cell basis. Figures 4-6a, 4-6b, and 4-6c present maps of model-predicted surface sediment concentrations at the end of simulation Year 1 for Alternatives 4, 5, and 6, respectively. Each figure shows the results from the Alternatives 1 through 3 simulation on the left panel (for comparison), the results for the given alternative on the center panel, and the difference between concentrations predicted for the given alternative and Alternatives 1 through 3 on the right panel (positive values on these panels indicate a predicted increase in concentration relative to Alternatives 1 through 3). These figures illustrate the predicted spatial patterns of TCDD redistribution following release during remediation for Alternatives 4, 5, and 6, as indicated by the areas of increased concentrations surrounding the TCRA Site. The magnitude of these increases and spatial extent over which they occur differs by alternative, according to the magnitude of TCDD mass simulated to be released during remediation. For example, for Alternative 4, a relatively small zone of increases in the range

of 1 to 3 ng/kg is predicted (Figure 4-6a), with larger increases of 3 to 10 ng/kg predicted within the TCRA Site footprint. The corresponding areas of similar increases are larger for Alternative 5 (Figure 4-6b), with increases of 3 to 10 ng/kg extending beyond the TCRA Site footprint and downstream of the I-10 Bridge, and increases of 1 to 3 ng/kg occurring over half of the USEPA's Preliminary Site Perimeter. In contrast, the redistribution following the simulated Alternative 6 dredge release is extensive; it is predicted to result in increases in 3 to 10 ng/kg over most of the USEPA's Preliminary Site Perimeter, with increases of over 30 ng/kg immediately adjacent to the TCRA Site.

Model results averaged over the TCRA Site footprint are shown on Figure 4-7. As described in Section 3.2.2.2, the results for Alternatives 1 through 3 shown on this plot represent the average TCDD concentration in sediments that deposit on the surface of the TCRA cap (which approach 2 ng/kg at the end of the Future Projection Period). The results for Alternatives 4, 5, and 6 show differences relative to Alternatives 1 through 3 that reflect the effects of simulated release/redistribution and dredge residuals in the case of Alternative 6. For Alternatives 4 and 5, the effects of simulated release during remediation within the TCRA Site and subsequent redeposition causes predicted TCDD concentrations to increase to 30 and 40 ng/kg, respectively. The model's representation of dredging conducted under Alternative 6 results in an average surface sediment concentration in this area that is more than two orders of magnitude higher than Alternatives 1 through 3 (i.e., over 200 ng/kg). This value is consistent with the concentration of the residual cover specified in this area (see Table 4-1) but higher as a result of TCDD that was predicted to be released during dredging and subsequently redeposited in that area. Following these initial increases associated with remediation, the concentrations within the TCRA Site are predicted to decrease by approximately a factor of two over the remainder of the simulations of Alternatives 4, 5, and 6, as a result of deposition of sediments derived from upstream areas.

Overall, the simulations of Alternatives 4, 5, and 6 indicate that short- and long-term impacts associated with simulated releases during sediment remediation and dredge residuals in the case of Alternative 6 are predicted to result in increases in estimated surface water and surface sediment concentrations when compared to the Alternatives 1 through 3 simulation. The magnitudes of these increases differ by alternative and the spatial scale over which

model results are averaged, with those associated with Alternative 6 and the small scale of the TCRA Site area being the largest.

5 SUMMARY

The modeling framework developed in the Chemical Fate and Transport Modeling Study was used as a tool for evaluating remedial alternatives in the FS.

As directed by USEPA (Miller 2012, pers. comm.), additional hydrodynamic and sediment transport model sensitivity analyses were first conducted. Analyses using an alternate data source to specify WSE at the downstream hydrodynamic model boundary indicated minimal effect on sediment transport within the USEPA's Preliminary Site Perimeter. Model simulations were conducted to evaluate high-flow events with return periods of 2, 10, and 100 years. Within the USEPA's Preliminary Site Perimeter, the model predicted areas of both net deposition and net erosion for these flood event simulations, with increases in the area and depth of erosion with increasing return period flows. In general, depths of erosion and deposition within the corresponding areas during these events were predicted to average a few cm or less, with bed scour greater than 10 cm only being predicted in a limited area for the 100-year event. Longer-term simulations that include the effects of an approximate 100-year flood event indicate that following such erosion during flood events, the system recovers, consistent with its state of long-term net deposition.

The chemical fate model was then used to develop future predictions of dioxin and furan concentrations in sediment and surface water within the Model Study Area. Simulations were first conducted for post-TCRA future conditions by configuring the model to represent the cap at the TCRA Site. This included changing sediment transport model inputs to reflect the characteristics of the armored TCRA cap and setting the chemical concentration of the corresponding grid cells to zero in the chemical fate and transport model (to represent the cap's elimination of dioxin/furan flux to the surface water). The model was run for a 21-year future period based on the hydrologic record from 1990 through 2011 that included wide variations in flows and tidal conditions, including an approximate 100-year event. These post-TCRA future simulations were also conducted with alternate sets of model input parameters, for both sediment transport and chemical fate, to develop uncertainty bounds on the model predictions.

By comparing results from the post-TCRA simulations to those from similar simulations conducted based on pre-TCRA sediment concentrations, the model was used to evaluate the effects of the TCRA on surface water dioxin and furan concentration estimates within the Model Study Area. The chemical fate model predicted significant improvements in surface water concentrations as a result of the TCRA; reductions were predicted over several spatial scales. Within the USEPA's Preliminary Site Perimeter, surface water concentration estimates were predicted to be reduced by a factor of 2 to 3 (with the post-TCRA concentrations being driven by sources of dioxins/furans from upstream transport and point and non-point sources in the Model Study Area). These findings were not significantly affected by the model uncertainty analysis, which provided quantitative bounds on these reductions. However, it should be noted that the underlying water column dataset used to develop and calibrate the fate and transport model was smaller than the sediment data, imparting some uncertainty in the predictions of absolute concentrations.

The long-term post-TCRA simulations were also used to predict rates of natural recovery in surface sediments; these predictions are representative of FS Alternatives 1, 2, and 3. The model predicted long-term declines in average surface sediment concentrations throughout the USEPA's Preliminary Site Perimeter consistent with an approximate 10-year half-life. Although there are periods of variability in the predicted surface sediment concentration trends that coincide with variations in flow and sediment transport conditions (e.g., periodic erosion), the longer-term predicted trends are characterized by declines throughout the simulation. Uncertainty analyses conducted for these simulations did not produce significantly differing results—despite the relatively wide ranges in parameter values evaluated, the model predicted long-term declines in surface sediment concentration in all cases and spatial scales. The model also predicted average surface sediment concentrations in the TCRA cap, which initially were set to zero, to increase to a level that approaches regional background concentrations.

Finally, simulations were conducted for the active sediment remediation alternatives (i.e., partial S/S and removal within the TCRA Site for FS Alternatives 4 and 5, respectively, and extensive sediment removal within the TCRA Site and one other area for Alternative 6). In addition to evaluating general long-term trends for these alternatives, the model was used to quantify potential short- and long-term impacts associated with the sediment remediation

activities (i.e., sediment resuspension and release during remediation and the effects of dredge residuals). Within and outside the TCRA Site footprint, the model predicted large increases in surface water concentrations during Year 1 of the simulations of Alternatives 4, 5, and 6 (relative to the simulation of Alternatives 1 through 3). These short-term increases in predicted surface water concentrations ranged from approximately an order of magnitude for Alternative 4 to greater than two orders of magnitude for Alternative 6, and were due to simulated releases during remediation. Following the initial simulated remediation period, model results for Alternatives 4 and 5 showed little to no increase in surface water concentration estimates relative to Alternatives 1 through 3, whereas predicted concentrations for Alternative 6 remained higher than the Alternatives 1 through 3 simulation by a factor of 2 or more throughout the duration of the long-term simulation. Increases in surface sediment concentration in and around the TCRA Site (relative to Alternatives 1 through 3) were also predicted for Alternatives 4, 5, and 6. These increases were a result of simulated dissolved phase releases during remediation that partition onto suspended sediments as they are transported in the area and subsequently deposit on the sediment bed, as well as dredge residuals in the case of Alternative 6. The magnitude of these increases differed by alternative and also by the spatial scale over which the model results were averaged, with those associated with Alternative 6 and the small scale of the TCRA Site area being the largest. The spatial extent of these predicted increases was also greatest for Alternative 6, for which increases were predicted to occur over large portions of the USEPA's Preliminary Site Perimeter.

Overall, the results from the post-TCRA simulations of natural recovery (i.e., Alternatives 1, 2, and 3) and the simulations of the active sediment remediation alternatives (i.e., Alternatives 4, 5, and 6) provide predictions of long-term relative changes in surface water and sediment dioxin/furan concentrations, as well as quantitative estimates of the potential short- and long-term effects of sediment remediation, that were used to support the comparative evaluation of alternatives conducted in the FS.

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FIGURES

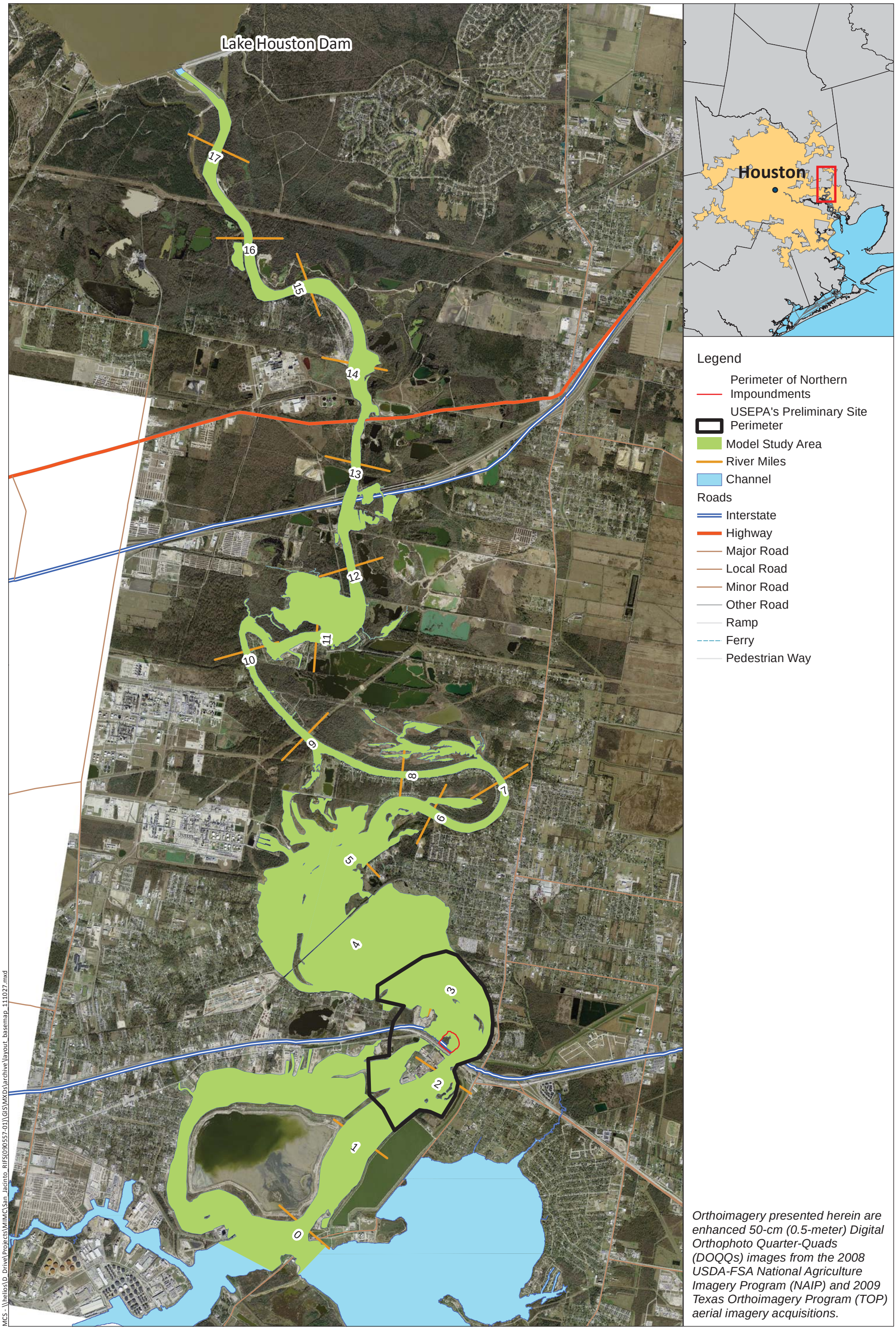

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Figure1-1
Model Study Area
Feasibility Study
San Jacinto River Waste Pits Superfund Site

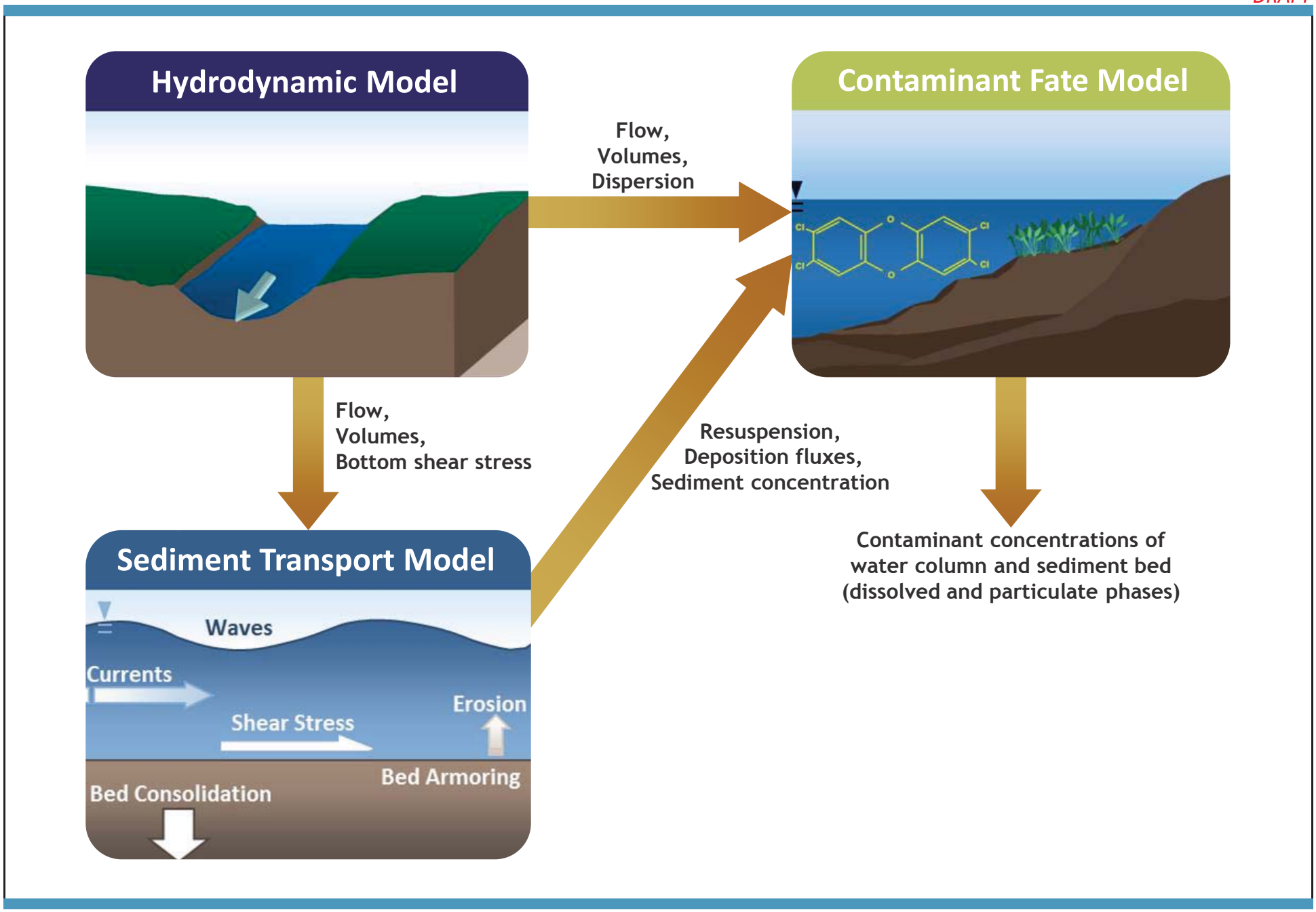

Figure 1-2
Fate Model Linkages
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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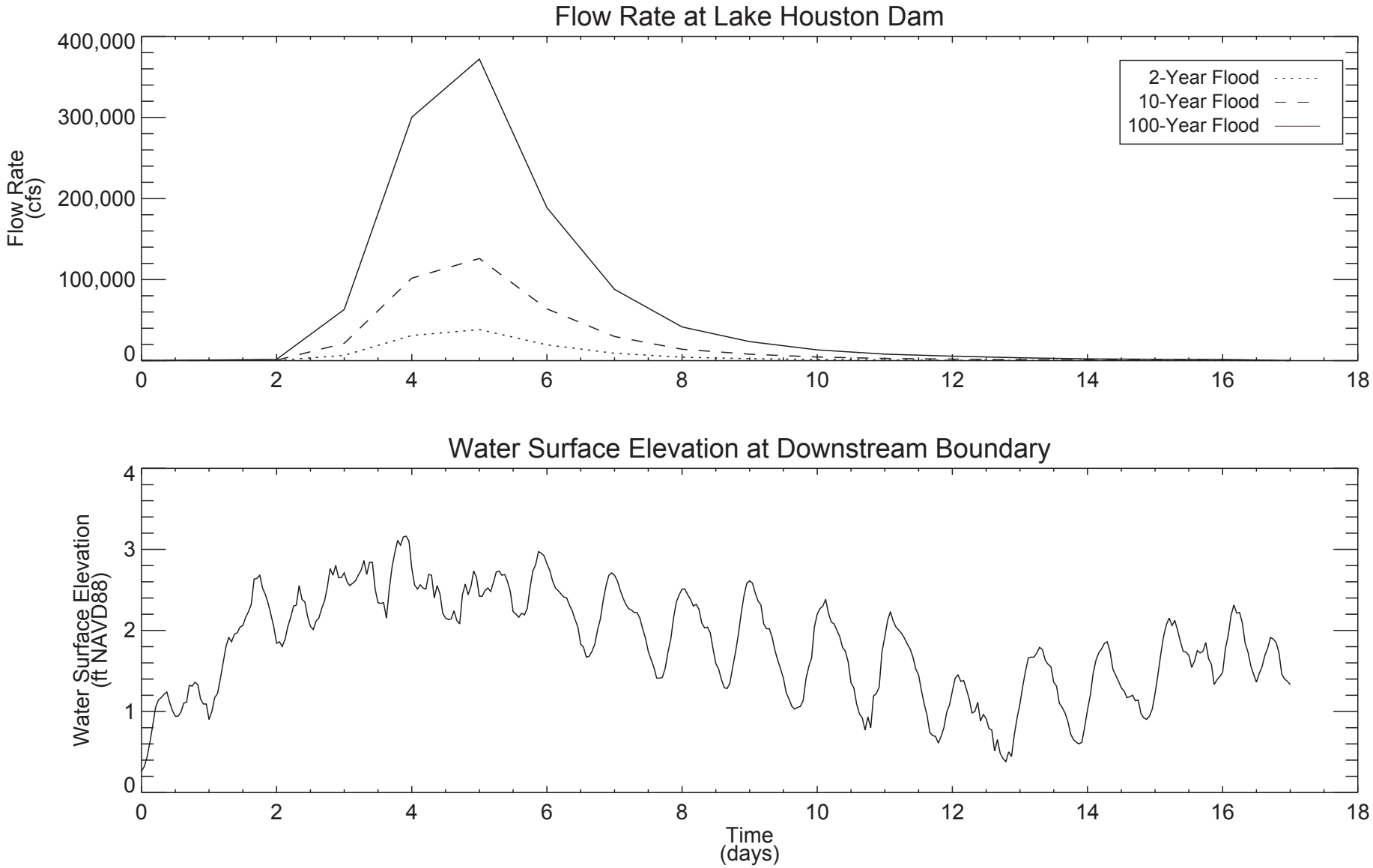

Figure 2-1

Time Variable Hydrodynamic Boundary Conditions for High-Flow Event Simulations
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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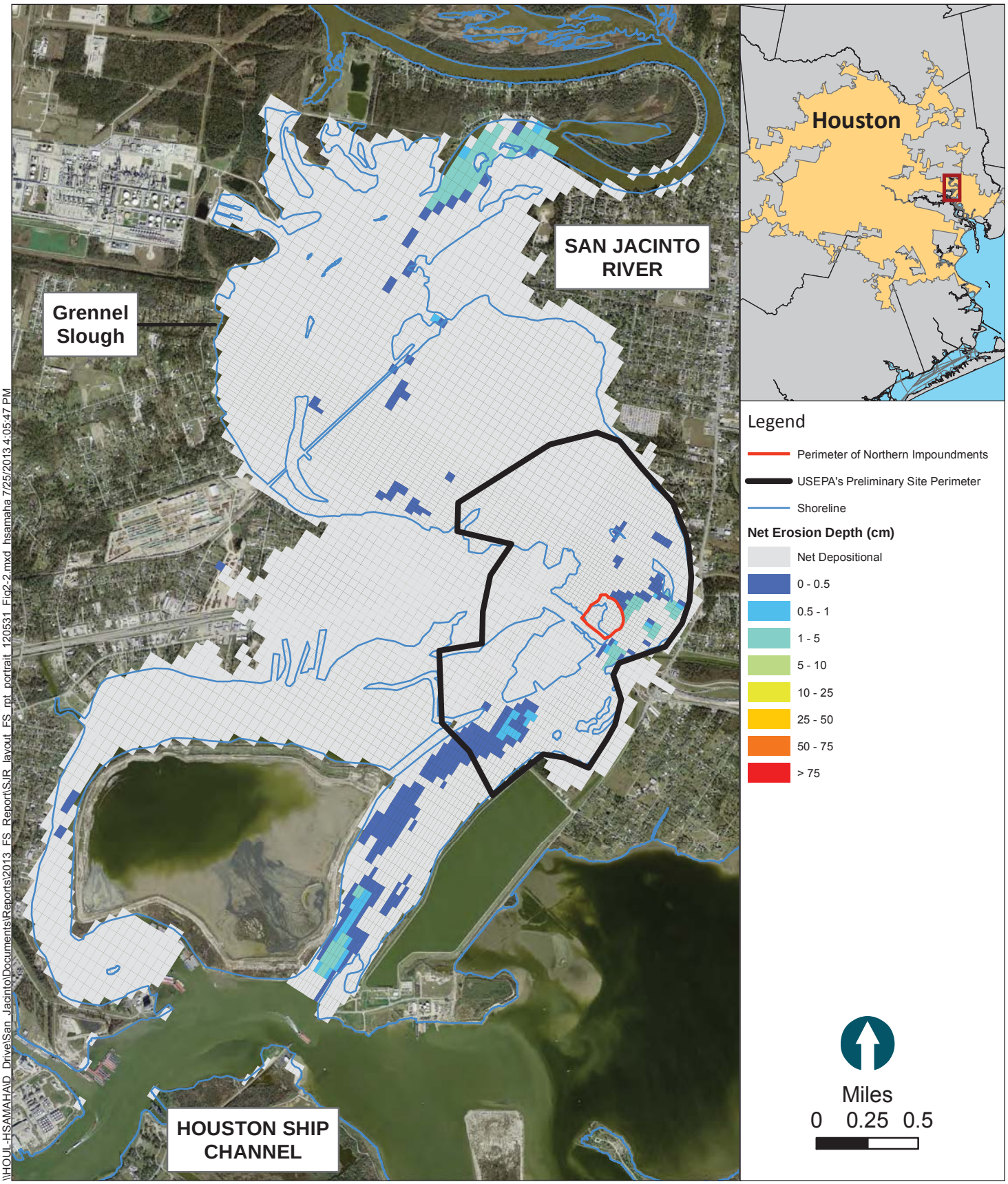

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Figure 2-2
Spatial Distribution of Predicted Net Erosion During 2-Year Flood
Feasibility Study
San Jacinto River Waste Pits Superfund Site

ANCHOR QEA

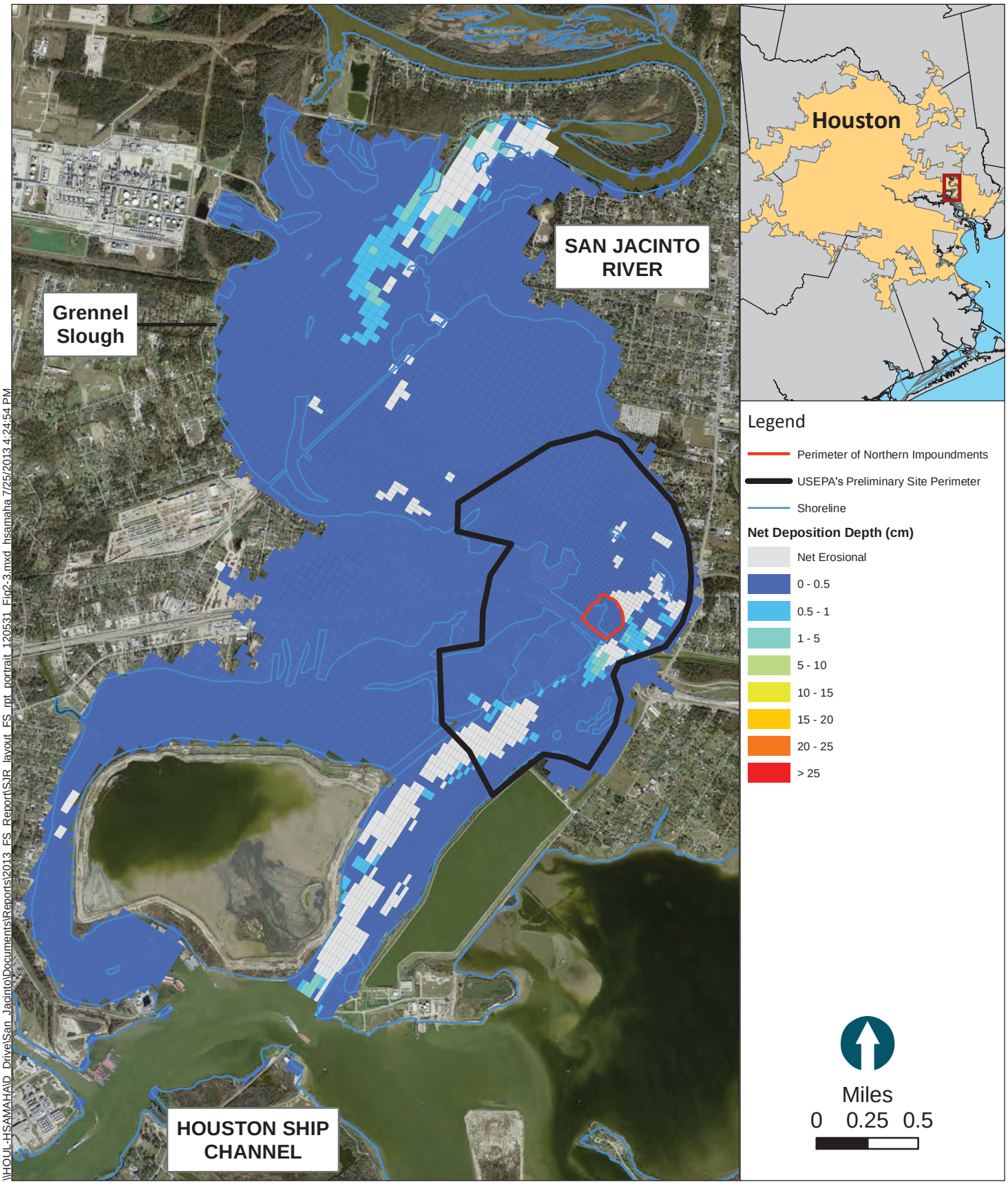

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Figure 2-3
Spatial Distribution of Predicted Net Deposition During 2-Year Flood
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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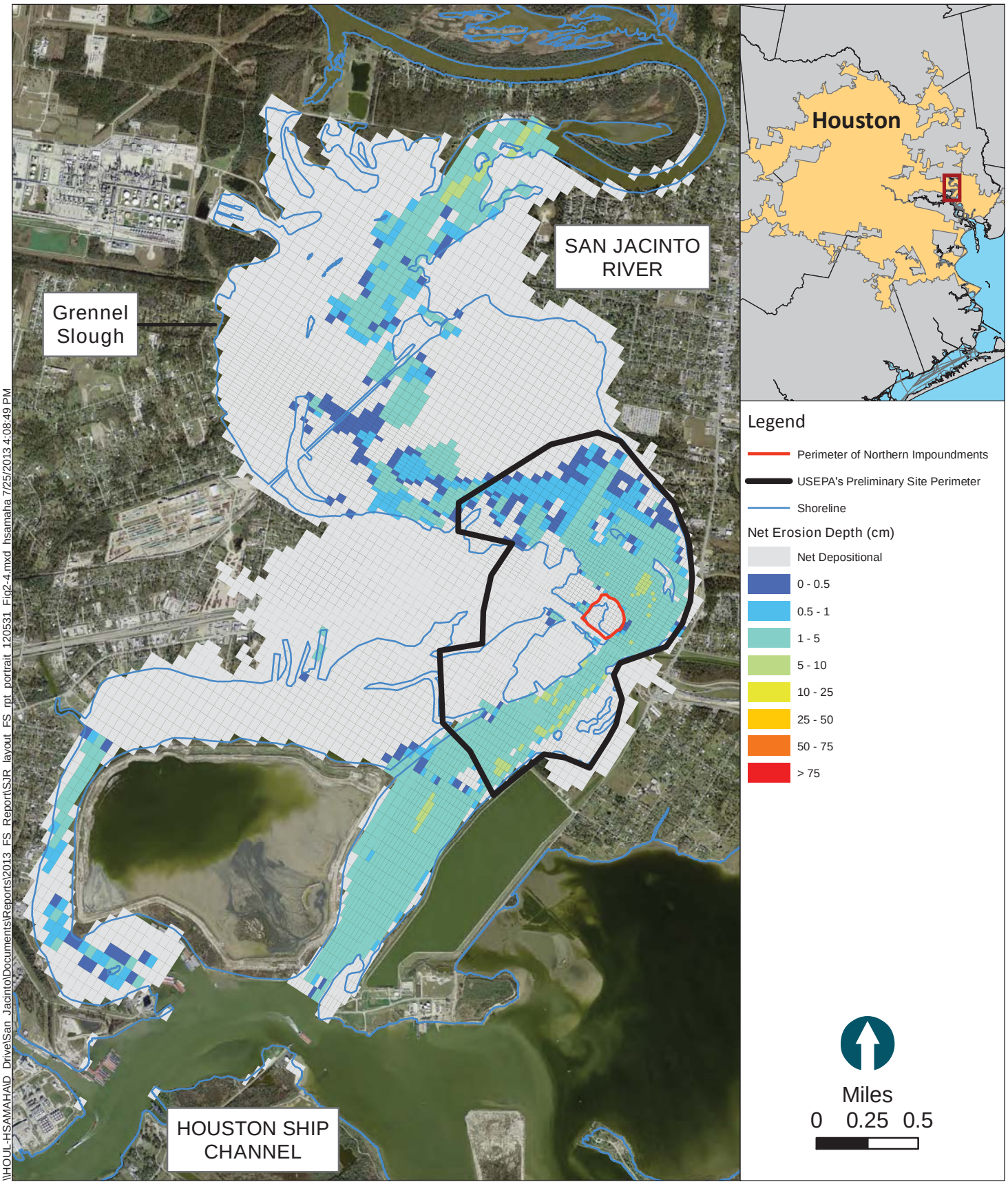

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Figure 2-4
Spatial Distribution of Predicted Net Erosion During 10-Year Flood
Feasibility Study
San Jacinto River Waste Pits Superfund Site

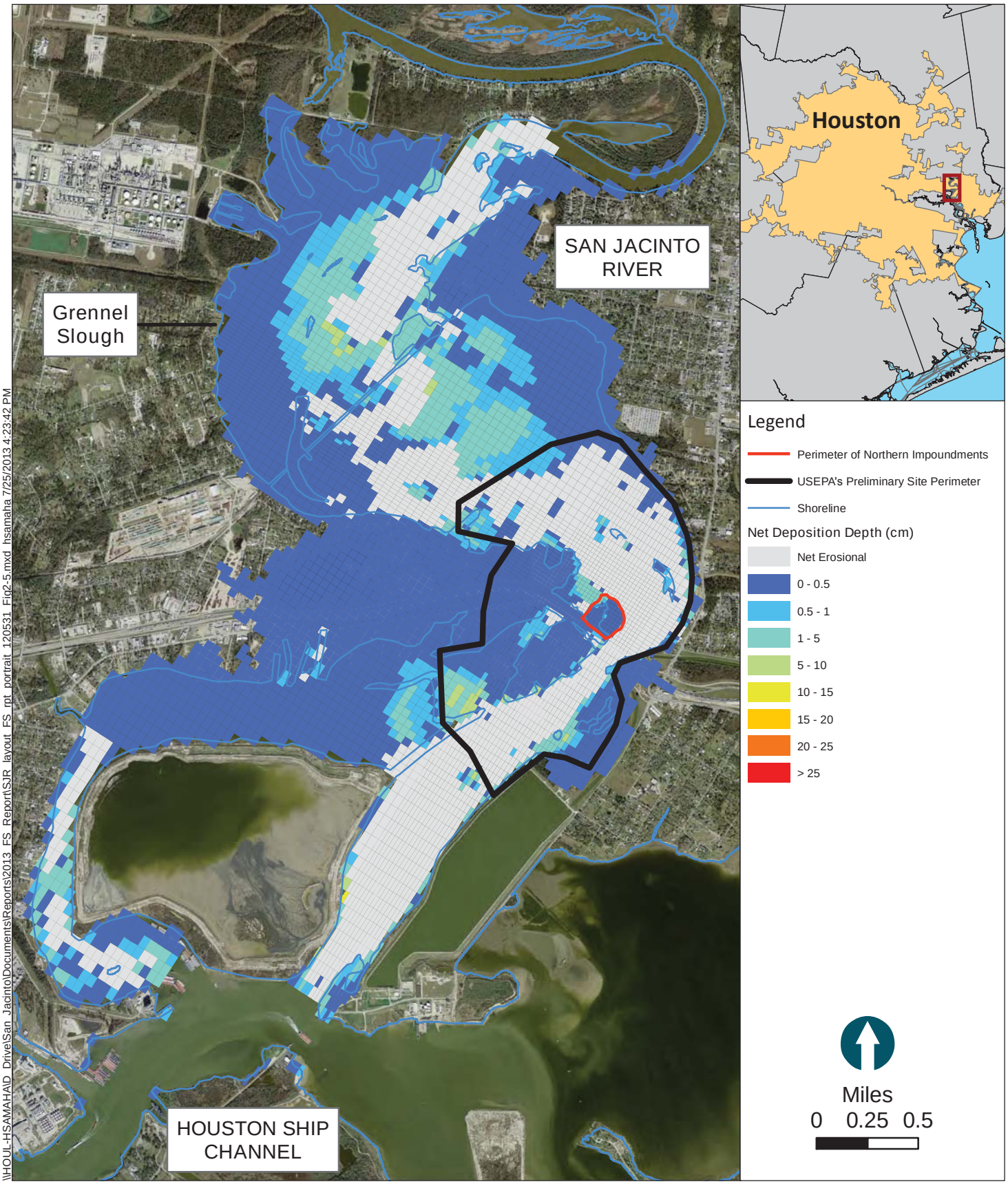

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Figure 2-5
Spatial Distribution of Predicted Net Deposition During 10-Year Flood
Feasibility Study
San Jacinto River Waste Pits Superfund Site

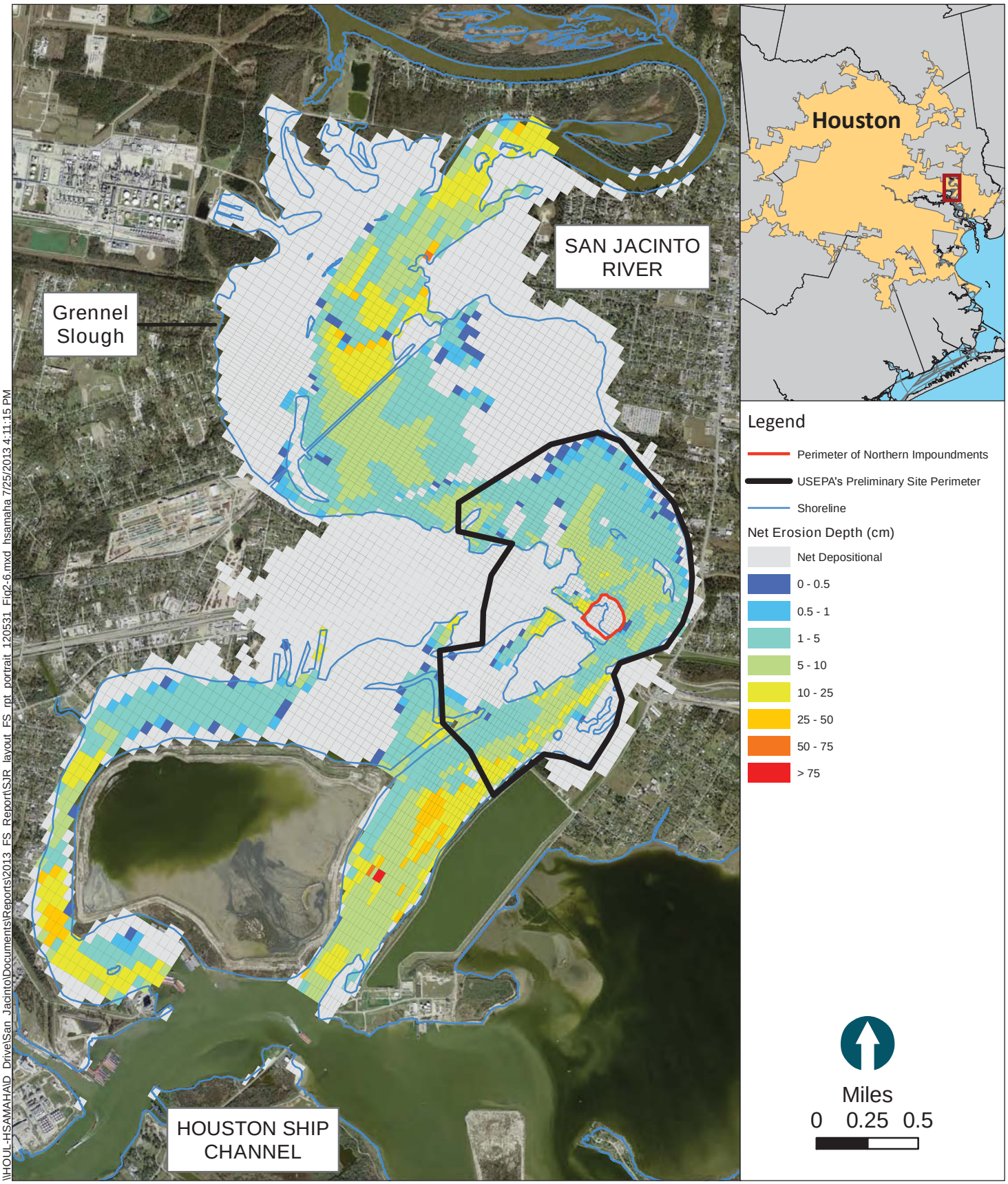

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Figure 2-6
Spatial Distribution of Predicted Net Erosion During 100-Year Flood
Feasibility Study
San Jacinto River Waste Pits Superfund Site

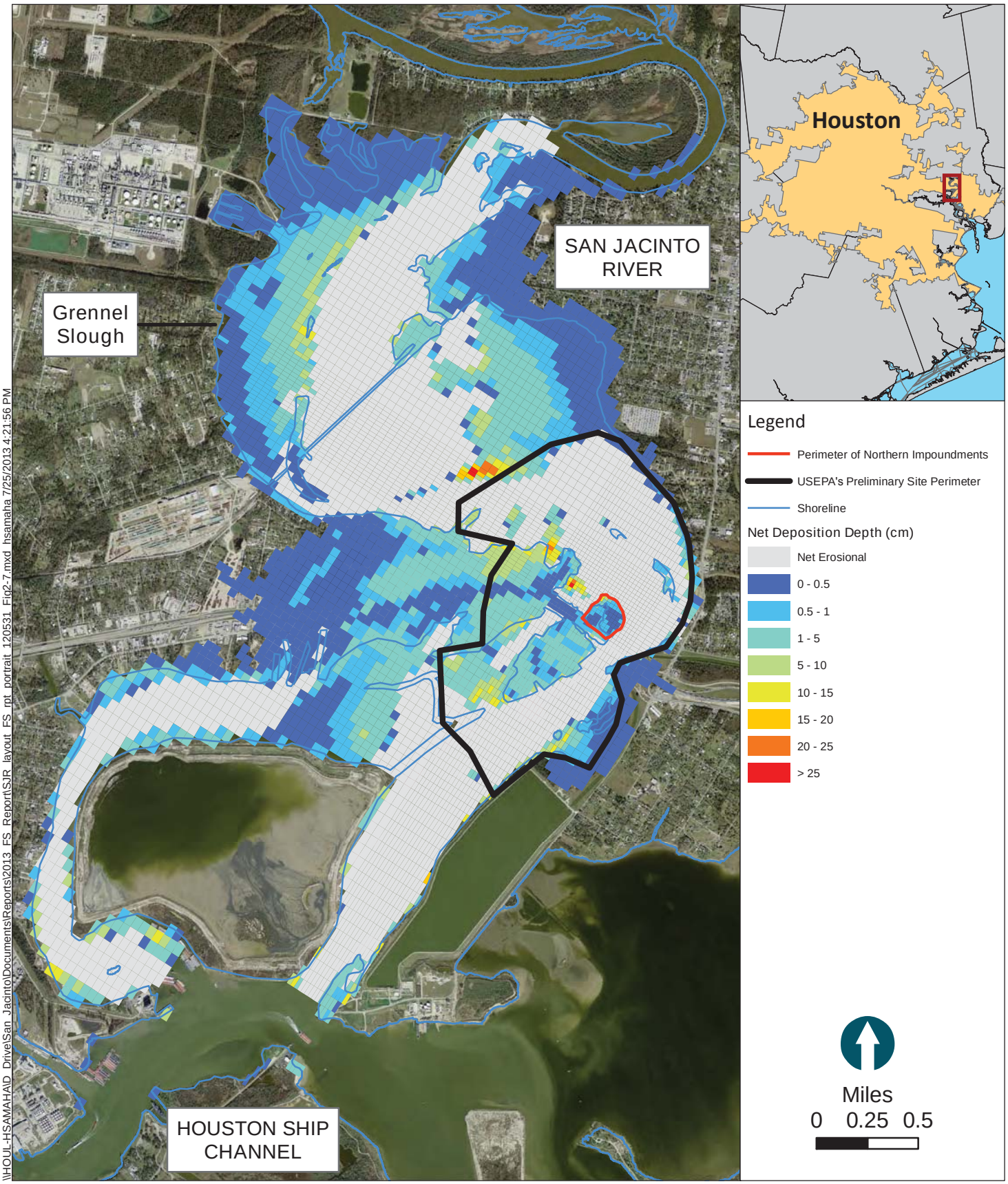

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Figure 2-7
Spatial Distribution of Predicted Net Deposition During 100-Year Flood
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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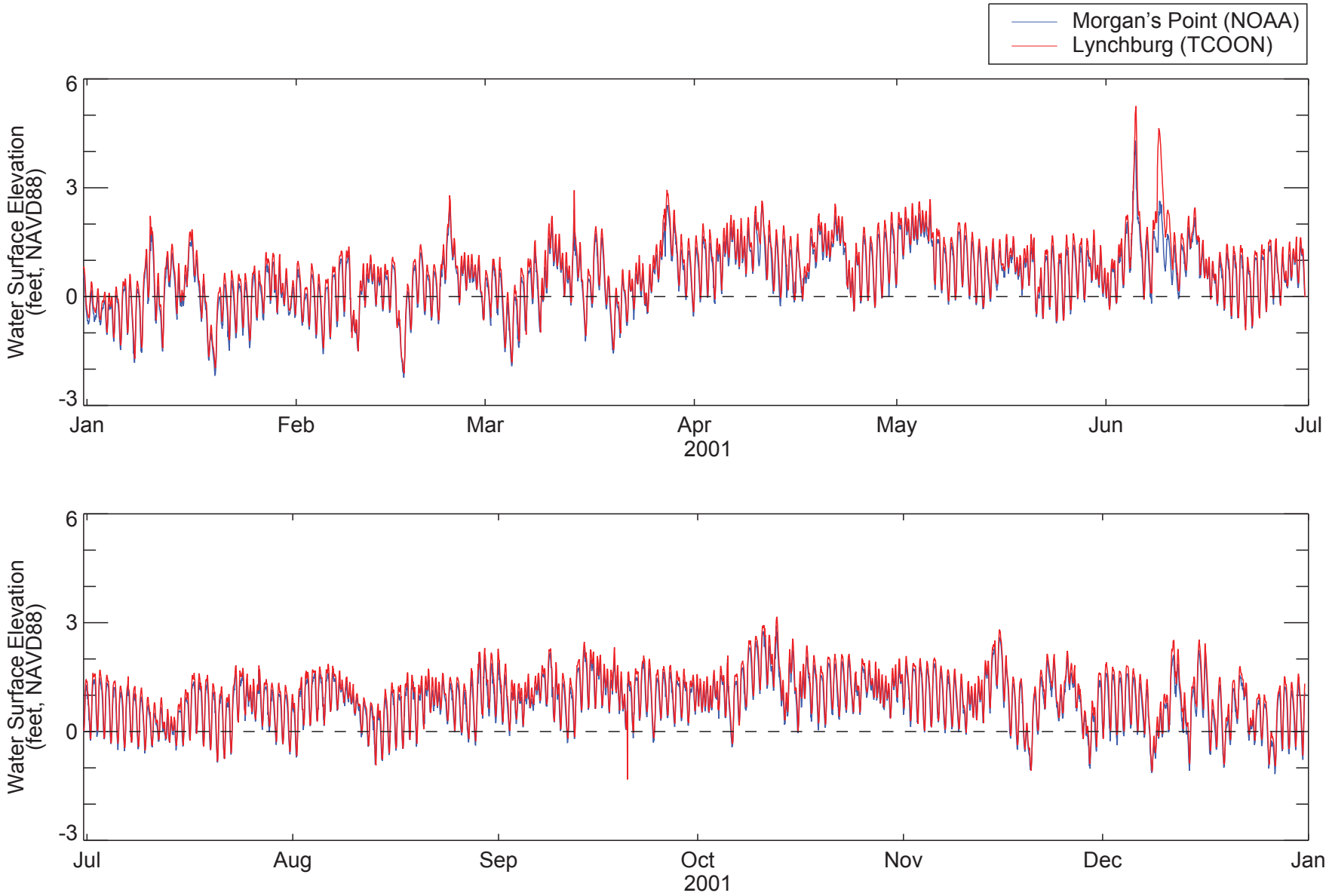

Figure 2-8

Comparison of Water Surface Elevations Measured at Morgan's Point and Lynchburg Gauge Stations During 2001
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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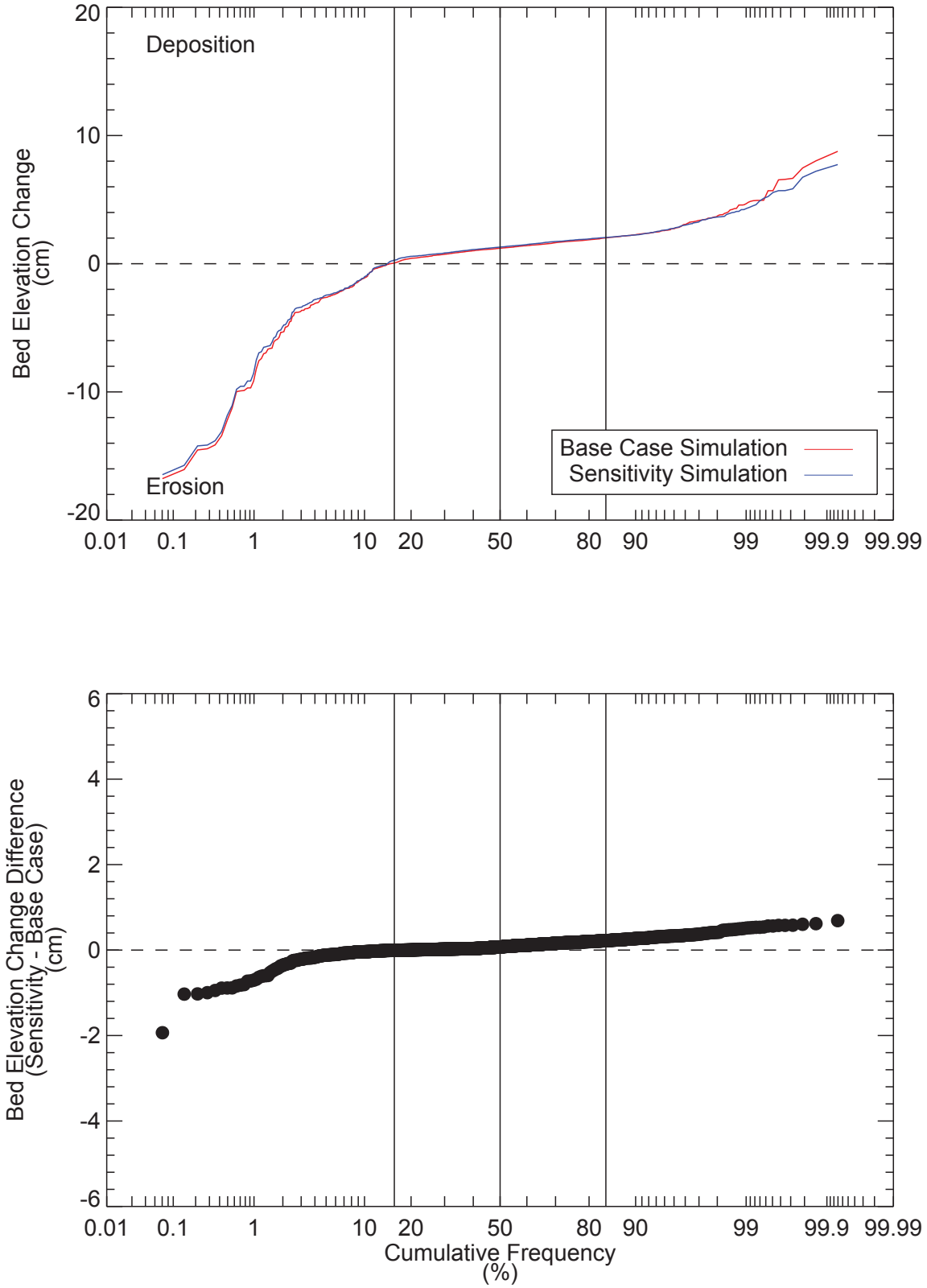

Figure 2-9

WSE Boundary Condition Sensitivity Analysis: Comparison of Cumulative Frequency Distributions of Bed Elevation Change for Base Case and Sensitivity Simulations
Feasibility Study
San Jacinto River Waste Pits Superfund Site

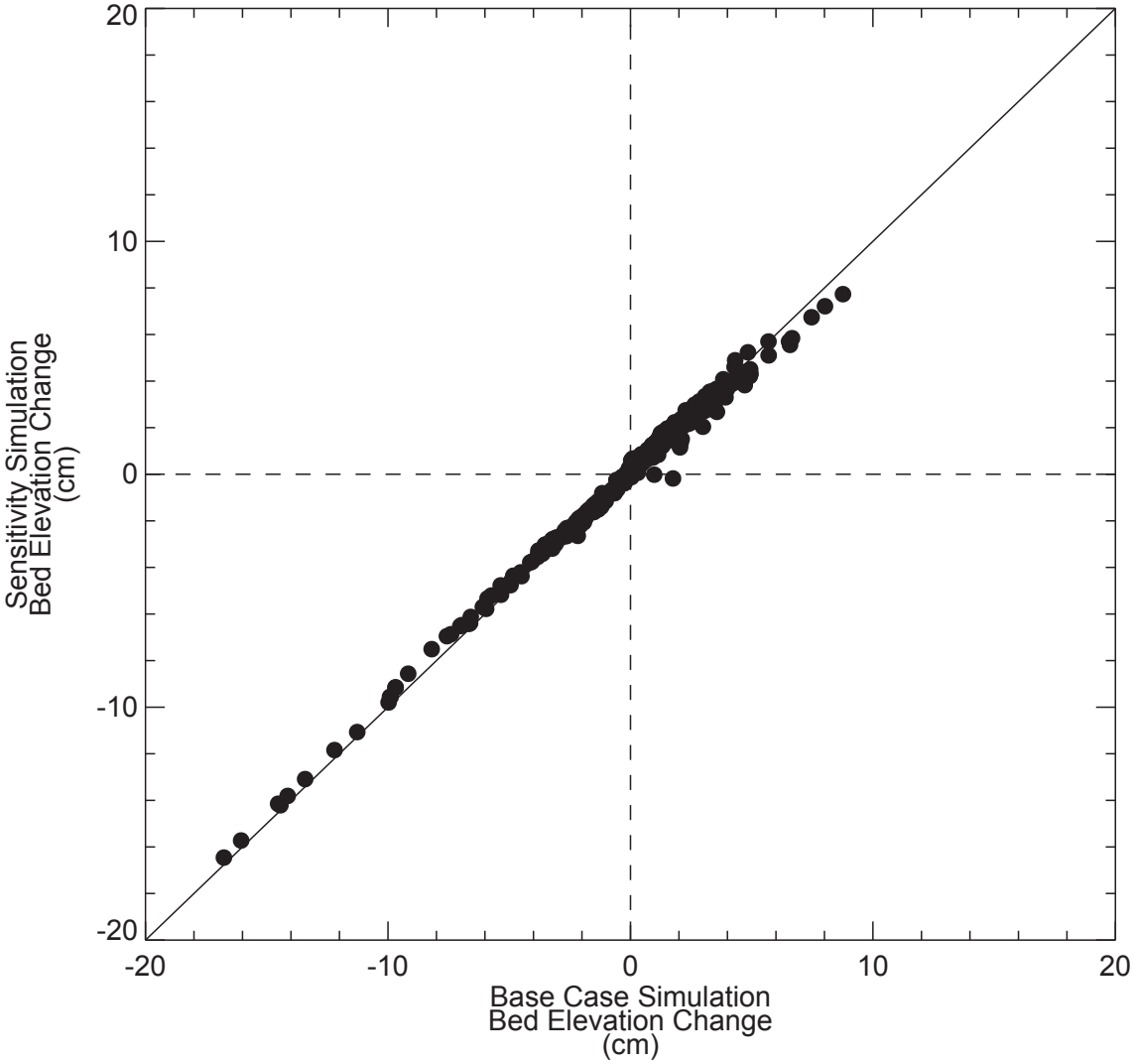

Figure 2-10

WSE Boundary Condition Sensitivity Analysis: One-to-One Comparisons of Bed Elevation Change for Base Case and Sensitivity Simulations
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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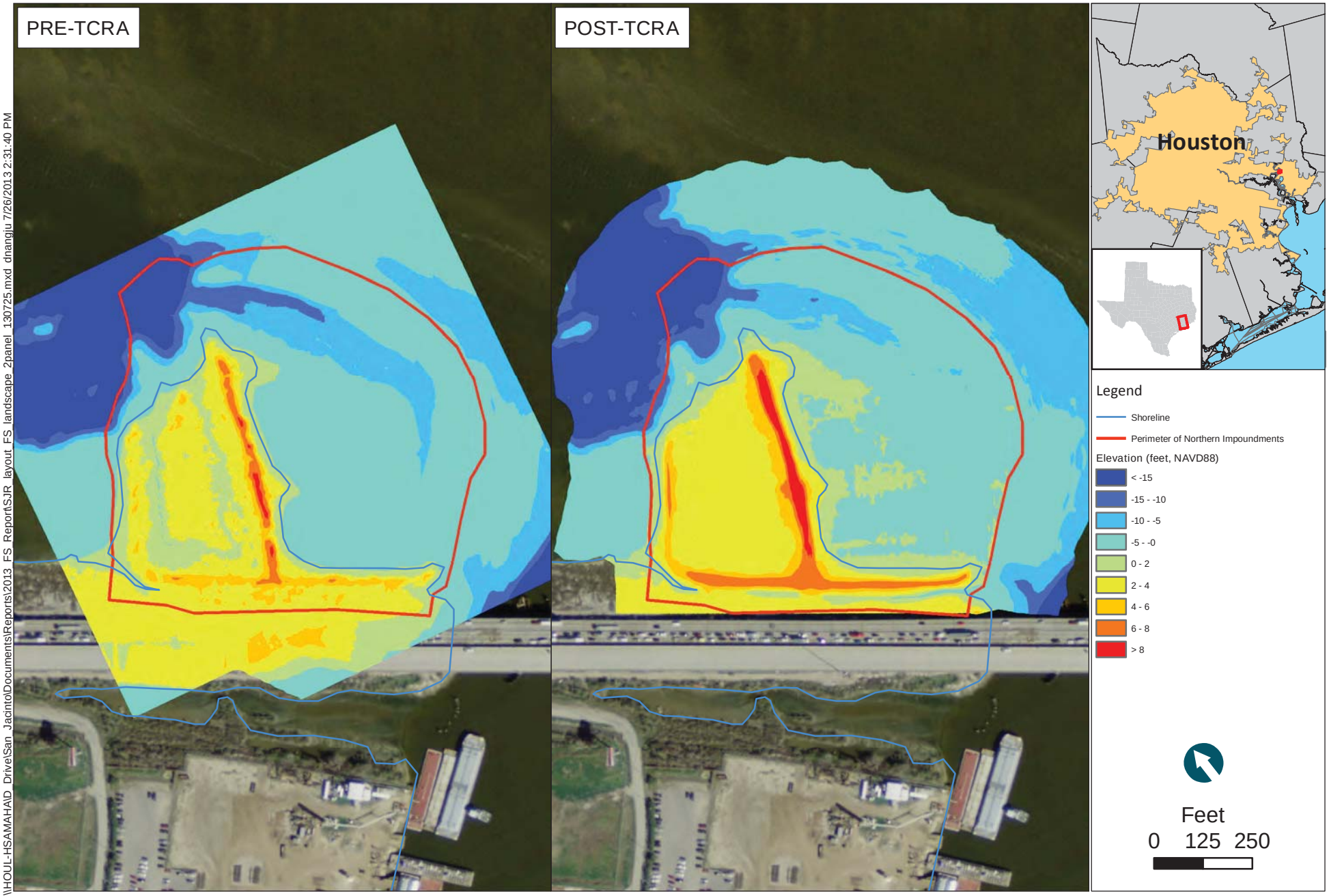

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Figure 3-1
Comparison of Bathymetry and Topography near the TCRA Site: Pre- and Post-TCRA
Feasibility Study
San Jacinto River Waste Pits Superfund Site

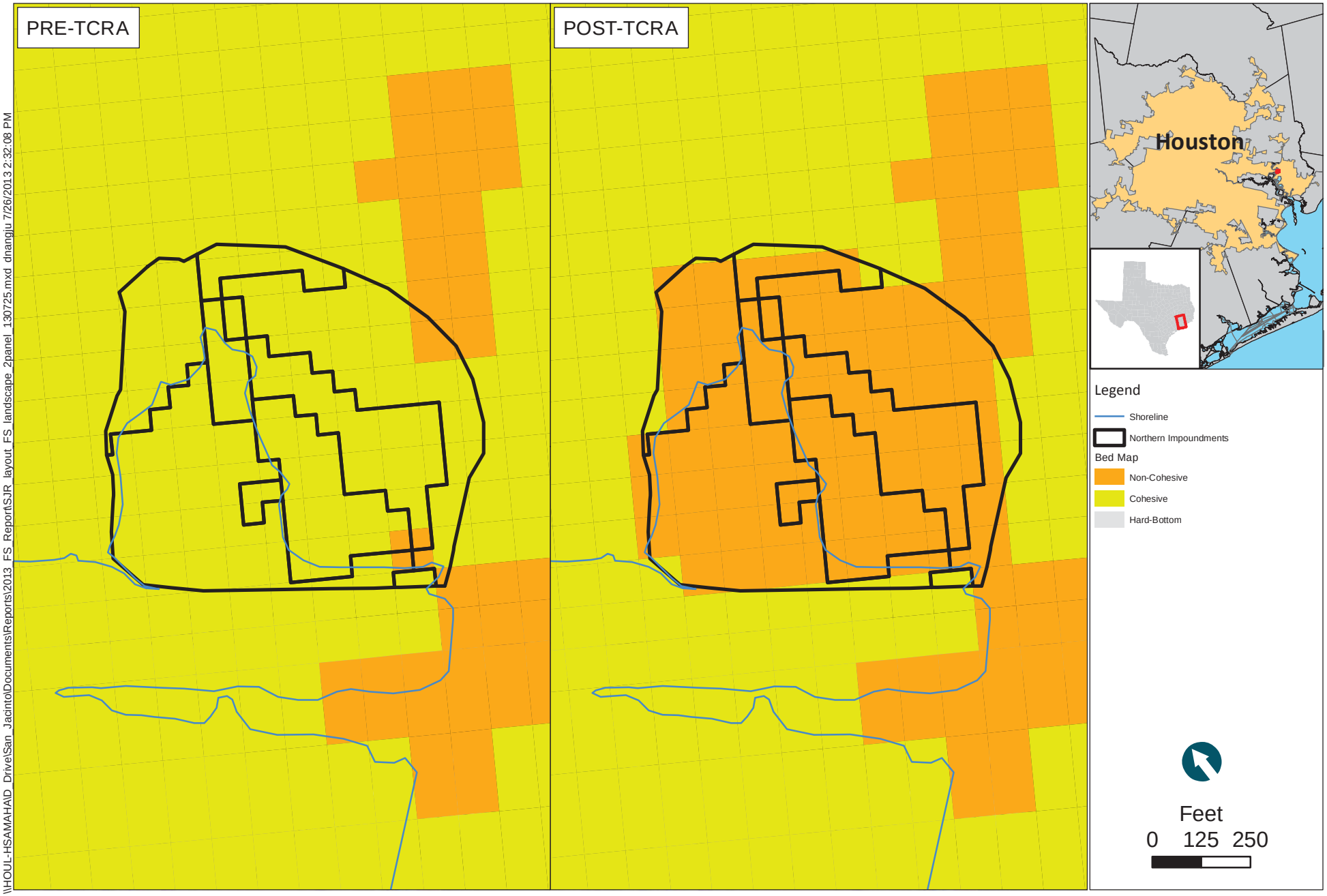

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Figure 3-2
Comparison of Sediment Bed Map in the TCRA Site Used for Model Input: Pre- and Post-TCRA
Feasibility Study
San Jacinto River Waste Pits Superfund Site

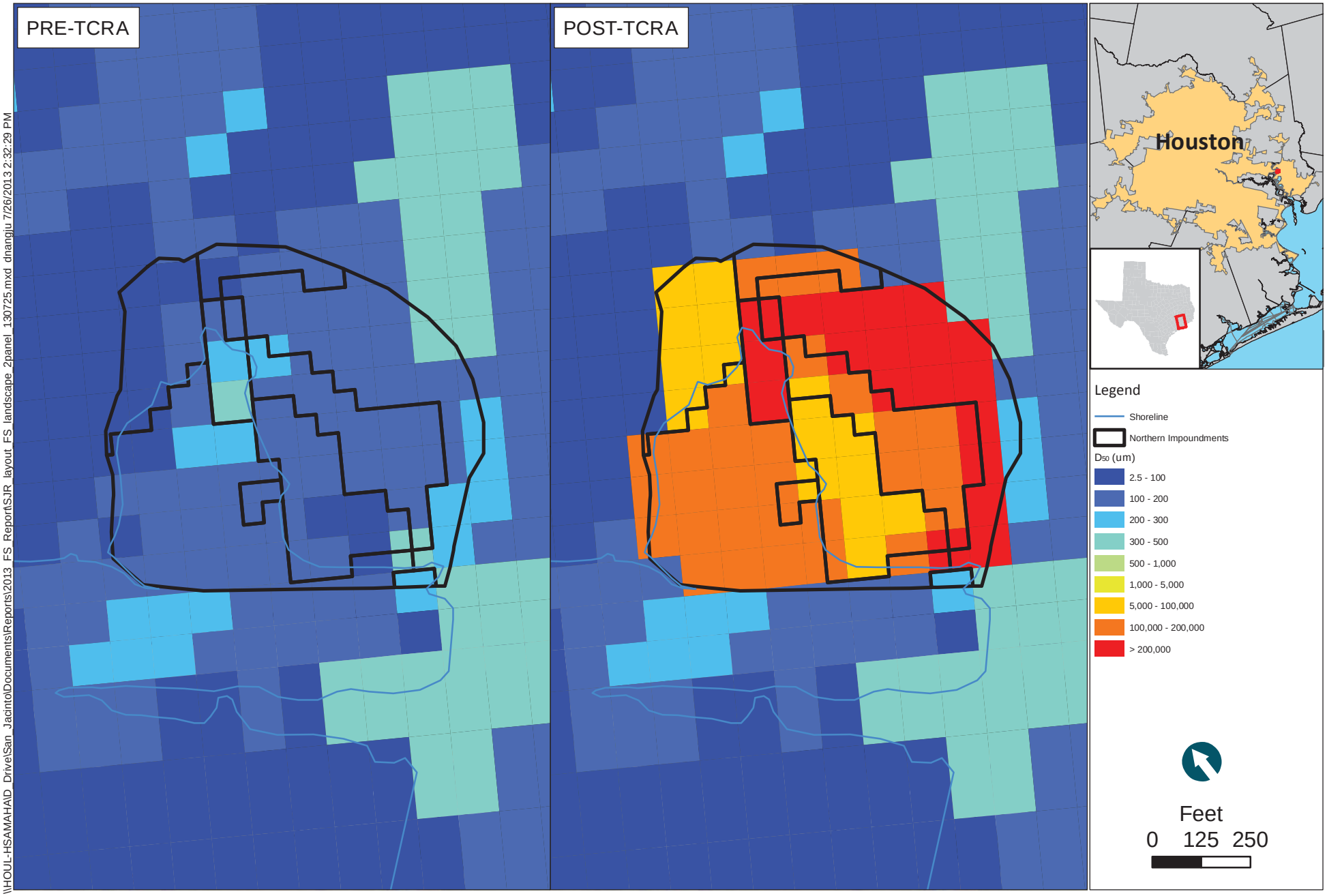

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Figure 3-3
Comparison of D_{50} in the TCRA Site Used to Specify Initial Conditions: Pre- and Post-TCRA
Feasibility Study
San Jacinto River Waste Pits Superfund Site

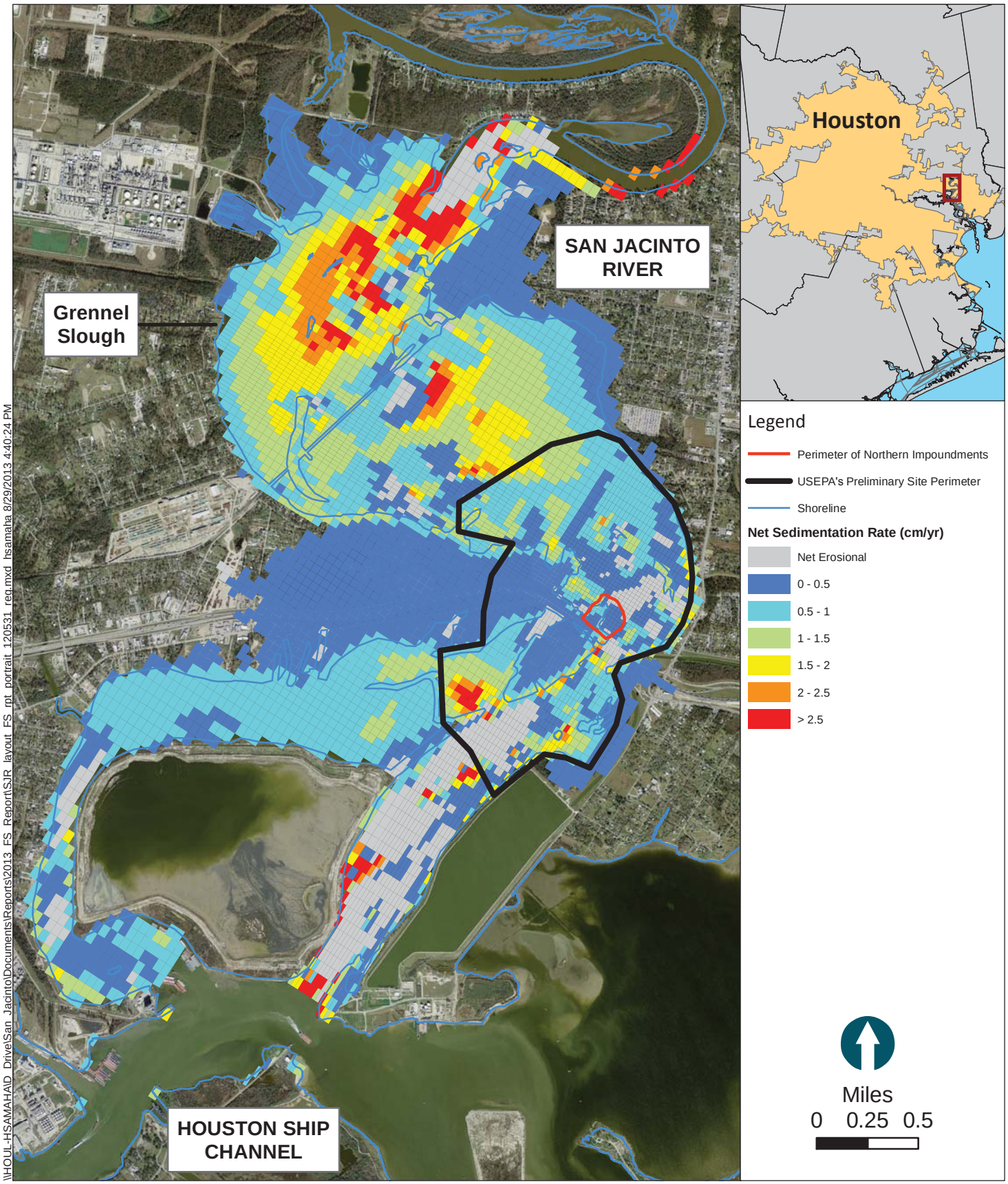

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Figure 3-4
Spatial Distribution of Predicted Net Sedimentation Rate for 21-Year Period: Pre-TCRA Base Case Simulation
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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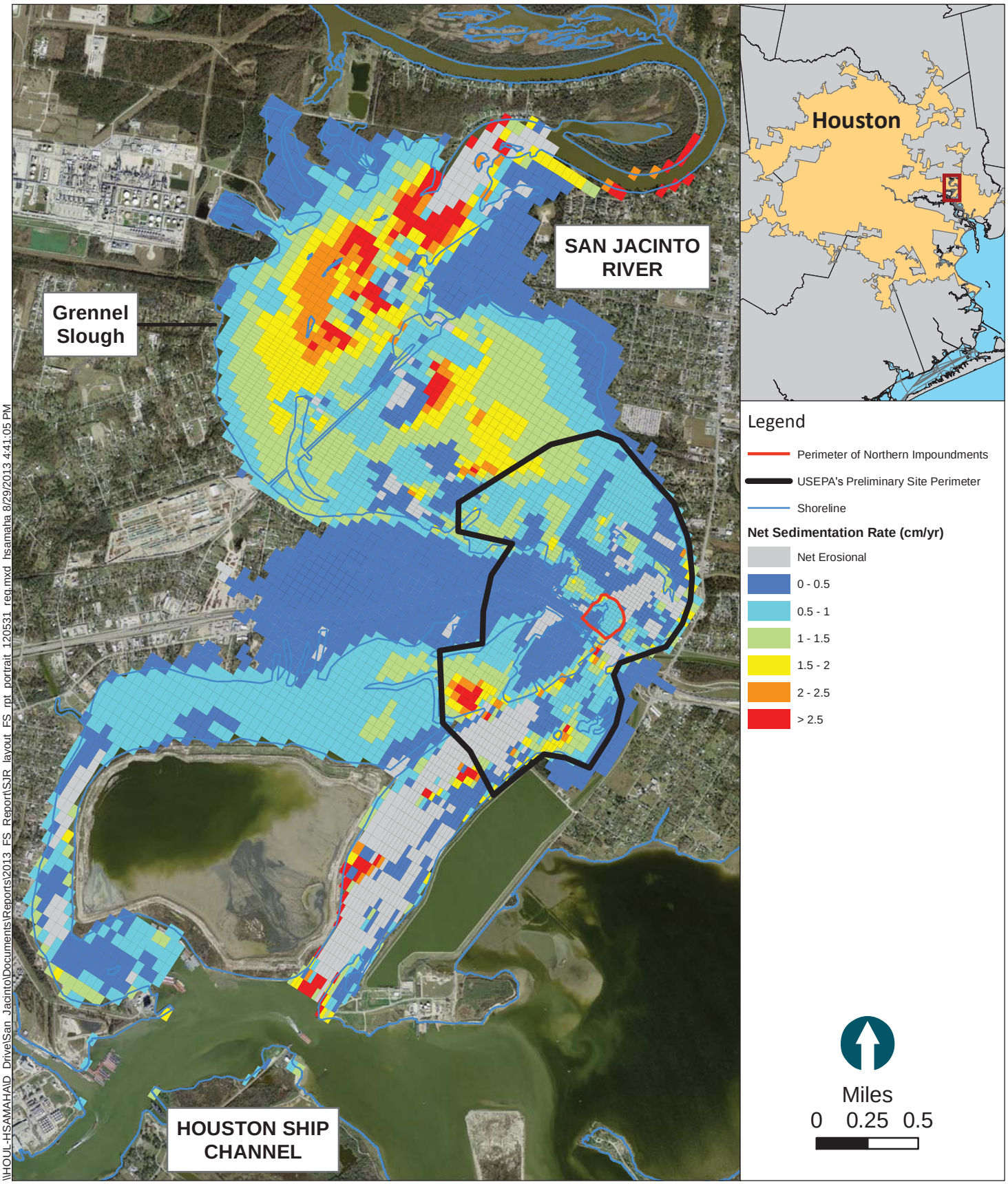

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Figure 3-5
Spatial Distribution of Predicted Net Sedimentation Rate for 21-Year Period: Post-TCRA Base Case Simulation
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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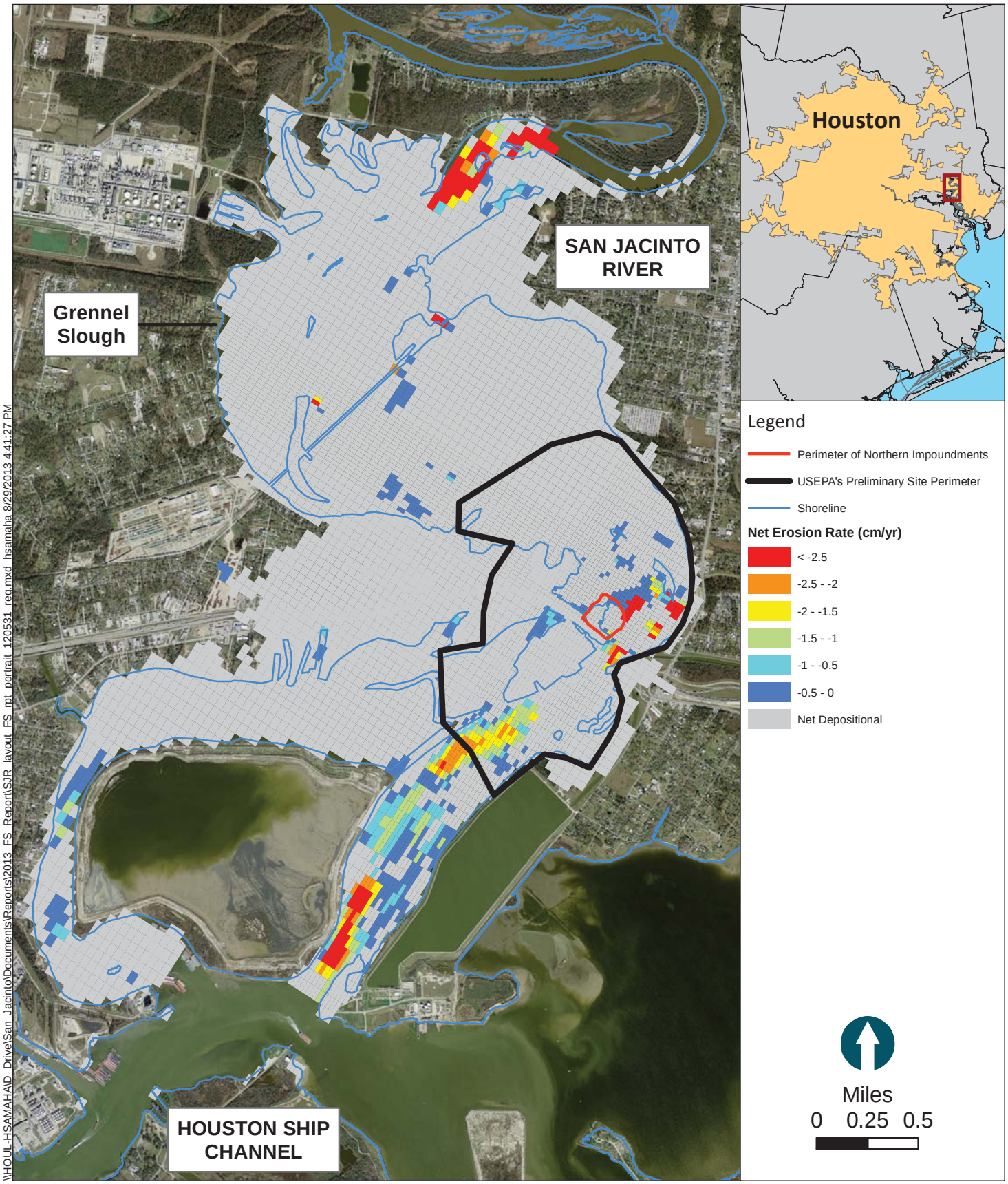

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Figure 3-6
Spatial Distribution of Predicted Net Erosion Rate for 21-Year Period: Pre-TCRA Base Case Simulation
Feasibility Study
San Jacinto River Waste Pits Superfund Site

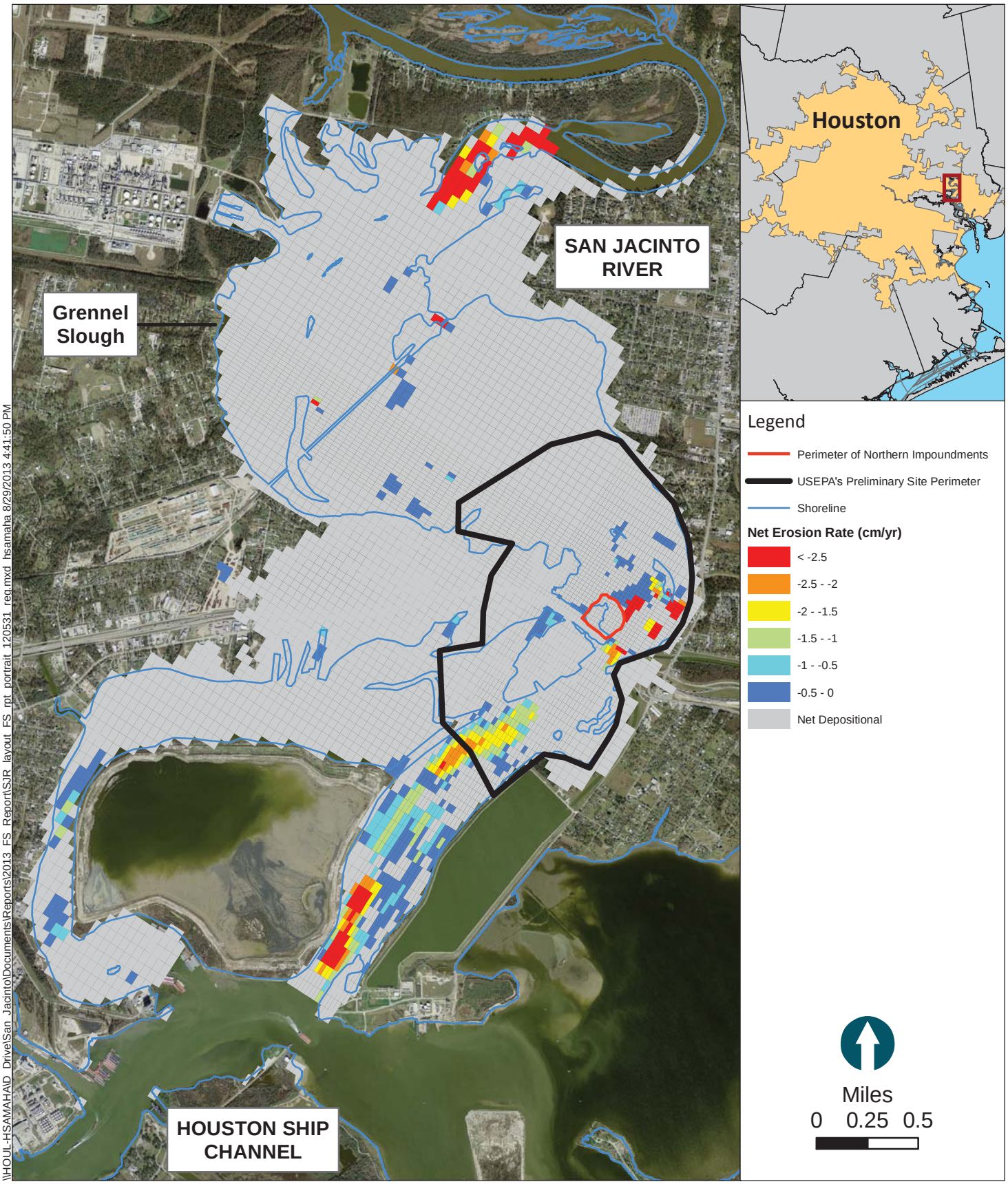

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Figure 3-7
Spatial Distribution of Predicted Net Erosion Rate for 21-Year Period: Post-TCRA Base Case Simulation
Feasibility Study
San Jacinto River Waste Pits Superfund Site

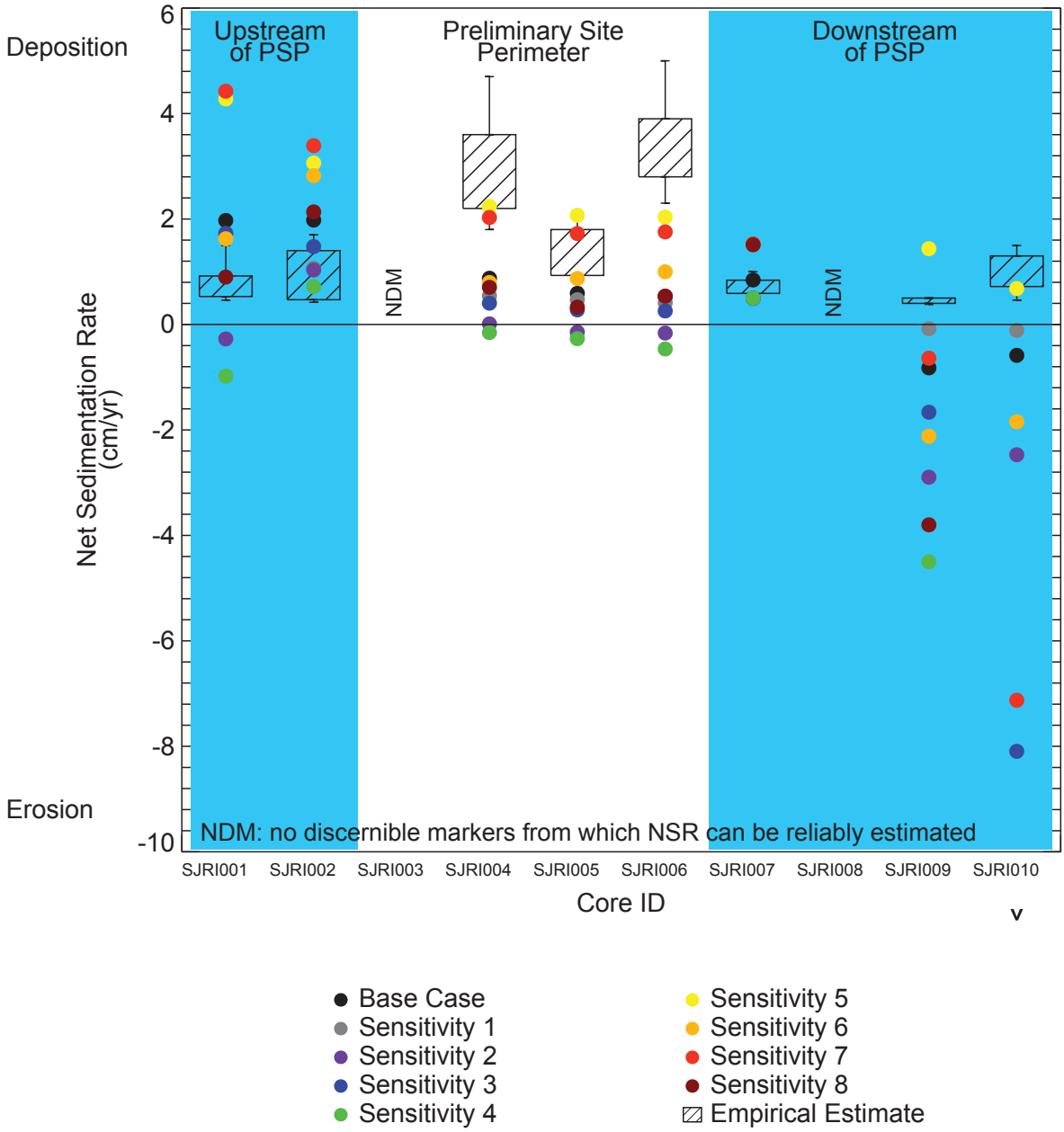

Figure 3-8

Comparison of Empirically Estimated and Predicted Net Sedimentation Rates for 21-Year Period: Post-TCRA Conditions
Feasibility Study
San Jacinto River Waste Pits Superfund Site

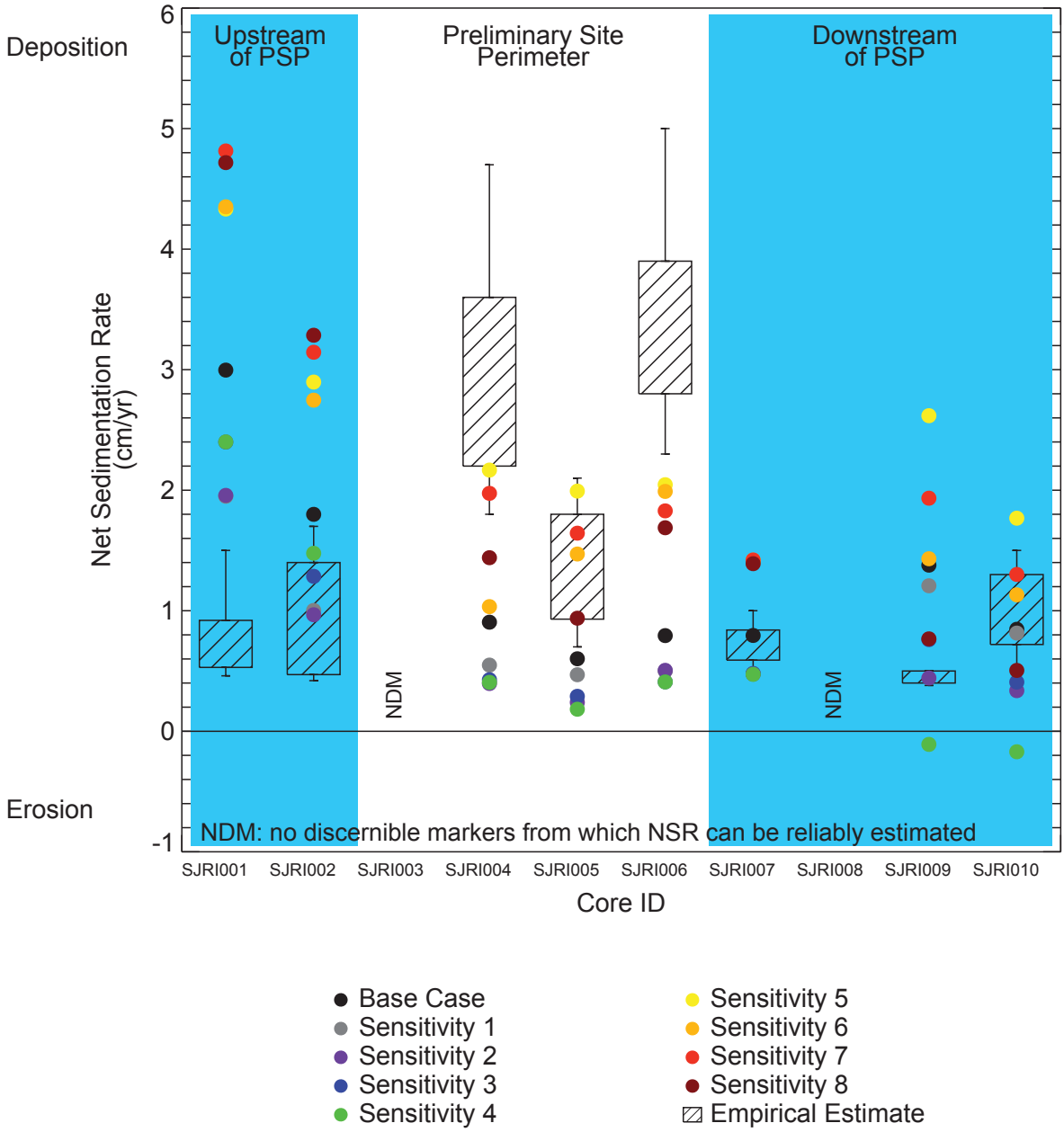

Figure 3-9

Comparison of Empirically Estimated and Predicted Net Sedimentation Rates for 16-Year Period: Post-TCRA Conditions
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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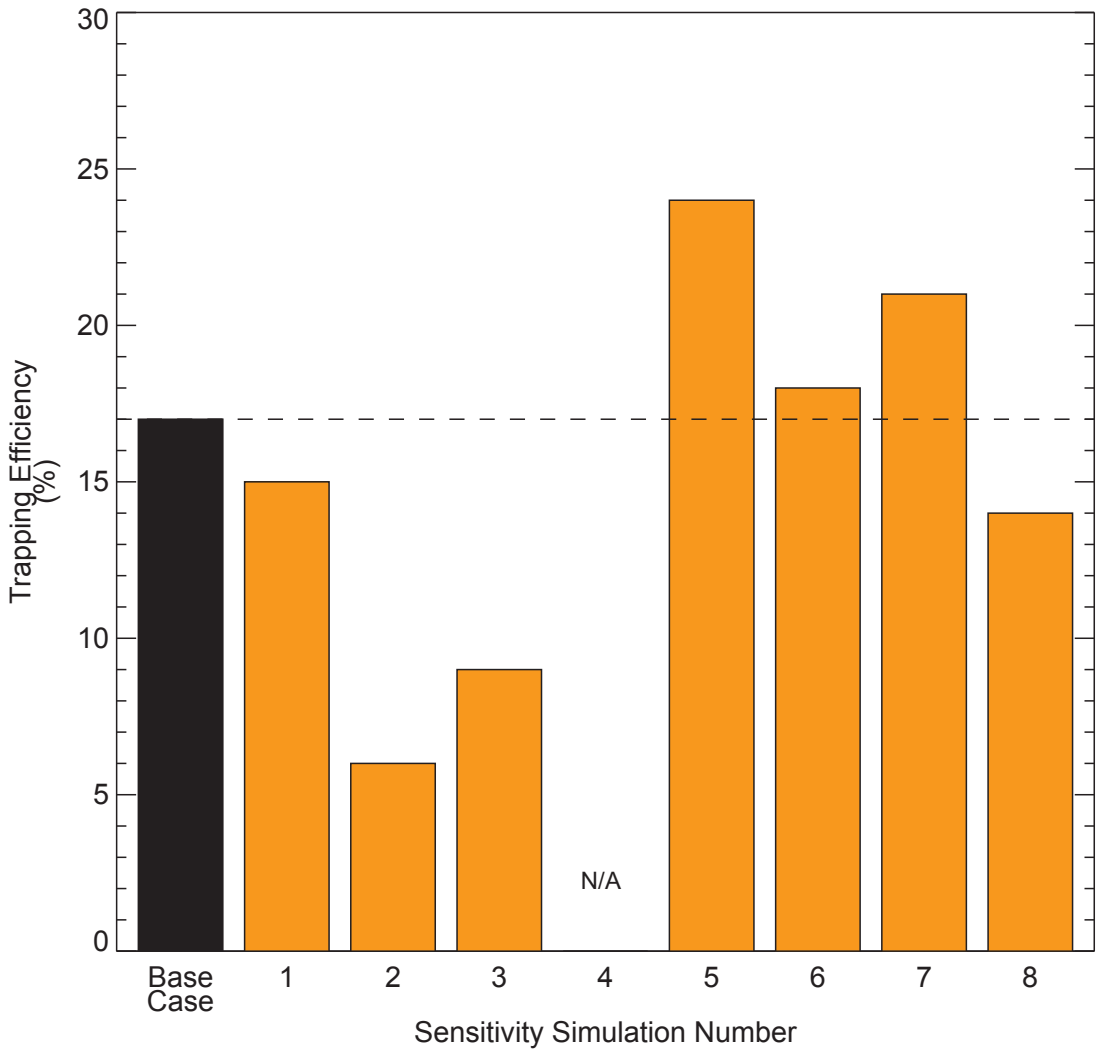

Figure 3-10

Comparison of Trapping Efficiency for Post-TCRA Sensitivity Simulations: Model Study Area
Feasibility Study
San Jacinto River Waste Pits Superfund Site

N/A: trapping efficiency could not be calculated because simulation was net erosional

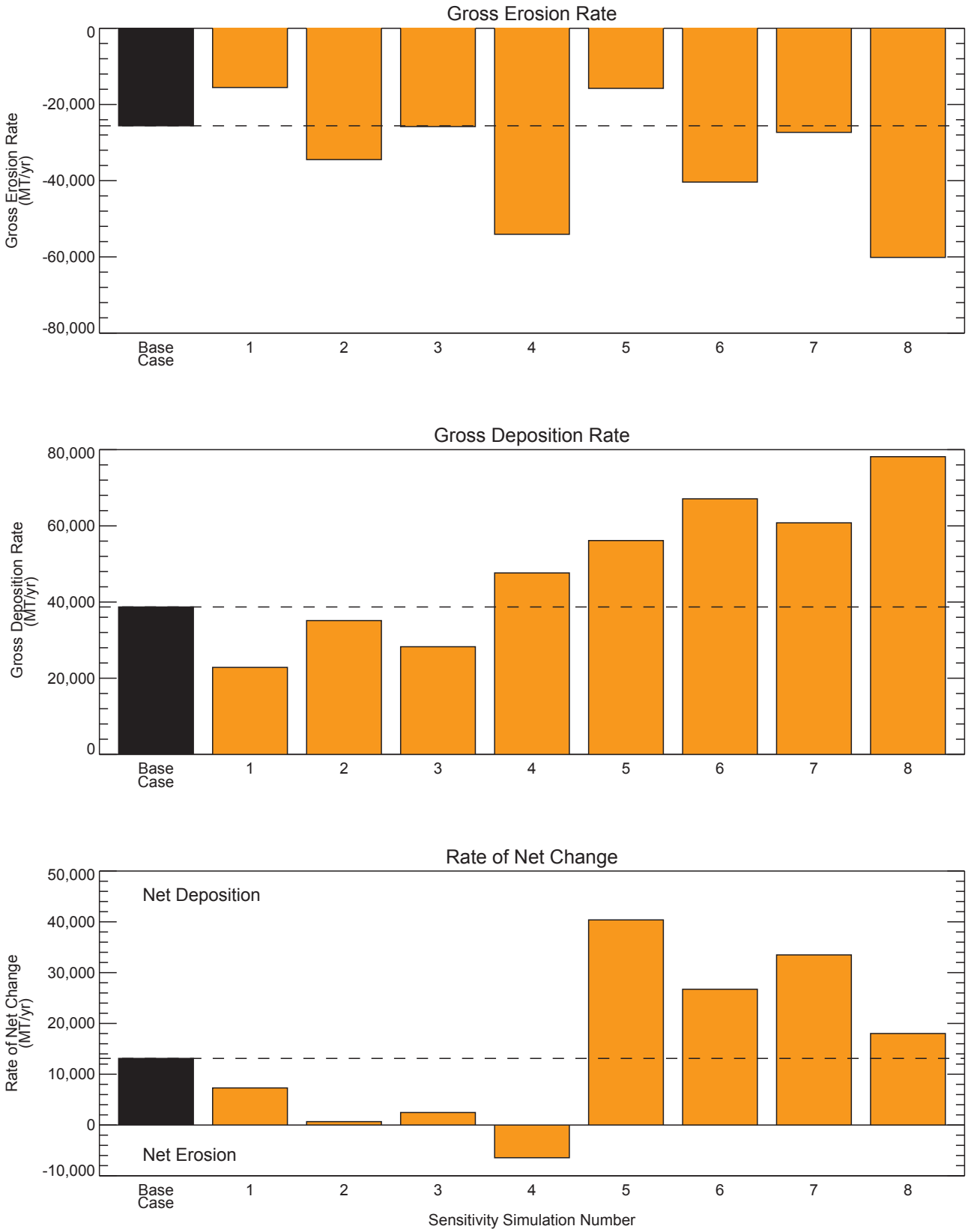

Figure 3-11

Comparison of Gross Erosion Rate, Gross Deposition Rate, and Rate of Net Change for Post-TCRA Sensitivity Simulations: USEPA's Preliminary Site Perimeter Feasibility Study
San Jacinto River Waste Pits Superfund Site

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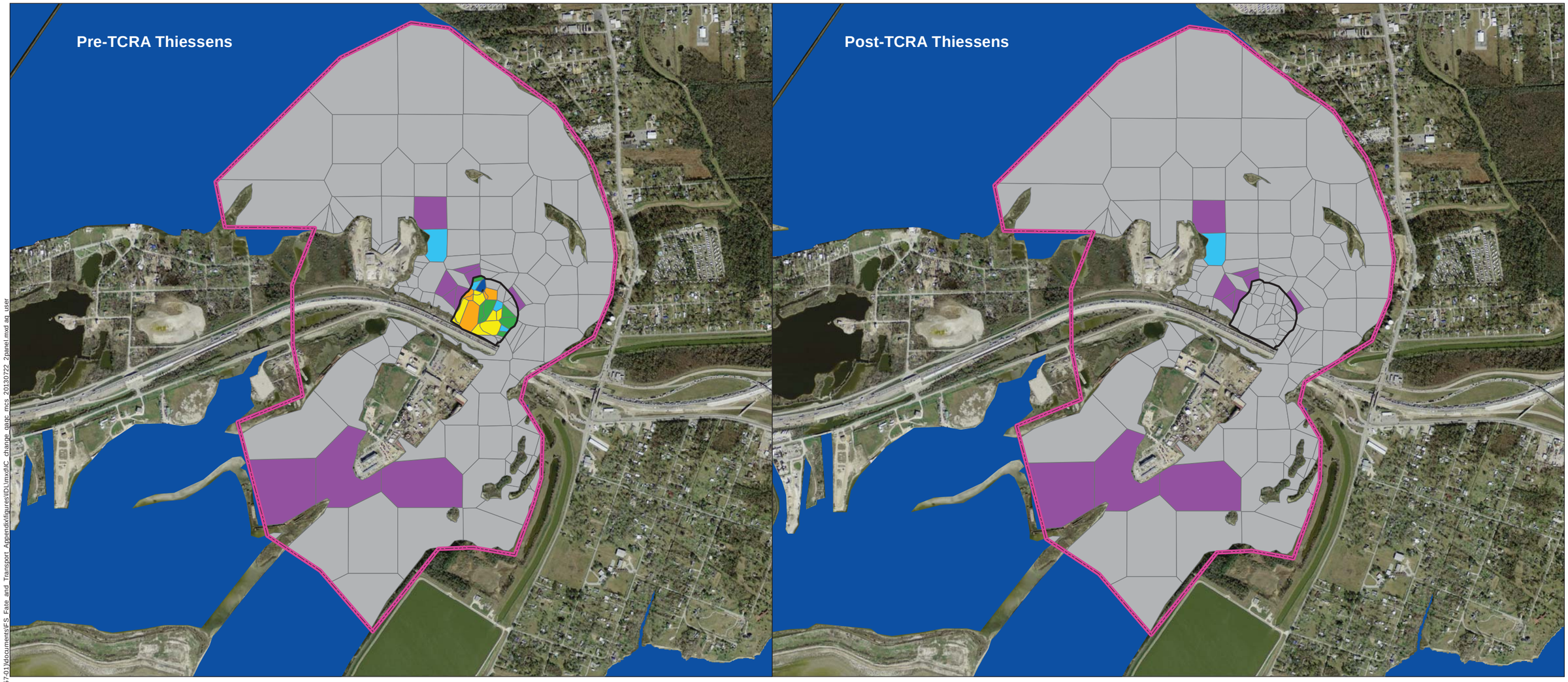

LEGEND

Perimeter of Northern Impoundments

USEPA's Preliminary Site Perimeter

TCDD Surface Sediment Concentration (ng/kg)

- < 30
- 30 - 100
- 100 - 300
- 300 - 1000
- 1000 - 3000
- 3000 - 10000
- > 10000
- Channel

NOTES:
Orthoimagery presented herein are enhanced 50-cm (0.5-meter) Digital Orthophoto Quarter-Quads (DOQQs) images from the 2008 USDA-FSA National Agriculture Imagery Program (NAIP) and 2009 Texas Orthoimagery Program (TOP) aerial imagery acquisitions.

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Figure 3-12a
Surface Sediment Thiessen Polygons Used for Fate Model Initial Conditions (TCDD)
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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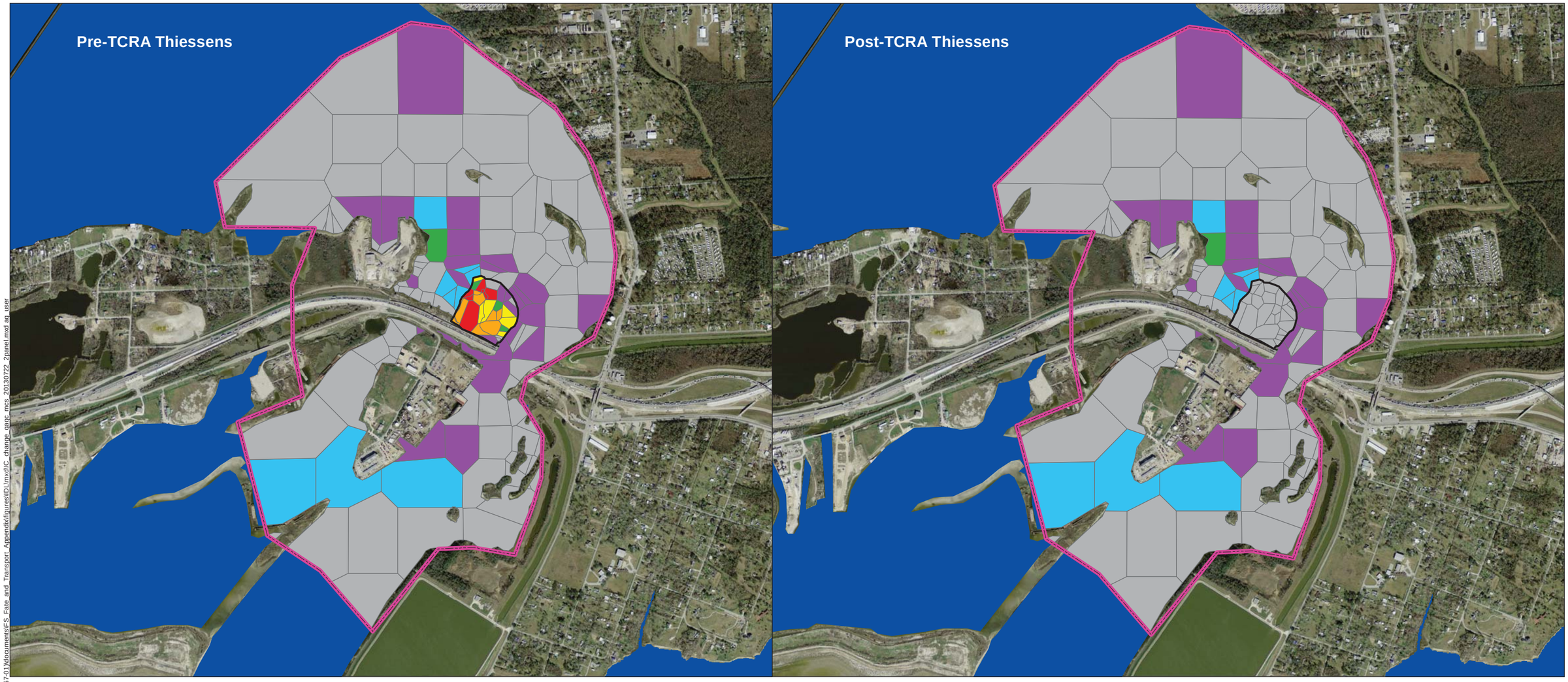

LEGEND

Perimeter of Northern Impoundments

USEPA's Preliminary Site Perimeter

TCDF Surface Sediment Concentration (ng/kg)

- < 30
- 30 - 100
- 100 - 300
- 300 - 1000
- 1000 - 3000
- 3000 - 10000
- > 10000
- Channel

NOTES:
Orthoimagery presented herein are enhanced 50-cm (0.5-meter) Digital Orthophoto Quarter-Quads (DOQQs) images from the 2008 USDA-FSA National Agriculture Imagery Program (NAIP) and 2009 Texas Orthoimagery Program (TOP) aerial imagery acquisitions.

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Figure 3-12b
Surface Sediment Thiessen Polygons Used for Fate Model Initial Conditions (TCDF)
Feasibility Study
San Jacinto River Waste Pits Superfund Site

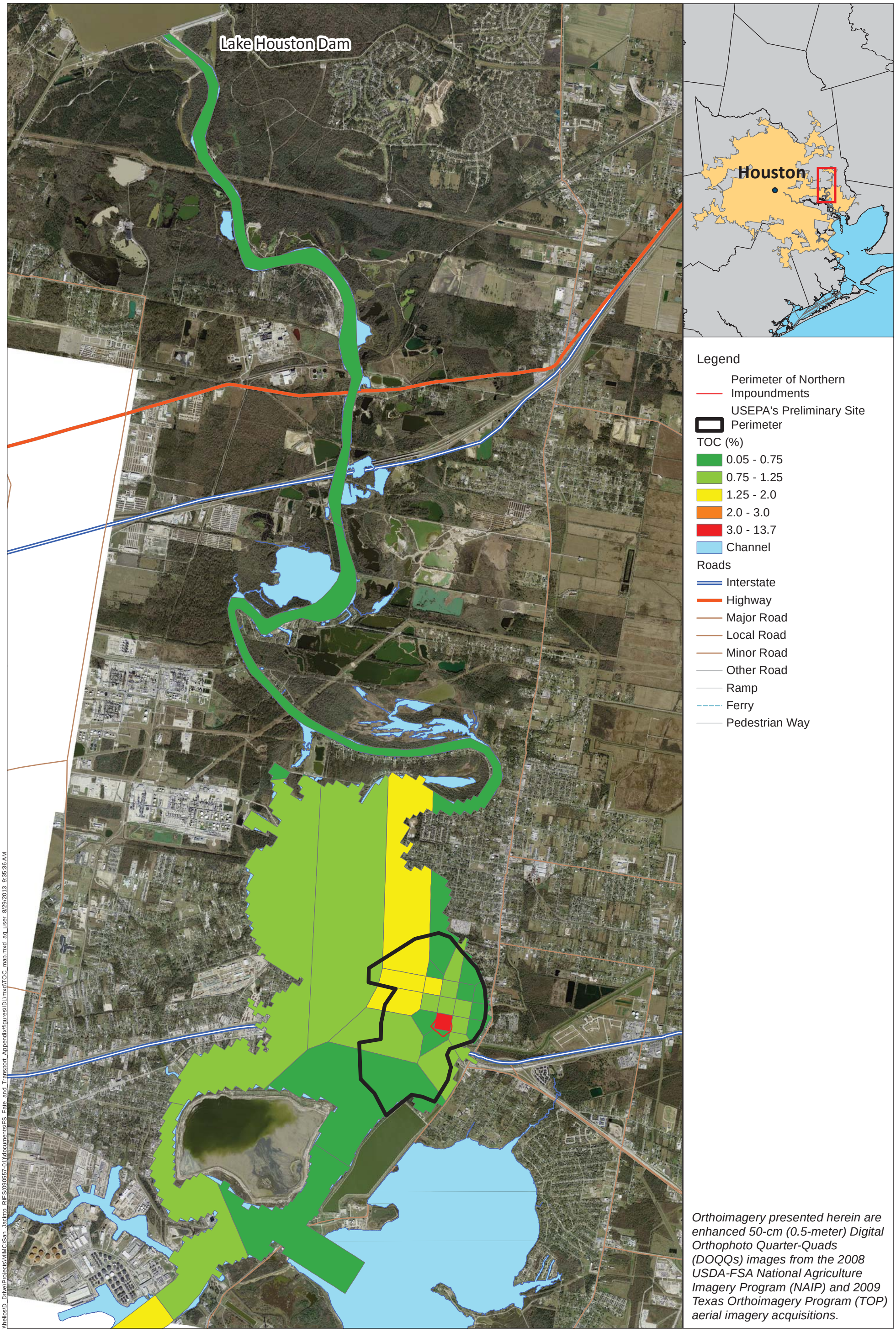

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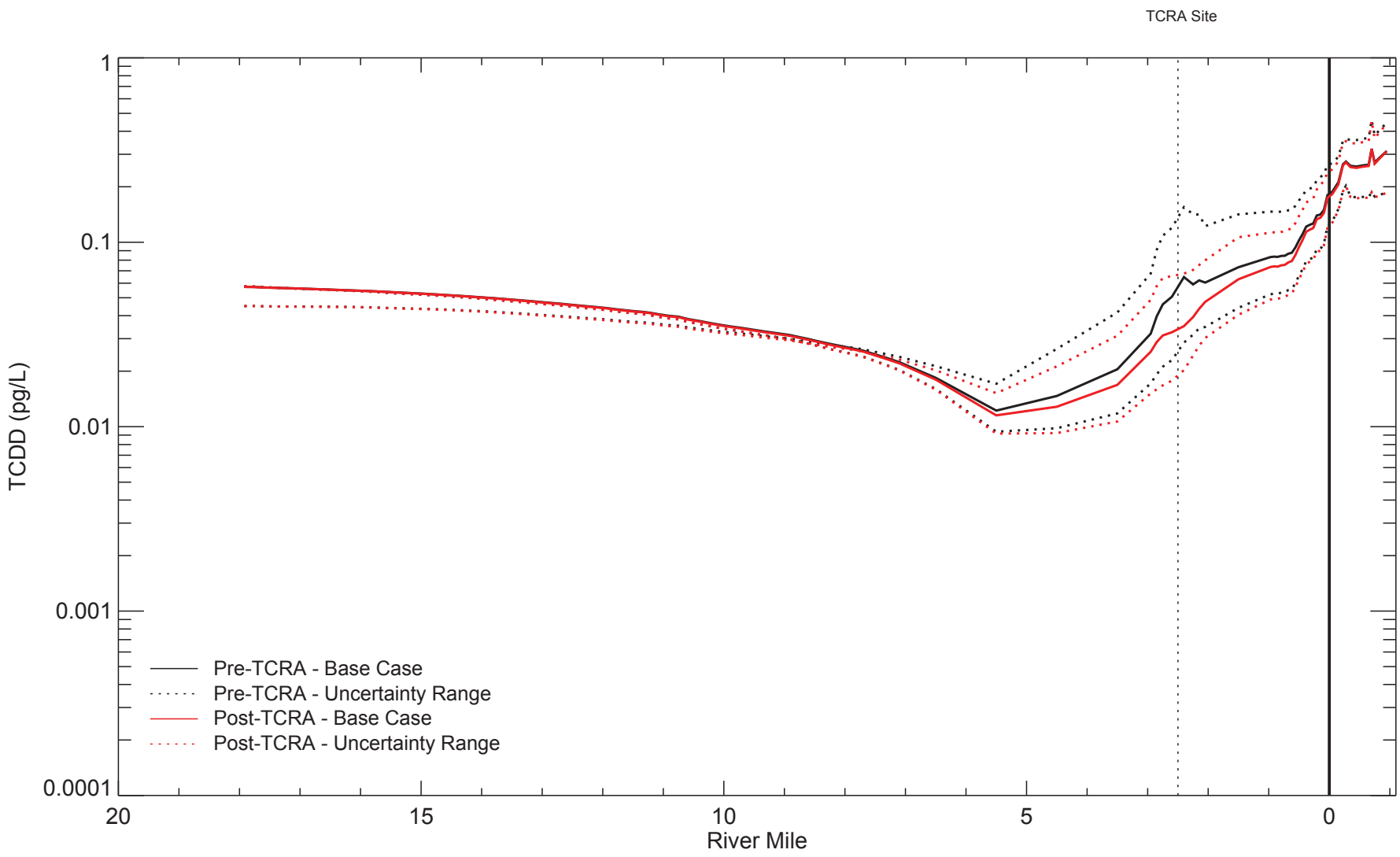
Figure 3-13
Thiessen Polygons of Total Organic Carbon
Feasibility Study
San Jacinto River Waste Pits Superfund Site



Model Run: SJR_PROJ1_BC_TCDD_1301-03, SJR_PROJ1_SENS1_TCDD_1305-41, SJR_PROJ1_SENS2_TCDD_1305-38, SJR_PROJ2_BC_TCDD_1301-06, SJR_PROJ2_SENS1_TCDD_1305-29, SJR_PROJ2_SENS2_TCDD_1305-26

Figure 3-14

Spatial Profiles of Model-Predicted Water Column TCDD Concentrations (Model Year 11)
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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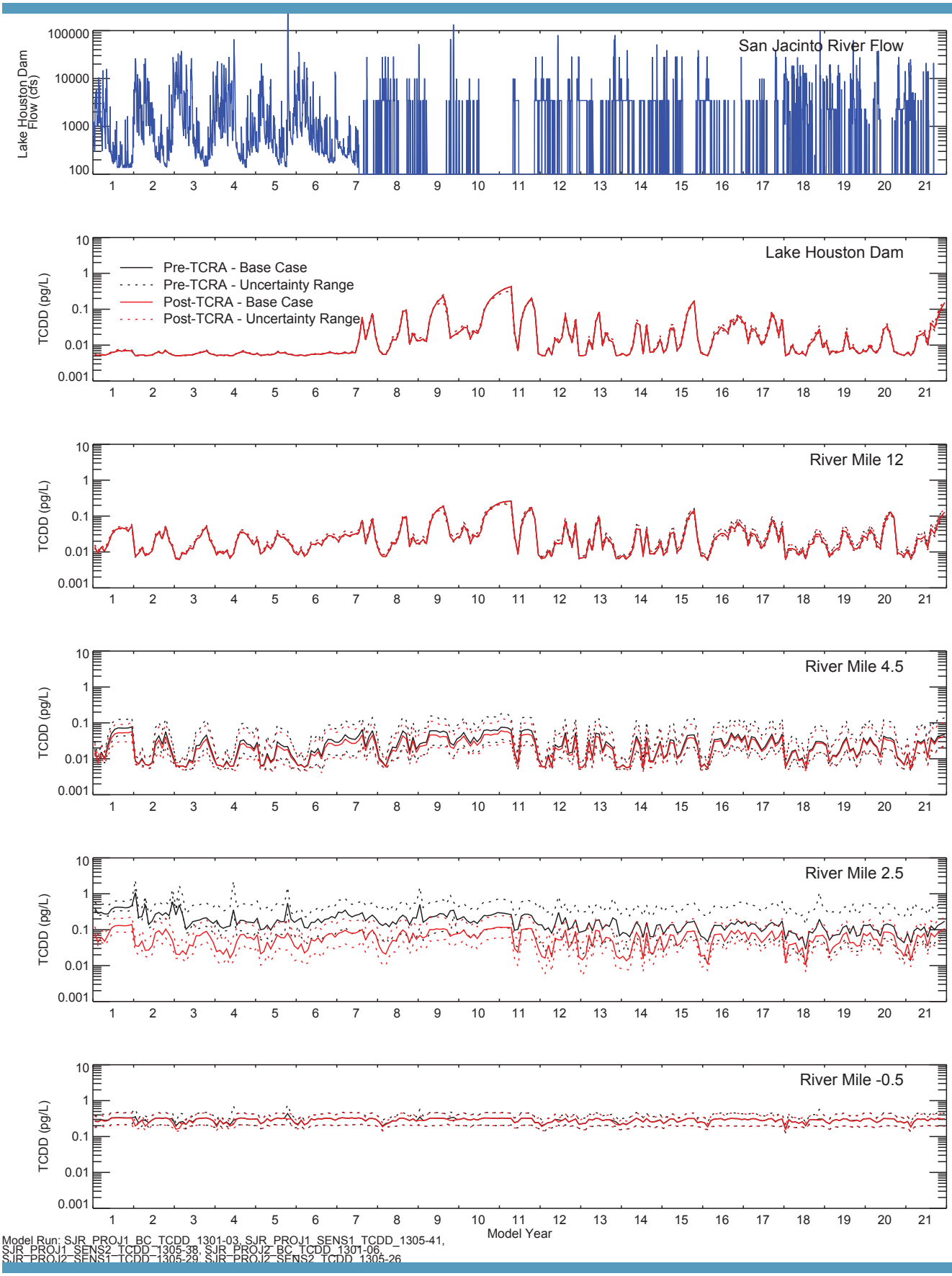

Model Run: SJR_PROJ1_BC_TCDD_1301-03, SJR_PROJ1_SENS1_TCDD_1305-41, SJR_PROJ1_SENS2_TCDD_1305-38, SJR_PROJ2_BC_TCDD_1301-06, SJR_PROJ2_SENS1_TCDD_1305-29, SJR_PROJ2_SENS2_TCDD_1305-26

Figure 3-15

Time Series of Model-Predicted Water Column TCDD Concentrations at Select Transects
Feasibility Study
San Jacinto River Waste Pits Superfund Site

Note: Flow less than 100 cfs plotted at 100 cfs.

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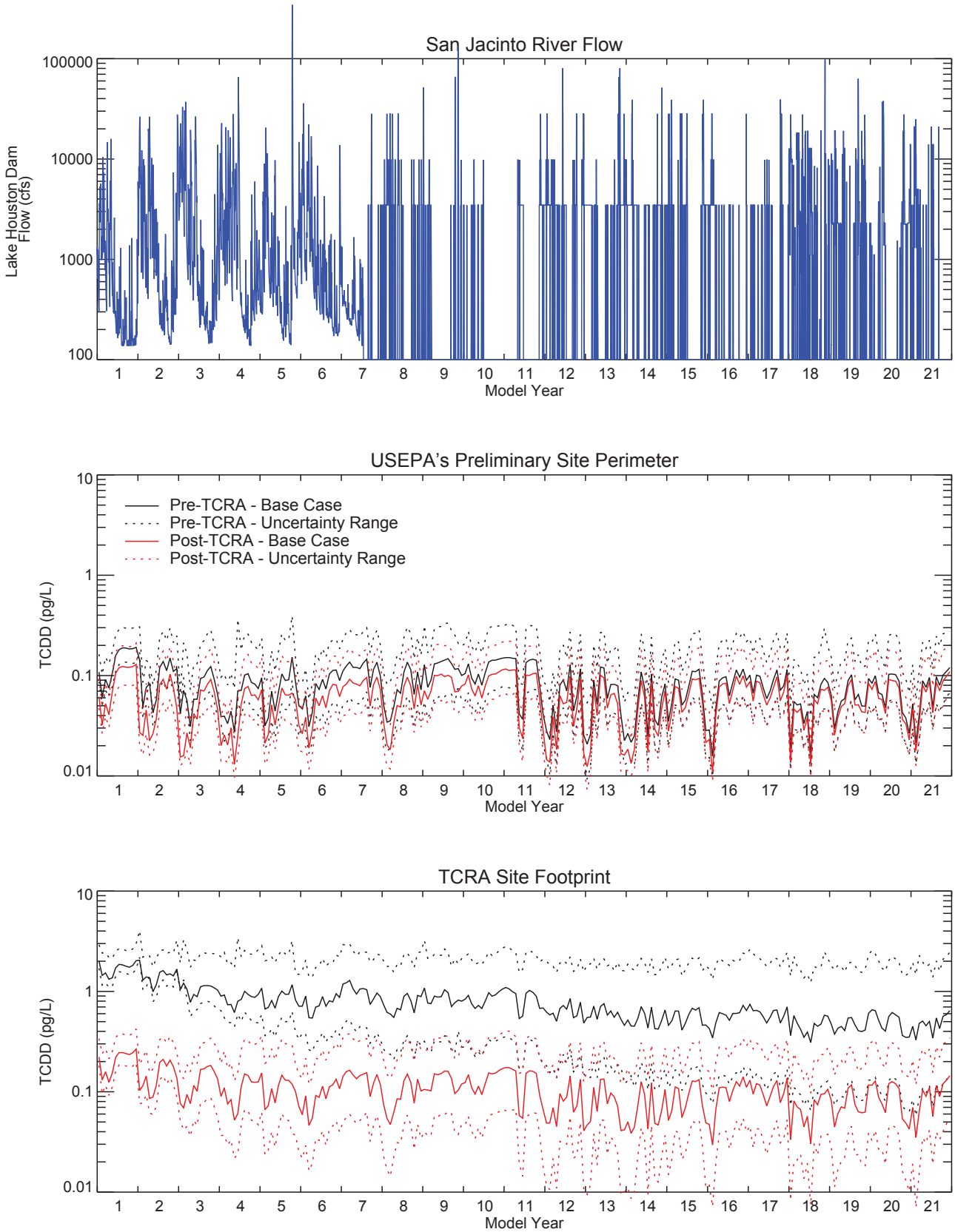
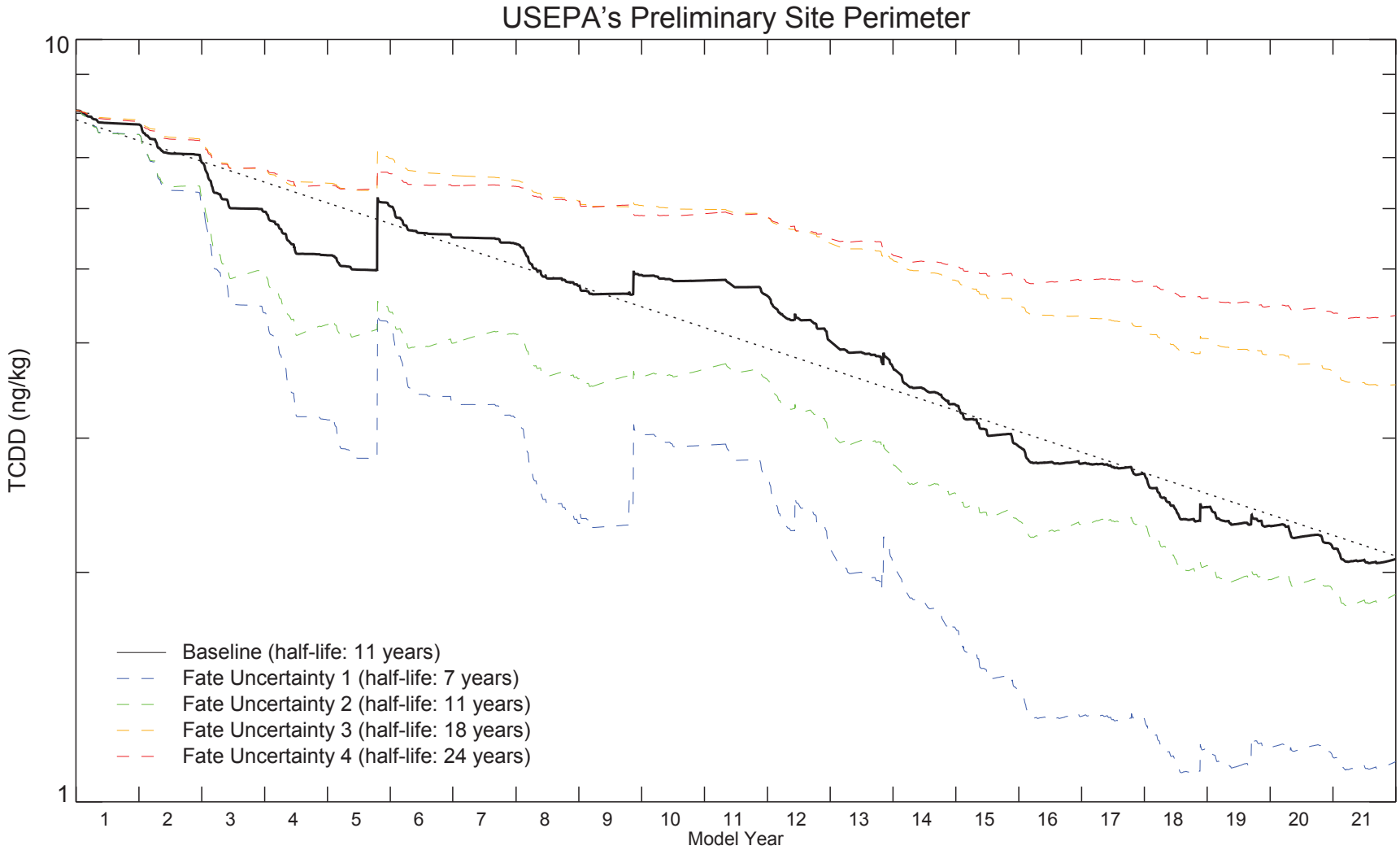


Model Run: SJR_PROJ1_BC_TCDD_1301-03, SJR_PROJ1_SENS1_TCDD_1305-41, SJR_PROJ1_SENS2_TCDD_1305-38, SJR_PROJ2_BC_TCDD_1301-06, SJR_PROJ2_SENS1_TCDD_1305-29, SJR_PROJ2_SENS2_TCDD_1305-26

Figure 3-16

Time Series of Model-Predicted Water Column TCDD Concentrations within the USEPA's Preliminary Site Perimeter and TCRA Site Footprint
Feasibility Study
San Jacinto River Waste Pits Superfund Site

Note: Flow less than 100 cfs plotted at 100 cfs.



Model Run: SJR_PROJ2_BC_TCDD_1301-06, SJR_PROJ2_SENS1_TCDD_1305-29, SJR_PROJ2_SENS4_TCDD_1305-21, SJR_PROJ2_SENS3_TCDD_1305-22, SJR_PROJ2_SENS2_TCDD_1305-26

Figure 3-17

Time Series of Model-Predicted Post-TCRA Surface Sediment (top 6 inches) TCDD Concentrations Averaged within the USEPA's Preliminary Site Perimeter

Feasibility Study

San Jacinto River Waste Pits Superfund Site

Note: Dotted line represents an exponential decay curve fit to the model results.

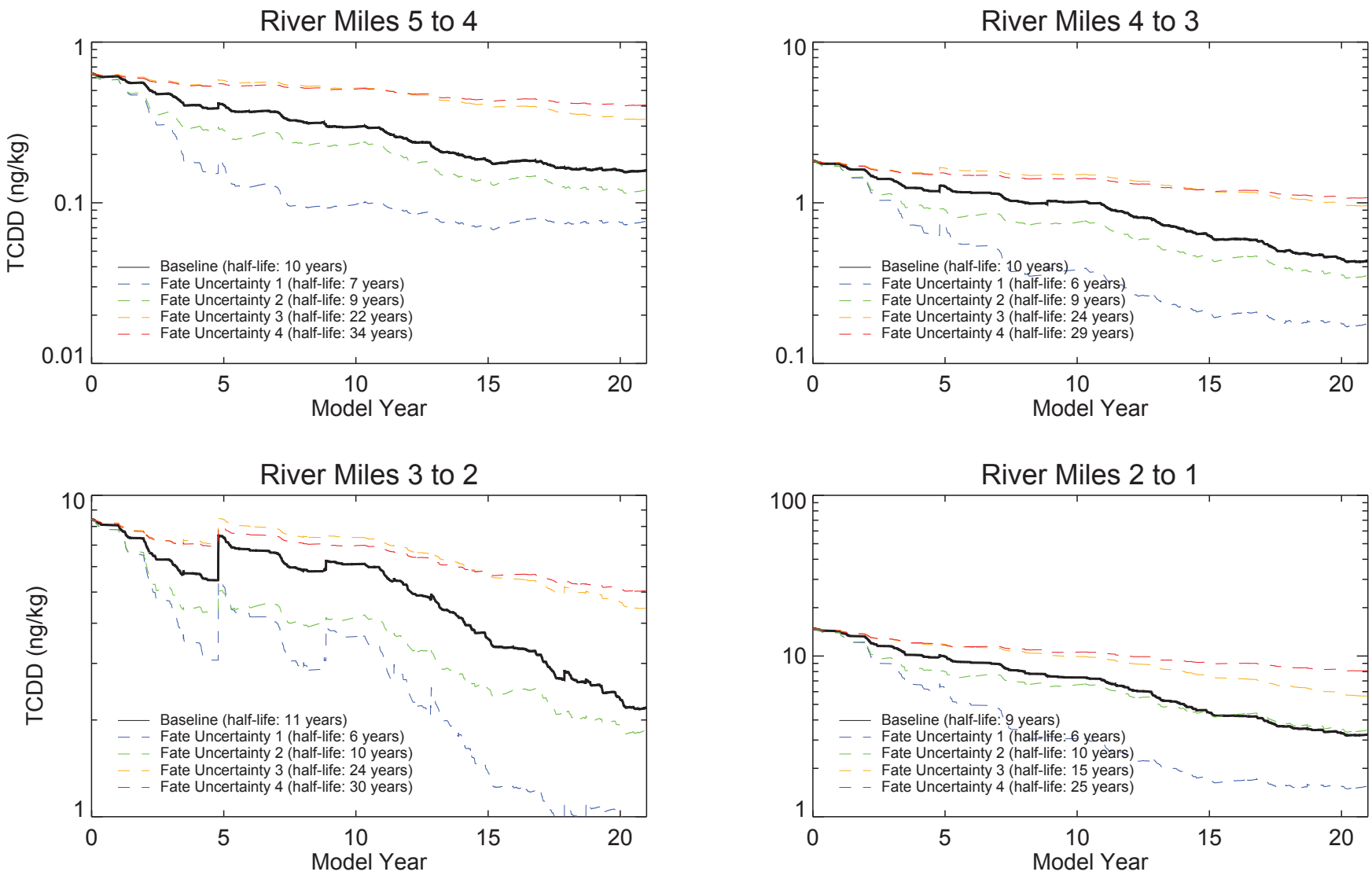


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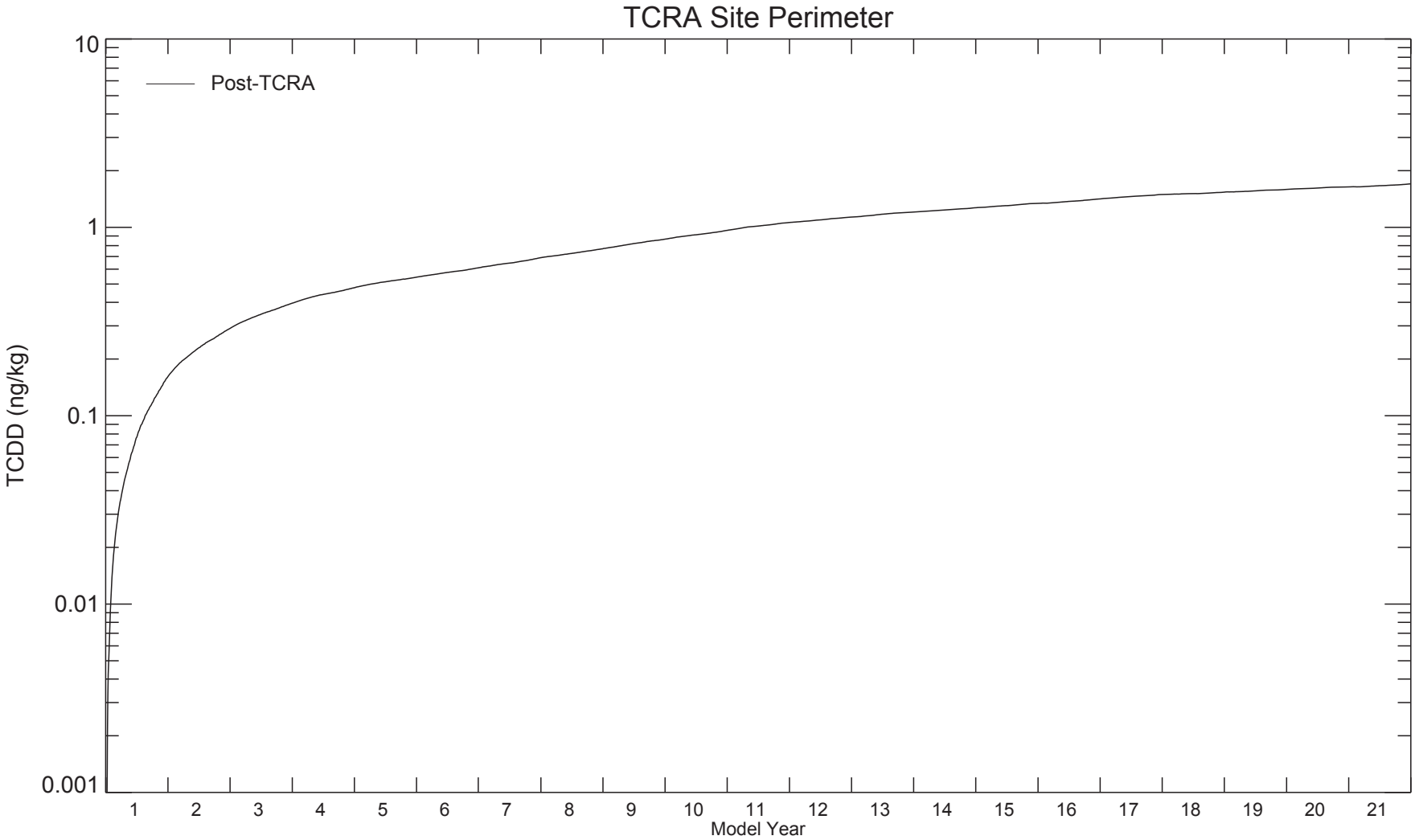
Figure 3-18

Time Series of Model-Predicted Post-TCRA Surface Sediment (top 6 inches) TCDD Concentrations Averaged by River Mile
Feasibility Study
San Jacinto River Waste Pits Superfund Site

ANCHOR QEA

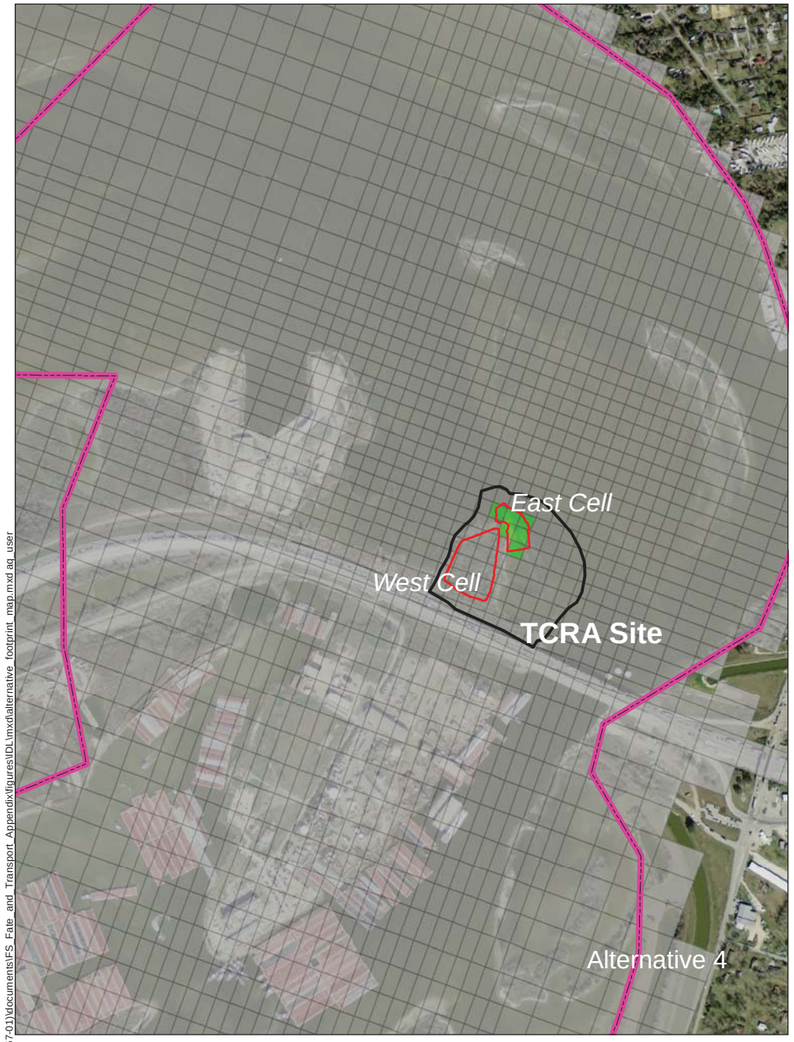


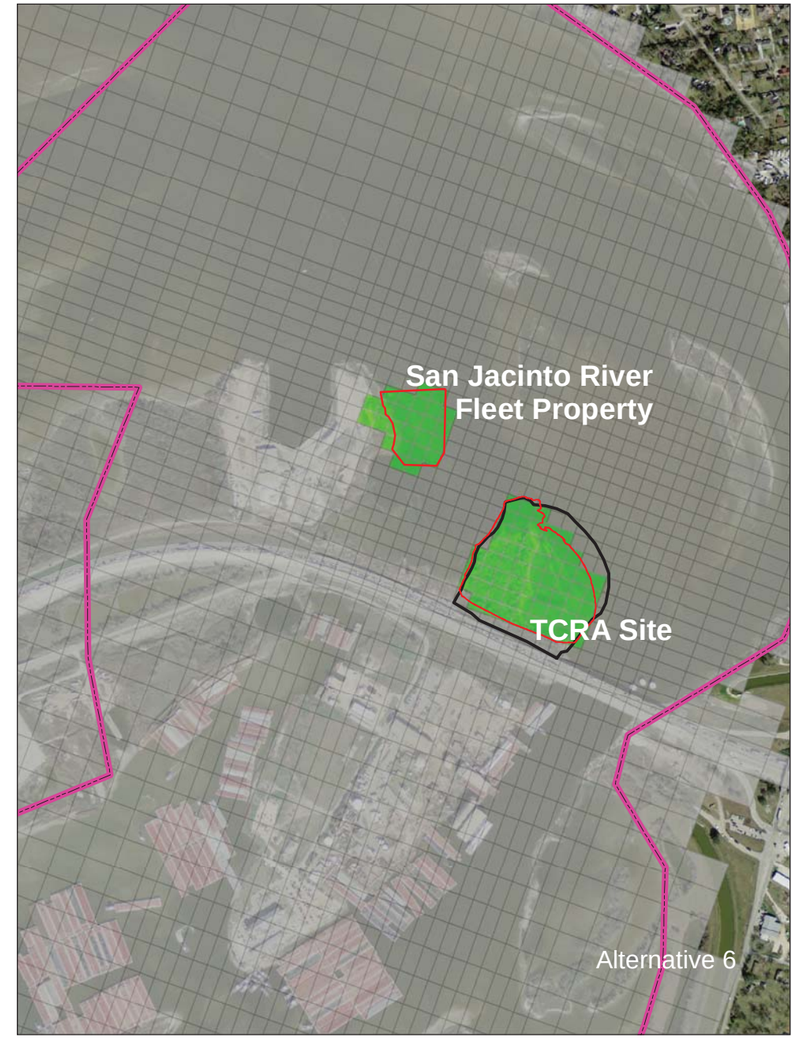
Model Run: SJR_PROJ2_BC_TCDD_1301-06

Figure 3-19

Time Series of Model-Predicted Post-TCRA Sediment TCDD Concentration on the Surface of the TCRA Cap
Feasibility Study
San Jacinto River Waste Pits Superfund Site

ANCHOR QEA





LEGEND

- USEPA's Preliminary Site Perimeter
- Perimeter of Northern Impoundments
- Remediation Footprint
- Model Grid
- Remediation Footprint Represented in Model

NOTES:
Orthoimagery presented herein are enhanced 50-cm (0.5-meter) Digital Orthophoto Quarter-Quads (DOQQs) images from the 2008 USDA-FSA National Agriculture Imagery Program (NAIP) and 2009 Texas Orthoimagery Program (TOP) aerial imagery acquisitions.

0 0.5 1 Miles

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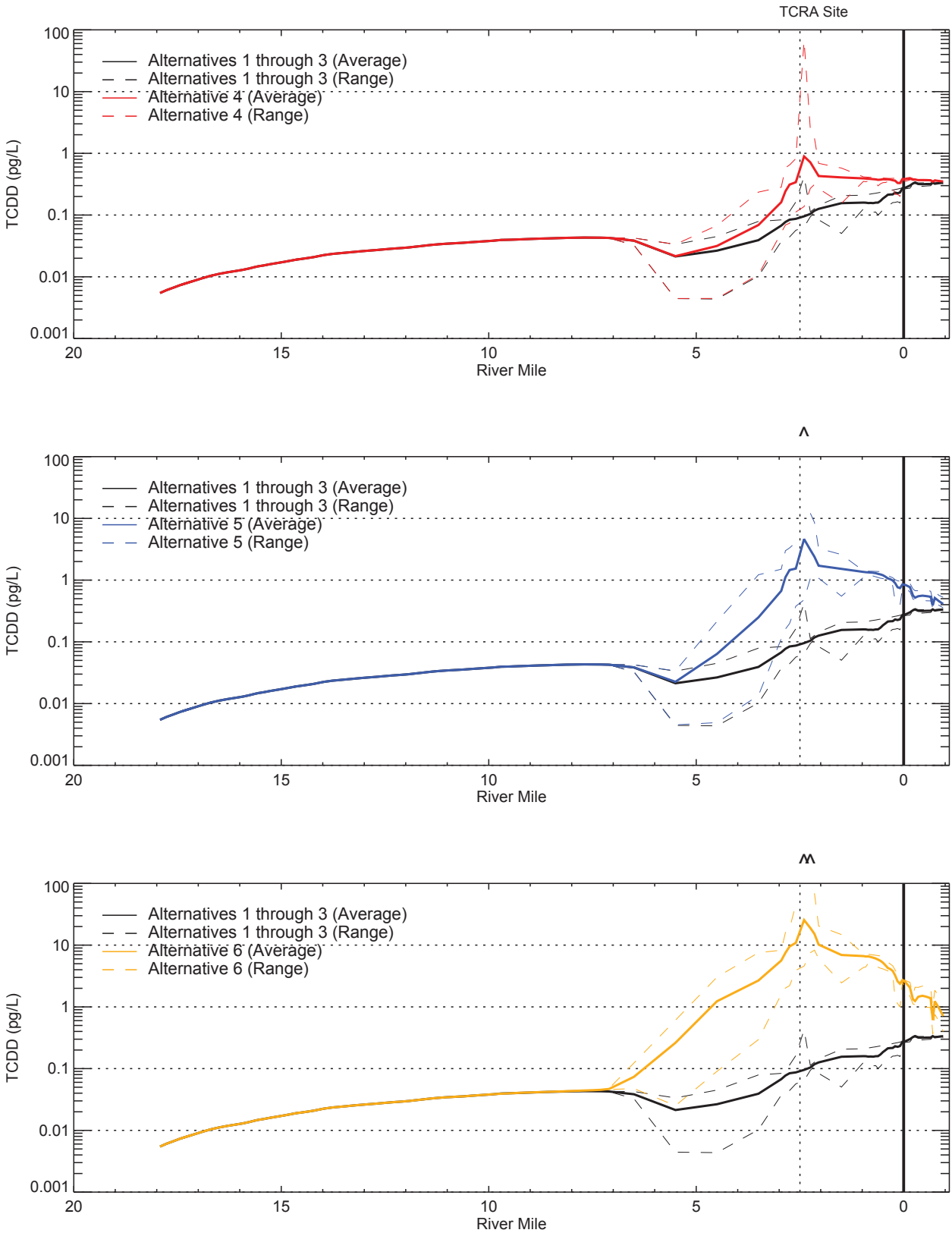
ANCHOR QEA

Figure 4-1
Alternatives 4, 5, and 6 Remediation Footprints
Feasibility Study
San Jacinto River Waste Pits Superfund Site



Model Run: SJR_PROJ2_BC_TCDD_1301-06, SJR_PROJ3_BC_TCDD_1307-01, SJR_PROJ3_BC_TCDD_1307-02, SJR_PROJ3_BC_TCDD_1307-03

Figure 4-2a

Spatial Profiles of Model-Predicted Water Column TCDD Concentrations for Alternatives 1 through 3 and Alternatives 4, 5, and 6 Simulations (Model Year 1)
Feasibility Study
San Jacinto River Waste Pits Superfund Site

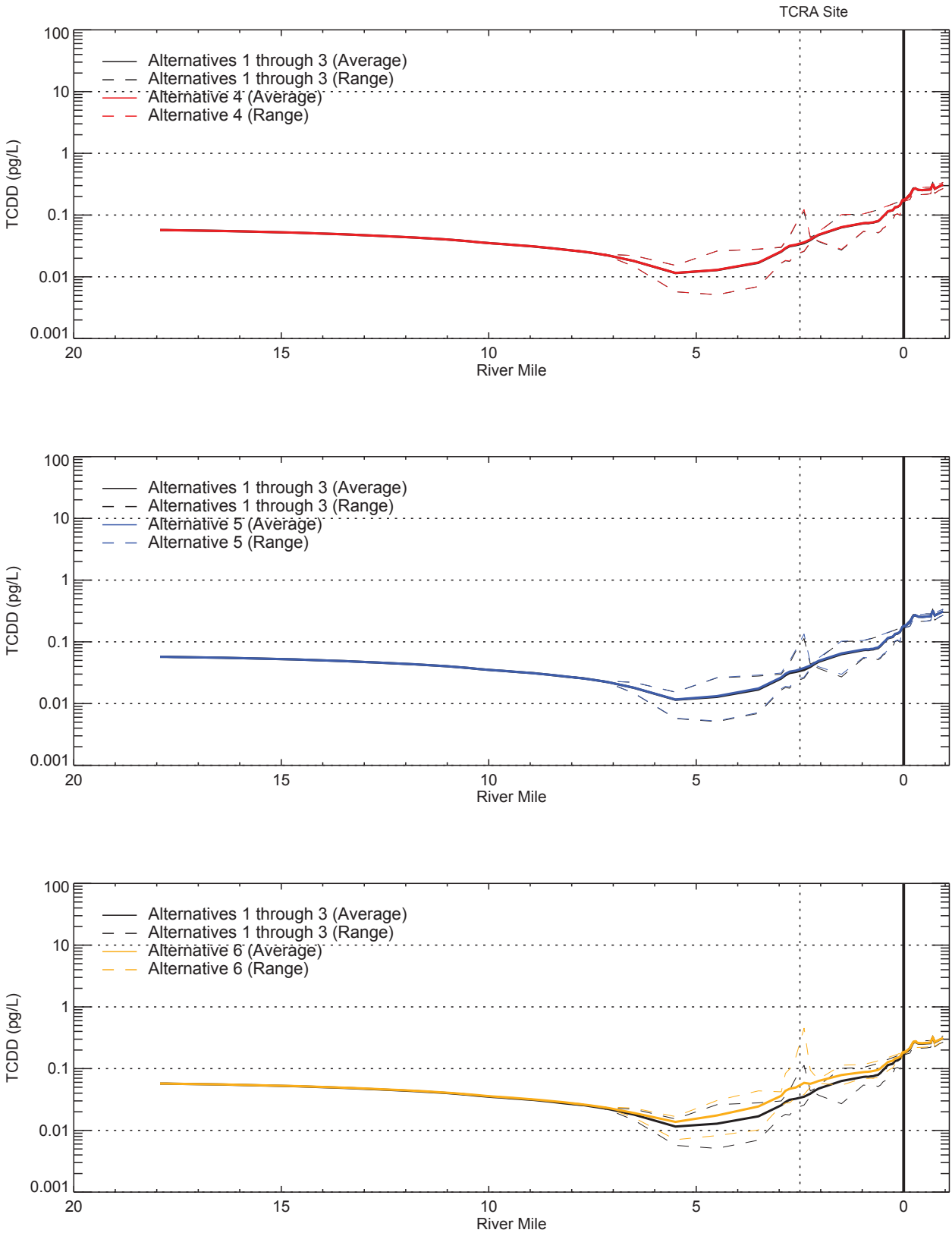


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Figure 4-2b

Spatial Profiles of Model-Predicted Water Column TCDD Concentrations for Alternatives 1 through 3 and Alternatives 4, 5, and 6 Simulations (Model Year 11)
Feasibility Study
San Jacinto River Waste Pits Superfund Site

ANCHOR QEA

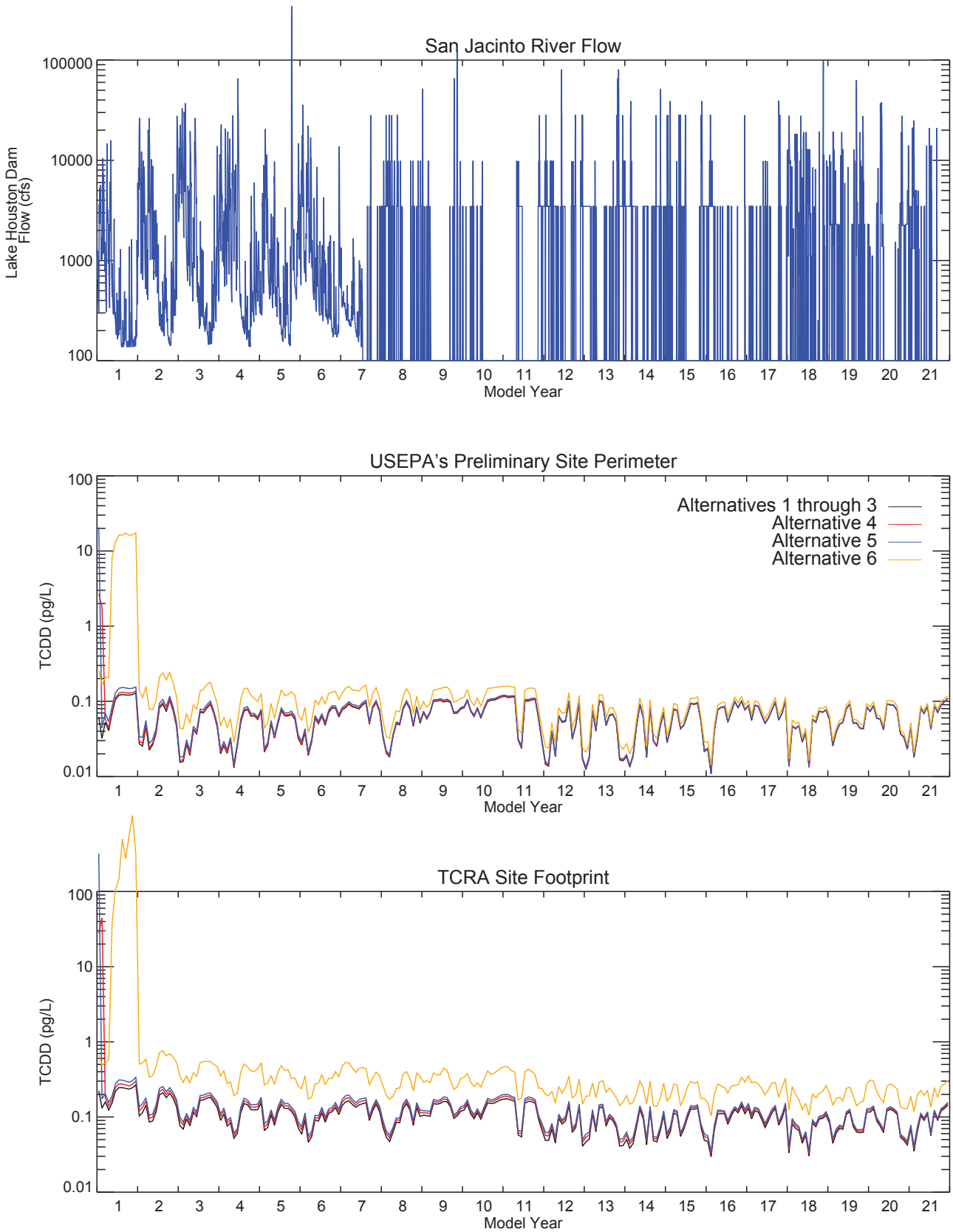

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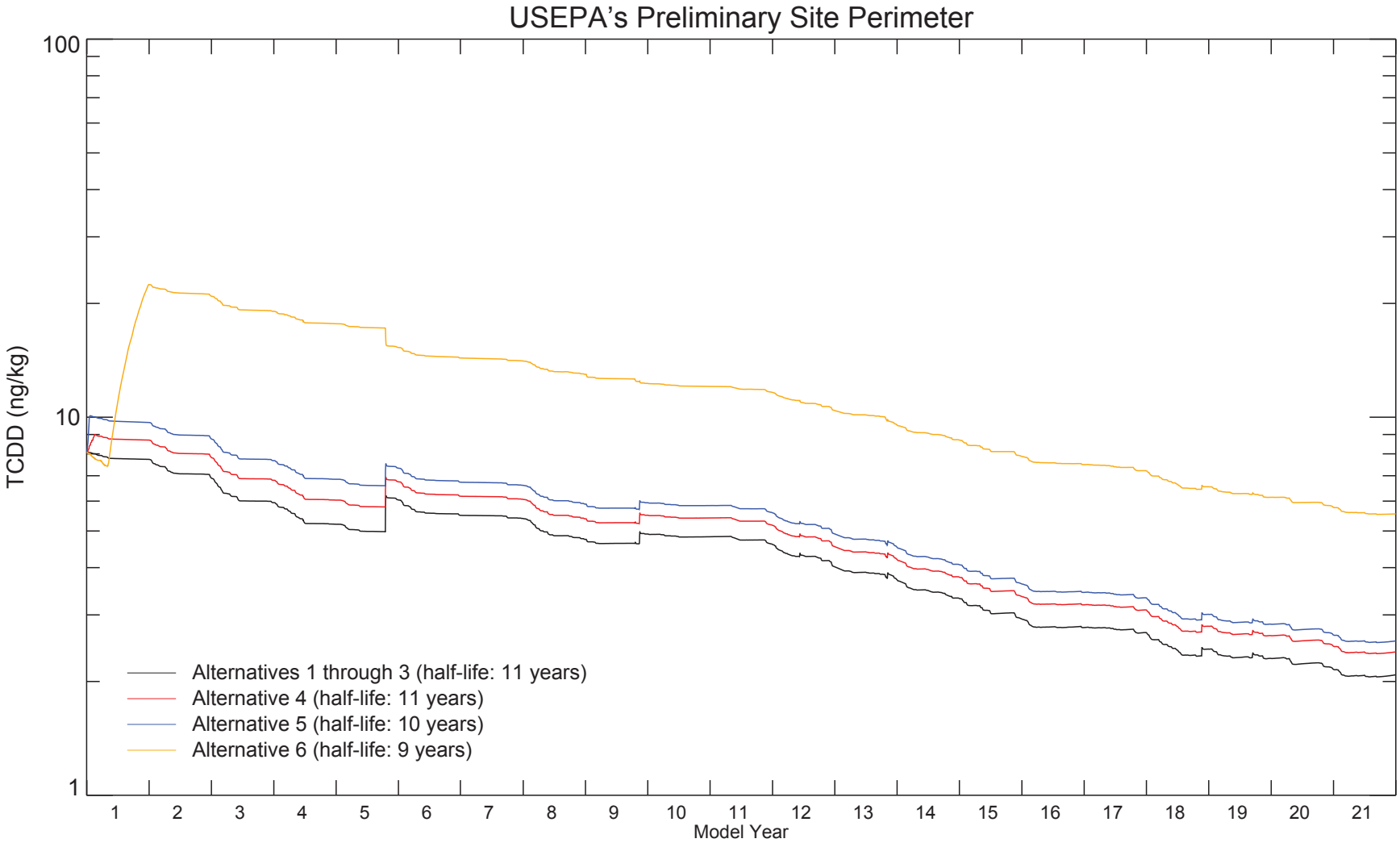
Figure 4-3

Time Series of Model-Predicted Water Column TCDD Concentrations Averaged within the USEPA's Preliminary Site Perimeter and TCRA Site Footprint for Alternatives 1 through 3 and Alternatives 4, 5, and 6 Simulations
Feasibility Study
San Jacinto River Waste Pits Superfund Site

Note: Flow less than 100 cfs plotted at 100 cfs.



* The remediation year (year 1) is excluded from the half-life calculation for all the simulations on this plot.

Model Run: SJR_PROJ2_BC_TCDD_1301-06, SJR_PROJ3_BC_TCDD_1307-01, SJR_PROJ3_BC_TCDD_1307-02, SJR_PROJ3_BC_TCDD_1307-03

Figure 4-4

Time Series of Model-Predicted Surface Sediment (top 6 inches) TCDD Concentrations Averaged within the USEPA's Preliminary Site Perimeter for Alternatives 1 through 3 and Alternatives 4, 5, and 6 Simulations
Feasibility Study
San Jacinto River Waste Pits Superfund Site

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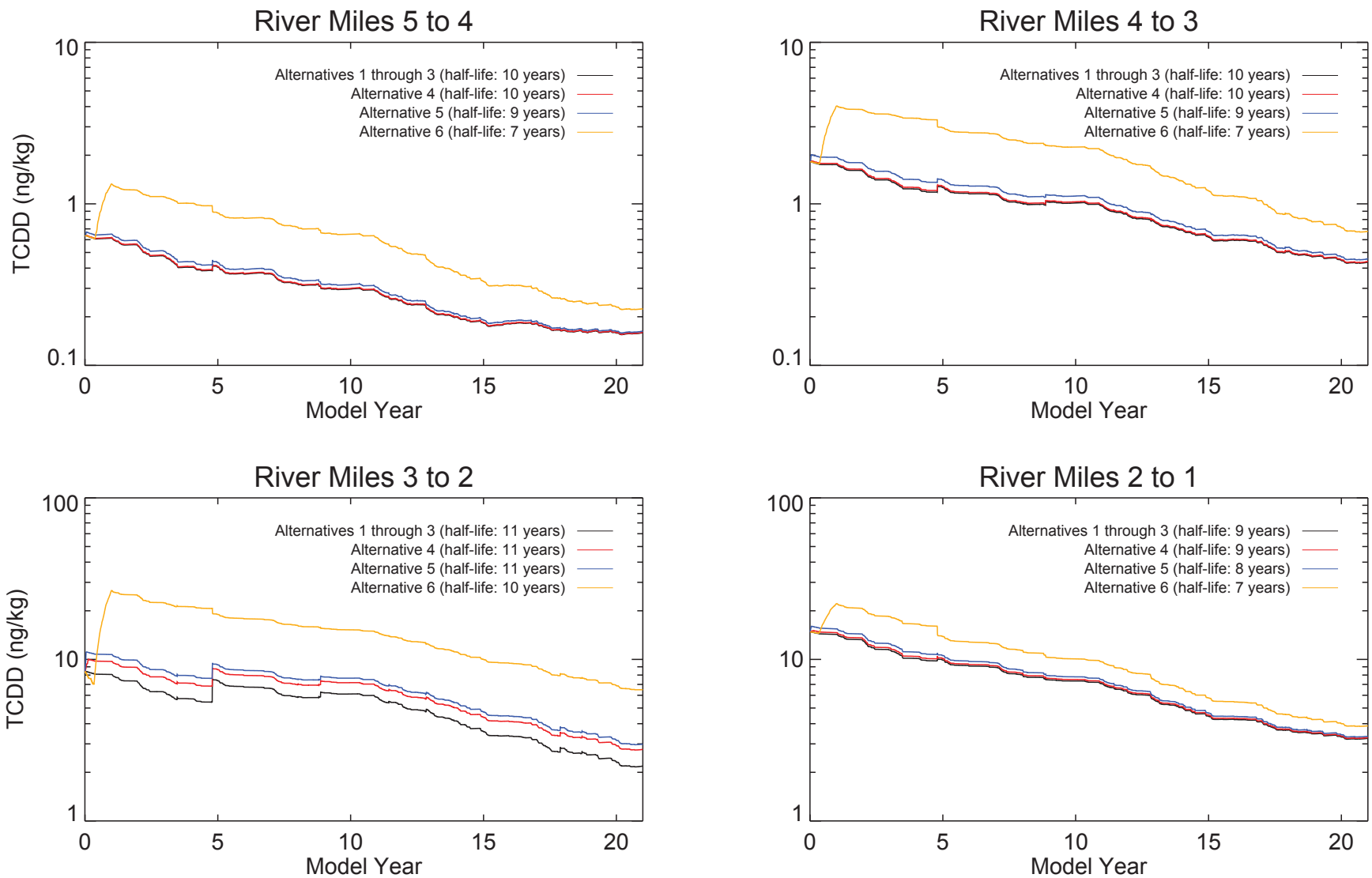


* The remediation year (year 1) is excluded from the half-life calculation for all the simulations on this plot.

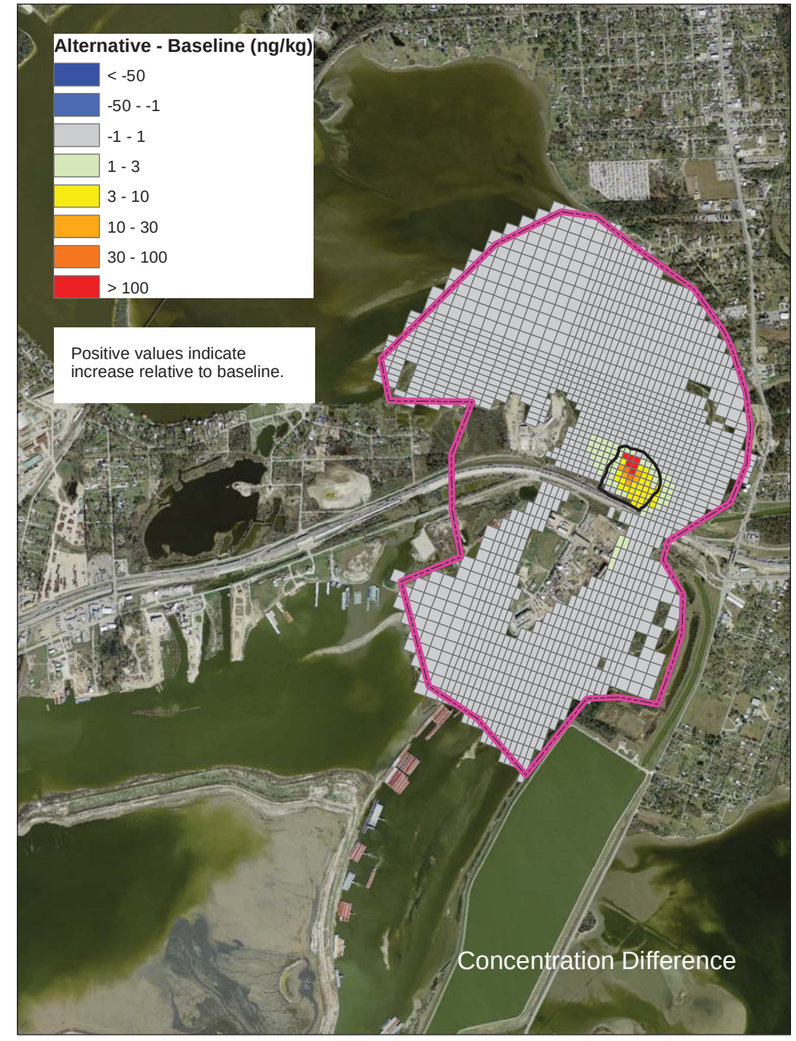
Model Run: SJR_PROJ2_BC_TCDD_1301-06, SJR_PROJ3_BC_TCDD_1307-01, SJR_PROJ3_BC_TCDD_1307-02, SJR_PROJ3_BC_TCDD_1307-03

Figure 4-5

Time Series of Model-Predicted Surface Sediment (top 6 inches) TCDD Concentrations Averaged by River Mile for Alternatives 1 through 3 and Alternatives 4, 5, and 6 Simulations
Feasibility Study
San Jacinto River Waste Pits Superfund Site

ANCHOR QEA

DRAFT



LEGEND

Perimeter of Northern Impoundments

USEPA's Preliminary Site Perimeter

NOTES:
Orthoimagery presented herein are enhanced 50-cm (0.5-meter) Digital Orthophoto Quarter-Quads (DOQQs) images from the 2008 USDA-FSA National Agriculture Imagery Program (NAIP) and 2009 Texas Orthoimagery Program (TOP) aerial imagery acquisitions.

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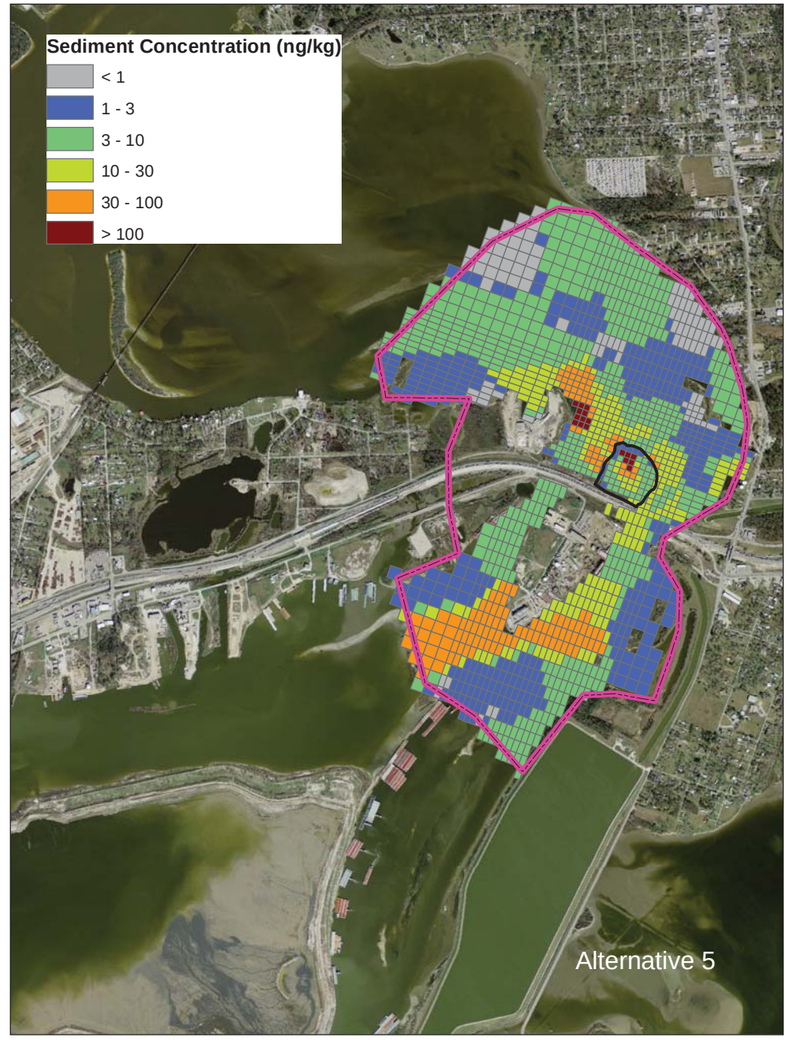
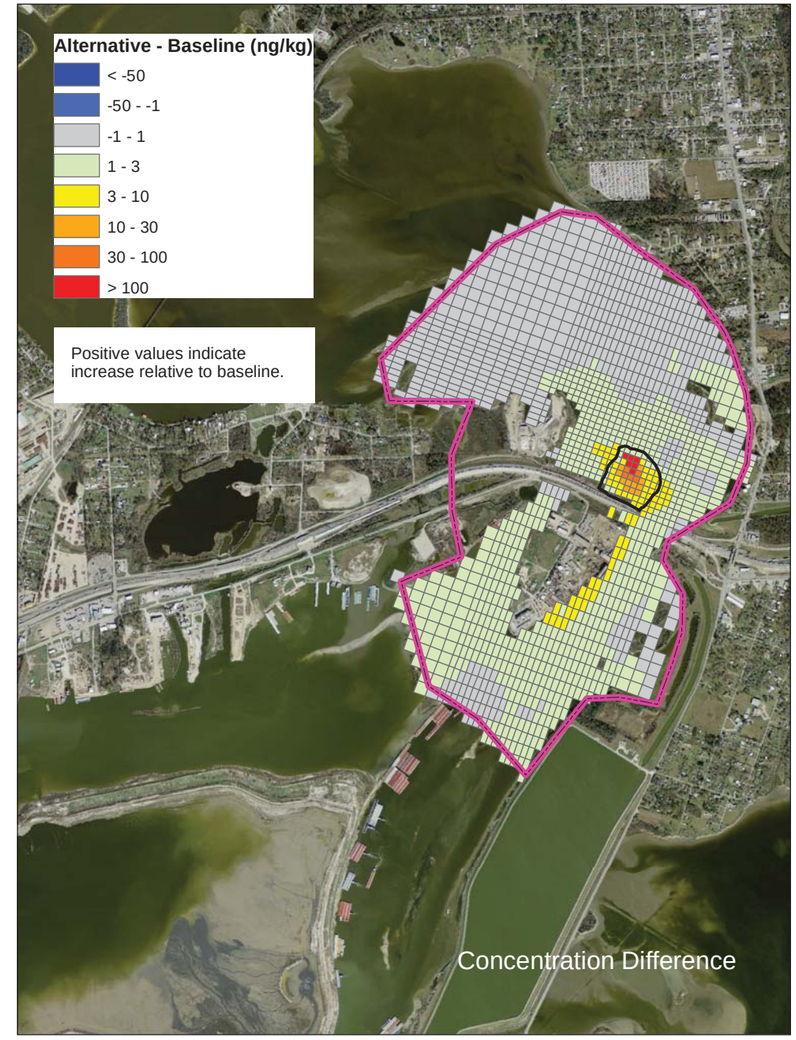
ANCHOR QEA

Figure 4-6a
Model-Predicted Surface Sediment (top 6 inches) TCDD Concentrations at the End of the First Model Year for Alternatives 1 through 3 and Alternative 4 Simulations
Feasibility Study
San Jacinto River Waste Pits Superfund Site

DRAFT





LEGEND

Perimeter of Northern Impoundments

USEPA's Preliminary Site Perimeter

NOTES:
Orthoimagery presented herein are enhanced 50-cm (0.5-meter) Digital Orthophoto Quarter-Quads (DOQQs) images from the 2008 USDA-FSA National Agriculture Imagery Program (NAIP) and 2009 Texas Orthoimagery Program (TOP) aerial imagery acquisitions.

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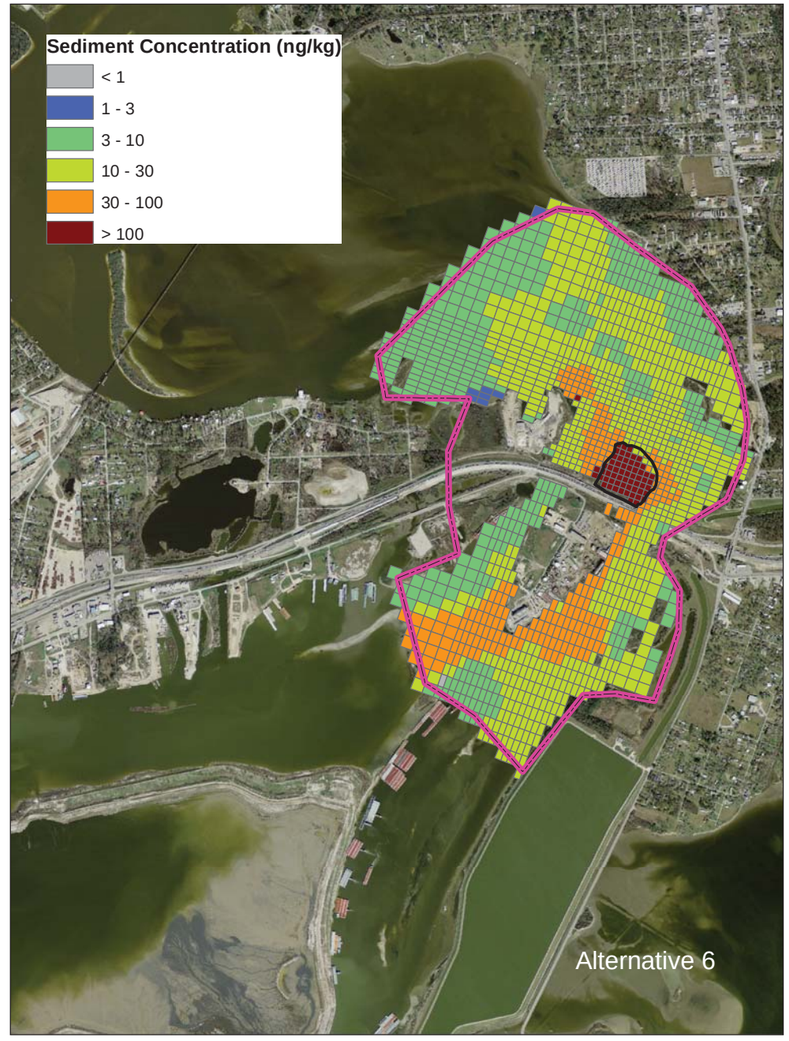
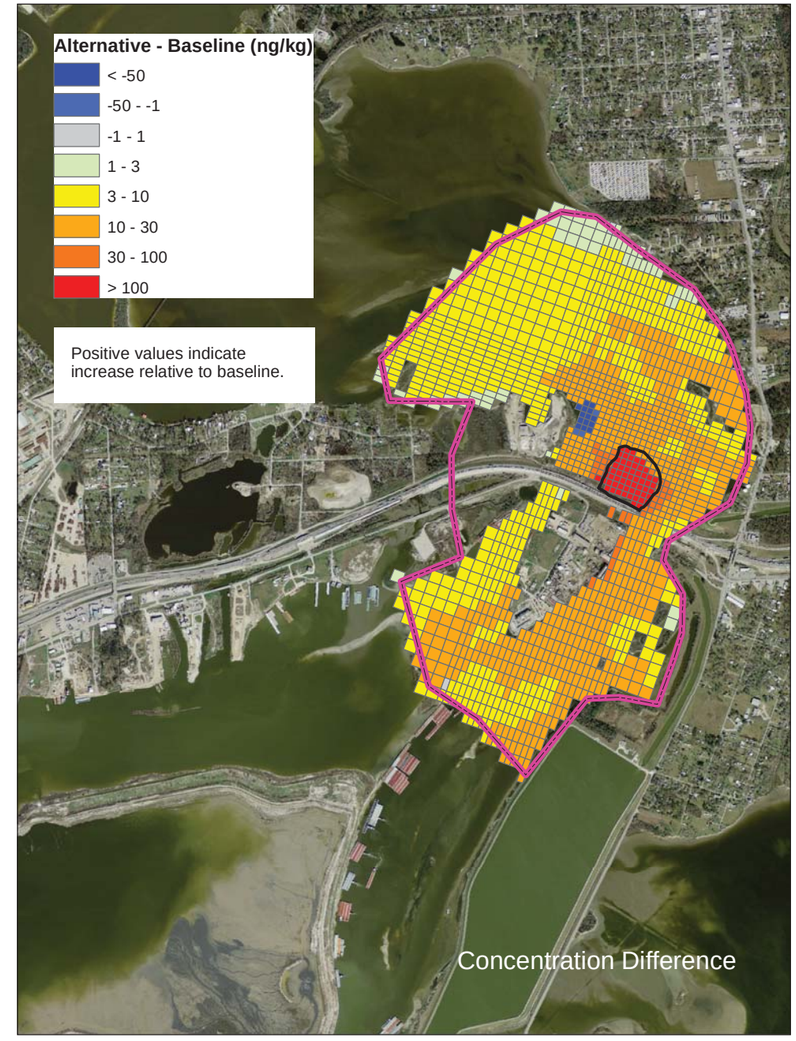
ANCHOR QEA

Figure 4-6b
Model-Predicted Surface Sediment (top 6 inches) TCDD Concentrations at the End of the First Model Year for Alternatives 1 through 3 and Alternative 5 Simulations
Feasibility Study
San Jacinto River Waste Pits Superfund Site

DRAFT





LEGEND

Perimeter of Northern Impoundments

USEPA's Preliminary Site Perimeter

NOTES:
Orthoimagery presented herein are enhanced 50-cm (0.5-meter) Digital Orthophoto Quarter-Quads (DOQQs) images from the 2008 USDA-FSA National Agriculture Imagery Program (NAIP) and 2009 Texas Orthoimagery Program (TOP) aerial imagery acquisitions.

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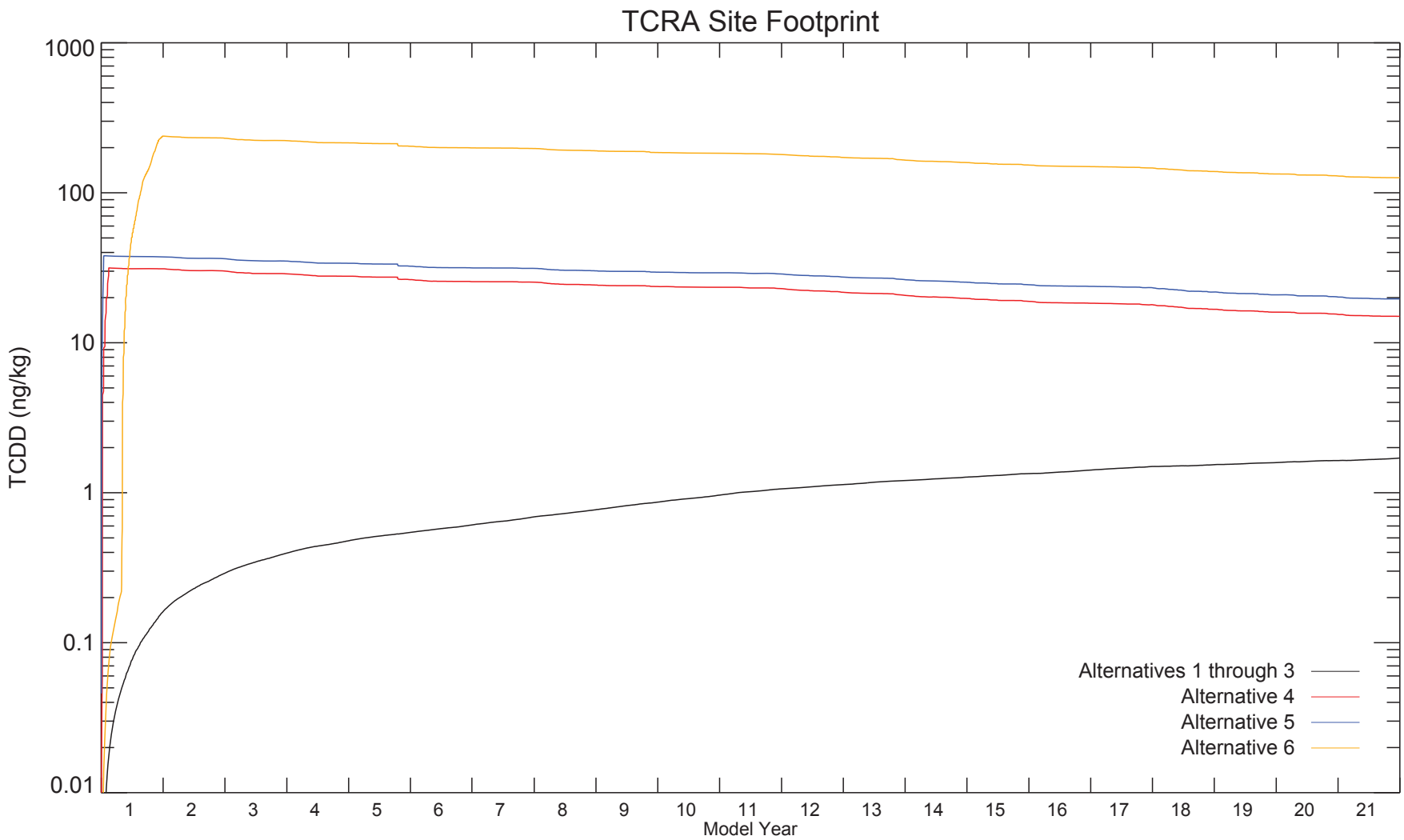
ANCHOR QEA

Figure 4-6c
Model-Predicted Surface Sediment (top 6 inches) TCDD Concentrations at the End of the First Model Year for Alternatives 1 through 3 and Alternative 6 Simulations
Feasibility Study
San Jacinto River Waste Pits Superfund Site



Model Run: SJR_PROJ2_BC_TCDD_1301-06, SJR_PROJ3_BC_TCDD_1307-01, SJR_PROJ3_BC_TCDD_1307-02, SJR_PROJ3_BC_TCDD_1307-03

Figure 4-7

Time Series of Model-Predicted Surface Sediment (top 6 inches) TCDD Concentrations Averaged over the TCRA Site Footprint for Alternatives 1 through 3 and Alternatives 4, 5, and 6 Simulations
Feasibility Study
San Jacinto River Waste Pits Superfund Site

ANCHOR QEA

ATTACHMENT 1

COMPLETE SET OF MODEL OUTPUT GRAPHICS FOR TCDD AND TCDF

(ON CD)

DRAFT FEASIBILITY STUDY REPORT APPENDIX B: HYDRODYNAMIC CAP MODELING

SAN JACINTO RIVER WASTE PITS SUPERFUND SITE

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LIST OF ACRONYMS AND ABBREVIATIONS

ACES	Automated Coastal Engineering System
Anchor QEA	Anchor QEA, LLC
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
D_{50}	median diameter
D_{100}	maximum diameter
EFDC	Environmental Fluid Dynamics Code
FS	Feasibility Study
H:V	horizontal to vertical
I-10	Interstate 10
mph	miles per hour
psf	pounds per square foot
RAWP	Removal Action Work Plan
S_f	safety factor
Site	San Jacinto River Waste Pits Superfund Site
SJRF	San Jacinto River Fleet
TCRA	Time Critical Removal Action
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency

1 INTRODUCTION

This appendix to the Draft Feasibility Study (FS) Report for the San Jacinto River Waste Pits Superfund Site (Site) presents the results of the hydrodynamic evaluation of a permanent cap considered as part of the FS. The permanent cap is included in remedial Alternatives 3, 4, and 5 described in the main text of the Draft FS. Specifically, this appendix documents the following:

- The design rock size for a permanent cap, focusing on the factor of safety for armor rock on slopes in the wave-breaking (i.e., surf) zone in the area of the impoundments located north of I-10 (Northern Impoundments) where a Time Critical Removal Action (TCRA) has already been completed (TCRA Site)
- The effect of varying assumptions for the design storm event magnitude on predicted stable armor rock sizes

1.1 Background

The TCRA included the design and installation of an armored cap over the TCRA Site. The TCRA cap was designed to provide immediate containment of the materials in the former Northern Impoundments and to be compatible with a final Site remedy. As with any cap design, the factor of safety can be increased, which ultimately will reduce the potential for long-term cap maintenance needs.

Subsequent to completion of the TCRA, U.S. Environmental Protection Agency (USEPA) raised questions about the basis of design for the TCRA, specifically the protectiveness of a cap design that is based on the 100-year return interval storm, which is recommended in USEPA's contaminated sediment remediation guidance (USEPA 2005). The TCRA cap was designed considering a range of storms up to the 100-year return interval. In support of the Draft FS, additional evaluations were performed to consider a range of specific modeled events, as well as an extreme-level storm event with a 500-year return interval.

1.2 Permanent Cap

The Draft FS includes a permanent cap for several alternatives, which entails flattening the slopes of the existing TCRA cap by adding additional armor rock material to increase the

factor of safety. Construction of a permanent cap would entail construction of 5 horizontal to 1 vertical (5H:1V) slopes along the central, western, and southern berms (flattening these berms from 2H:1V to 5H:1V) to increase the factor of safety in the wave-breaking zone, and flattening the submerged slopes from 2H:1V to 3H:1V to increase the factor of safety for submerged slopes.

Armor Cap D material, as described in the TCRA *Final Removal Action Work Plan* (RAWP; Anchor QEA 2010), would be used for the permanent cap. This is a natural stone material with the following estimated gradation:

- D_{100} = 15 inches
- D_{85} = 12 inches
- D_{50} = 10 inches
- D_{15} = 8 inches

1.3 Design Storm Event Evaluation

In addition to evaluating design slopes and armor size for the permanent cap, this appendix describes the analysis that was performed to evaluate the long-term protectiveness of the permanent cap under a variety of storm conditions, including several actual storms that have occurred in the vicinity of the Site. An evaluation of current velocities and stable cap grain size was performed for wind- and vessel-generated waves breaking in the surf zone, as well as for river currents during the following storm and flood scenarios:

- 5-year flood
- 10-year flood
- 25-year flood
- 50-year flood
- 100-year flood
- 500-year flood
- Hurricane Ike
- Tropical Storm Allison
- October 1994 Harris County flood

2 DESIGN AND PERFORMANCE CRITERIA

The USEPA's and U.S. Army Corps of Engineers' (USACE's) Guidance for In-Situ Subaqueous Capping of Contaminated Sediments (Palermo et al. 1998) states the following:

> *The cap component for stabilization/erosion protection has a dual function…to stabilize the contaminated sediments being capped…[and] to make the cap itself resistant to erosion.*

In addition, USEPA's Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (USEPA 2005) states the following:

> *[T]he design of the erosion protection features of an in-situ cap (i.e., armor layers) should be based on the magnitude and probability of occurrence of relatively extreme erosive forces estimated at the capping site. Generally, in-situ caps should be designed to withstand forces with a probability of 0.01 per year, for example, the 100-year storm.*

The TCRA cap was designed to provide isolation of underlying sediment and protection from erosive forces in the San Jacinto River (waves and currents). The permanent cap will provide enhanced long-term protection of the underlying materials. The evaluation of the permanent cap was performed using methods developed by USEPA and USACE specifically for in situ caps. This includes the methods included in Armor Layer Design of Guidance for In Situ Subaqueous Capping of Contaminated Sediments (Maynord 1998).

In addition to the recommended 100-year storm design criterion, this appendix considers a range of storm and flood scenarios up to the 500-year storm to assess the sensitivity of the stable armor rock size to the magnitude of the storm, and to evaluate the performance of the permanent cap under these extreme scenarios.

3 WIND WAVE AND VESSEL WAKE EVALUATION

This section describes evaluations of wind-generated waves and vessel-generated wakes, both of which were used to assess the permanent cap that is described in the FS.

3.1 Wind-Generated Waves

Winds blowing across the surface of bodies of water transmit energy to the water, and waves are formed. The size of these wind-generated waves depends on the wind velocity, the length of time the wind is blowing, and the extent of open water over which it blows (i.e., the "fetch" length; USACE 1991).

The wind-generated wave evaluation performed as part of this assessment consisted of the following major components:

1. Obtaining historical wind speeds and directions near the TCRA Site
2. Conducting a statistical evaluation of wind data to estimate the various return interval wind speeds for the largest fetch distances adjacent to the TCRA Site
3. Estimating the corresponding wave height and period from the wind data

3.1.1 Wind Data Evaluation

Hourly wind measurements (speed and direction) from 1973 through July 2012 were obtained from George Bush Intercontinental Airport in Houston, Texas. A wind rose diagram for the data, illustrating how wind speed and direction are typically distributed for the TCRA Site, is shown on Figure 1. The wind data were reported in 2-minute averages every hour. As can be seen in this figure, the prevailing winds in the area are from the south and southeasterly directions, although there can be significant wind events from the north.

The methodology used to estimate wind speeds for wave prediction was consistent with that described in Part II – Chapter 2 of the USACE's Coastal Engineering Manual (USACE 2006). A statistical evaluation was performed on the maximum annual wind speeds to estimate various return interval wind speeds from the north and northwest (the two longest fetch distances that could create wind-generated waves that could impact the TCRA Site). Figure 2 shows the fetch distances from the north and northwest used in the calculation.

Five candidate probability distribution functions were fitted to the maximum 2-minute averaged annual wind speeds to develop representative wind speeds with different return periods. The candidate distribution functions evaluated were Fisher-Tippet Type I and Weibull distributions with the exponent k varying from 0.75 to 2.0. The return interval wind speeds used in the design were chosen from the distribution that best fit the data. Figures 3 and 4 show the plots of the computed return interval wind speeds for winds blowing from north and northwest, respectively.

3.1.2 Wave Prediction

The USACE Automated Coastal Engineering System (ACES) computer program was used to model wave growth and propagation due to winds (USACE 1992). The ACES program was developed by USACE and is an accepted worldwide reference for modeling water wave mechanics and properties. To compute the wave height for each direction, the wind speed was applied along the fetch distance shown on Figure 2 for each direction. The wave height and period were determined using the ACES Wave Prediction Module. Tables 3-1 and 3-2 summarize the results for winds from the north and northwest, respectively.

Table 3-1
Computed Significant Wave Heights and Periods for Winds Blowing from the North (0.8-mile fetch length)

Description	2-year	5-year	10-year	25-year	50-year	100-year
Wind speed (miles per hour)	26.9	33.0	37.0	42.1	45.9	49.7
Significant wave height (feet)	0.71	0.88	0.99	1.13	1.24	1.34
Wave period (seconds)	1.49	1.60	1.67	1.75	1.80	1.85

Table 3-2
Computed Significant Wave Heights and Periods for Winds Blowing from the Northwest (1.4-mile fetch length)

Description	2-year	5-year	10-year	25-year	50-year	100-year
Wind Speed (miles per hour)	29.2	34.3	37.7	41.9	45.1	48.2
Significant Wave Height (feet)	0.99	1.17	1.28	1.42	1.53	1.63
Wave Period (seconds)	1.80	1.91	1.97	2.05	2.10	2.15

Note:
In the ACES Wave Prediction Module, the 2-minute averaged wind speeds input to ACES were converted to 15-minute averaged wind speeds in the wave generation model because the wave generation process correlates to 15-minute interval wind speeds. Shorter-duration gusts are generally not sufficient for significant wave generation.

Because the estimated 100-year wind speed from the north (49.7 miles per hour [mph]) was below the maximum northerly wind speed measured (53.0 mph), a calculation of the wave height and period was performed using the maximum measured wind speed. The computed significant wave height and period for a wind speed of 53.0 mph from the north was 1.43 feet and 1.90 seconds, respectively.

Based on this evaluation, wind-generated significant wave heights could range from 0.71 to 1.63 feet.

3.2 Vessel Wake Evaluation

Waves can also be generated by a boat moving through the water. These vessel-generated waves are often referred to as wakes. An evaluation was performed to estimate the potential vessel-generated wake heights associated with the tugboats that may operate in the river near the TCRA Site, and in particular in the vicinity of the San Jacinto River Fleet (SJRF) barge fleeting operations that were established near the TCRA Site, subsequent to the original TCRA design. In the area of the TCRA Site, the limited water depth prohibits large vessels from operating close to the cap.

Based on information provided by local vessel operators, the vertical clearances of bridges limit river operations to smaller tugboats north of Interstate 10 (I-10), and the tugboats that operate in this area typically move at speeds between 2 and 4 knots (2.3 to 4.6 mph), which

minimizes vessel wakes ("no wake") but allows for steerage and control. Local vessel operators also state that the largest tugboats that operate north of I-10 adjacent to the TCRA Site are typically 400- to 800-horsepower class craft. These tugboats operate in the main channel of the San Jacinto River. Based on bathymetric surveys conducted in the vicinity of the TCRA Site, there is a 26-foot-deep channel located 250 feet east of the TCRA Site, a 20-foot-deep channel located 950 feet northeast of the TCRA Site, and a 16-foot-deep channel located 1,350 feet north of the TCRA Site.

Based on a review of the river bathymetry and the location of the SJRF area, tugboats operating to support the SJRF barge activities operate in 12 to 16 feet of water approximately 430 feet or more north and northwest of the TCRA Site. In a report entitled Final Sampling and Analysis Plan for Pre-Construction Baseline Site Assessment, San Jacinto River Fleet Property, Harris County, Texas (Tolunay-Wong 2012), SJRF has proposed to install a line of pylons approximately 430 feet from the TCRA Site, physically separating SJRF operations from the TCRA Site.[1]

The TCRA Site is also marked with floating buoys located around the perimeter of the eastern cell. These buoys provide for an additional visible warning to vessel operators to minimize the potential for inadvertent vessel operations in close proximity to the cap.

The Sorensen-Weggel method (Sorensen and Weggel 1984; Weggel and Sorensen 1986) was used to estimate potential vessel wakes for tugboats. The Sorensen-Weggel method is an empirical model (developed from available laboratory and field data on vessel-generated waves) used to predict maximum wave height as a function of vessel speed, vessel geometry, water depth, and distance from the sailing line. This model is applicable to various vessel types (ranging from tugboats to large tankers), vessel speeds, and water depths. The method calculates the wave height generated at the bow of a vessel as a function of the vessel speed, distance from the sailing line, water depth, vessel displacement volume, and vessel hull geometry (i.e., vessel length and draft).

[1] Nothing contained in this appendix is intended to acknowledge that Respondents concur in the appropriateness or sufficiency of the proposed line of pylons by SJRF as a measure to address impacts from SJRF's operations.

For the vessel wake calculation, a tugboat with a length of 75 feet and a displacement of 7,800 cubic feet was used. This vessel size is typical of tugboats that can physically fit beneath the relatively low I-10 Bridge, and was selected for the design evaluation based on conversations with local marine contractors who operate tugboats in the San Jacinto River upstream of I-10. The vessels were conservatively assumed to operate 250 to 1,000 feet from the TCRA Site. Water depths used in the calculation ranged from 12 feet to 26 feet. As described above, the vessels operate at speeds from 2 to 4 knots (essentially a "no wake zone" speed). A vessel-wake calculation was performed for vessels travelling at the high end of the expected speed, 4 knots. An additional scenario was considered for vessels travelling at 8 knots—this higher speed representing a conservative case that is expected to overestimate potential wake impacts.

Table 3-3 presents a summary of the results of the vessel-generated wave evaluation.

Table 3-3
Vessel-Generated Wave Heights

Vessel Class	Water Depth (feet)	Vessel Speed (knots)	Distance from Sailing Line (feet)	Wave Height (feet)
Tugboat operating in the river channel	16	4	250	0.0
			1,000	0.0
		8	250	1.0
			1,000	0.6
	26	4	250	0.0
			1,000	0.0
		8	250	1.1
			1,000	0.7
Tugboat operating at the SJRF barge area	12	4	430	0.0
		8		0.8
	16	4	430	0.0
		8		0.8

Note:
SJRF - San Jacinto River Fleet

The results indicate that vessel wakes at the TCRA Site would be less than 1.2 feet.

In summary, wind-generated waves are estimated to be less than 1.7 feet, and vessel-generated wakes are expected to be less than 1.2 feet at the TCRA Site. The vessel wake results, combined with the wind-generated wave results, are used to evaluate required armor rock sizes in the wave-breaking zone of the permanent cap, as discussed below.

3.3 Evaluation of Armor Layer Material

Due to the amount of turbulence generated by breaking waves in the surf zone, the armor layer was modeled in the TCRA design as a rubble mound berm (i.e., a sloped berm [or revetment] consisting of rock). Armor stone for sloped berms was sized using guidance from USACE 2006 as part of the original TCRA design. The USACE guidance was used because the methodology to evaluate armor stone sizes for sediment caps presented in USEPA's design guidance (Maynord 1998) does not consider the effects of waves breaking on a cap, as would be the case for the sloped berms at the TCRA Site. The surf zone is defined as the region extending from the location where the waves begin to break to the limit of wave run-up on the shoreline slope. Within the surf zone, wave-breaking is the dominant hydrodynamic process (USACE 2006).

The ACES Rubble Mound Revetment Design Module was used to evaluate the armor stone gradation and thickness in the surf zone. The ACES methodology is based on van der Meer's (1988) paper entitled Deterministic and Probabilistic Design of Breakwater Armor Layers. The ACES method assumes that the waves would propagate and break on the slope of the armor layer. The structure was assumed to be permeable, thereby minimizing wave reflection. Stable particle sizes (i.e., armor sizes) were evaluated using the model for the proposed permanent cap slope of 5H:1V.

Revetments used for coastal protection projects are often designed allowing for some movement of the armor layer, which could necessitate maintenance over time. The revetment design methodology allows consideration of variable amounts of displacement (movement) of the armor layer. The amount of displacement considered can be categorized as follows:

- **No Displacement**: Little to no armor stone displacement due to wave energy
- **Minor Displacement**: Minimal movement (less than 5 percent) of armor stones displaced due to wave energy and potentially redistributed within or in the near vicinity of the armor layer
- **Intermediate Displacement**: Displacement ranges from moderate to severe; armor stones are expected to be displaced

The existing TCRA armor cap armor was designed for minimal movement (Anchor QEA 2010), also referred to as the "Minor Displacement" scenario in the rubble mound design guidance. The Minor Displacement scenario is the same as that applied at other Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) cap sites (e.g., Onondaga Lake Superfund Site in Syracuse, New York; Lower Fox River Superfund Site in Green Bay, Wisconsin), to ensure protectiveness.

For design of the permanent cap, the No Displacement and Minor Displacement scenarios were evaluated for slopes constructed at 5H:1V using a wave height of 1.63 feet and wave period of 2.15 seconds, the maximum wave height and wave period shown in Tables 3-1 and 3-2.

Table 3-4 presents the computed median and maximum particle sizes and acceptable ranges of layer thickness for the specific materials, based on the ACES calculation.

Table 3-4
Median (D_{50}) and Maximum (D_{100}) Particle Size and Thickness – Significant Wave Height of 1.63 feet and Period of 2.15 Seconds – Natural Stone Materials

Particle Size/Thickness	Natural Stone[1] (5H:1V)	
	No Displacement (inches)	Minor Displacement[2,3] (inches)
D_{50} (median particle size)	8.3	3.3
D_{100} (maximum particle size)	13.2	5.3
Range of thickness of armor layer[4]	12.5 to 17	5 to 7

Notes:
1. Assumes a unit weight of 165 pounds per cubic foot.
2. Computed using No Displacement and Minor Displacement scenarios. Note that No Displacement represents little to no movement of armor stones. Minor Displacement refers to minimal movement of the armor stones under extreme wave action. Repairs associated with such events (if any) would be handled as part of a maintenance program.
3. Minor Displacement was the design scenario for the TCRA cap armor.
4. Thickness ranges based on guidance from Maynord (1998) and USACE (1994).

The analysis shows that the Armor Cap D material (with a median particle size [D_{50}] of approximately 10 inches and a D_{100} of approximately 15 inches) would provide long-term protection at the TCRA Site. Although a factor of safety is not included specifically in the calculation, the Armor Cap D material proposed for the permanent cap is three times larger than that required under the Minor Displacement scenario; Armor Cap D also exceeds the criteria for the No Displacement scenario.

4 DESIGN STORM EVALUATION

4.1 Background

Hydrodynamic flows, particularly during high-flow events, can result in elevated water velocities and corresponding bed shear stresses, which have the potential to erode sediments. To evaluate the current velocities and stable particle size to resist these velocities, the hydrodynamic model developed as part of the TCRA design was used. The model framework, boundary conditions, development, and calibration is described in detail in RAWP Appendix I – Hydrodynamic Modeling of Anchor QEA (2010), which considered a range of design events up to the 100-year storm.

Based on inquiries from USEPA during development of the FS, the sensitivity of the cap design was assessed for additional storm events, as well as an extreme 500-year recurrence interval storm to evaluate the protectiveness of the cap design. In response to this inquiry, the model presented in Appendix I of the RAWP was updated and run for these additional scenarios.

4.2 Model Update and Simulations

The elevations of the Northern Impoundments in the model were updated based on a survey performed in April 2013, which was performed after completion of the TCRA. High-flow event hydrodynamic simulations were conducted using the updated model. Predicted current velocities within the Study Area were used to calculate the median particle diameter (D_{50}) for the cover material and to compare this diameter to the design of the permanent cap.

A wide range of events were simulated to capture the maximum velocities that may act upon the permanent cap. Using a constant upstream flow rate, the 5-year, 10-year, 25-year, 50-year, 100-year, and 500-year high-flow events were simulated (the downstream tidal elevations are described in Appendix I of Anchor QEA 2010). In addition, for comparison, measured data from the following three actual events were used in simulations with the hydrodynamic model:

- The October 1994 high-flow event (that occurred between October 11, 1994, and October 25, 1994)

- Tropical Storm Allison (that occurred between June 2, 2001, and June 16, 2001)
- Hurricane Ike (that occurred between September 7, 2008, and September 21, 2008)

The design equations to compute the stable particle size to resist river currents use depth-averaged velocities and water depth. Figure 5 shows a depiction of depth-averaged velocity in comparison to the actual distribution of velocity that would be expected in a naturally flowing system. The hydrodynamic model used in the analysis computed depth-averaged velocities. To demonstrate that the range of storm events considered cover the full range of flows that produce the maximum velocities over the TCRA Site, maximum depth-averaged velocities were computed at various locations over the Northern Impoundments. Figure 6 shows the locations where the depth-averaged velocities were computed. Figure 7 shows the maximum depth-averaged velocity for each event at each location. Figure 8 shows the corresponding water depth at the time of the maximum velocity at each location.

The results of this analysis indicate that the peak of depth-averaged velocities over the cap vary in location for each storm and flood event evaluated (Figure 7). This is primarily due to the variable topographic and bathymetric profile of the surface of the cap, and is expected because the water surface elevations in the San Jacinto River vary by storm event. As a result, the water depth, flow patterns, and scour velocities vary spatially across the Northern Impoundments for each storm event depending on the depth of the water at various locations on the cap. In many areas of the cap, as the water depth becomes deeper with larger storm events, the maximum depth averaged velocity decreases. This is especially true for the 500-year flood event.

4.3 Stable Particle-Size Calculation

The stable particle size (expressed as D_{50}) to resist the flow velocity and related bed shear stress was estimated using the Maynord method, from USEPA Guidance for In-Situ Subaqueous Capping of Contaminated Sediment – Appendix A: Armor Layer Design (Maynord 1998). The method presented in Maynord (1998) and shown below is based on the USACE's Hydraulic Design of Flood Control Channels (USACE 1994). This method uses depth-averaged velocity and flow depth to determine the stable median armor stone size (D_{50}).

$$D_{50} = S_f C_s C_v C_T C_G d \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{1/2} \frac{V}{\sqrt{K_1 g d}} \right]^{2.5} \quad (1\text{-}1)$$

where:

D_{50}	=	Median particle size in feet
S_f	=	Safety factor = 1.5 from page A-6 of Maynord 1998. Per Maynord (1998), the minimum safety factory for riprap design is 1.1. A safety factor of 1.3 was used for the TCRA to be more conservative and protective. For the permanent cap, a safety factor of 1.5 is used in this calculation (a more detailed discussion is presented below).
C_s	=	Stability coefficient for incipient failure = 0.3 for angular rock (from page A-6 of Maynord 1998)
C_V	=	Velocity distribution coefficient = 1.0 (from page A-6 of Maynord 1998)
C_T	=	Blanket thickness coefficient = 1.0 for flood flows and thickness = D_{100} (from page A-6 of Maynord 1998)
C_G	=	Gradation coefficient = $(D_{85}/D_{15})^{1/3}$
D_{85}/D_{15}	=	Gradation uniformity coefficient = 1.55 for Armor Cap D material (with D_{85} = 11.8 inches and D_{15} = 7.6 inches)
d	=	Water depth in feet (from the hydrodynamic model)
γ_s	=	Unit weight of stone = 165 pounds per cubic foot
γ_w	=	Unit weight of water = 62.4 pounds per cubic foot
V	=	Maximum depth-averaged velocity in feet per second (from the hydrodynamic model)
K_1	=	Side slope correction factor = 1.0 for a slope of 5H:1V(from Plate B-39 from USACE 1994)
g	=	Acceleration due to gravity = 32.2 feet per second squared

As described above, a safety factor of 1.5 was used in the calculation. Maynord (1998) recommends a minimum safety factory for riprap design of 1.1. In addition, as described in the following from USACE (1994):

> *Equation 3-3 gives a rock size that should be increased to resist hydrodynamic and a variety of nonhydrodynamic-imposed forces and/or uncontrollable physical*

conditions. The size increase can best be accomplished by including the safety factor, which will be a value greater than unity. The minimum safety factor is $S_f = 1.1$.

For the TCRA design, the safety factor (S_f) was increased to 1.3 in Maynord's equation from the recommended 1.1 as a conservative method to account for variations in bathymetry and topography and the associated potential variations in velocities and turbulence intensity for small-scale site variations that are smaller than the two-dimensional Environmental Fluid Dynamics Code (EFDC) model grid resolution. For the permanent cap evaluation, the safety factor was further increased to 1.5.

As an example, Table 4-1 summarizes the armor stone D_{50} results based on a berm slope of 5H:1V and a safety factor of 1.5 for the maximum velocity predicted for the western berm area of the TCRA Site.

Table 4-1
Median (D_{50}) Particle Size to Resist River Currents

Location	Event	Maximum Depth-Average Velocity (feet per second)	Water Depth (feet)	D_{50} (inches)
Western berm	5-year flood	3.1	1.3	0.7
	10-year flood	1.8	1.4	0.2
	25-year flood	6.7	2.4	4.1
	50-year flood	6.4	4.6	3.1
	100-year flood	7.1	7.7	3.5
	500-year flood	3.4	18.7	0.5
	Hurricane Ike	2.2	1.4	0.3
	Tropical Storm Allison	2.5	1.2	0.4
	October 1994 high-flow event	6.5	2.5	3.7

As shown on Figure 6 and Table 4-1, the range of design storms for this evaluation is appropriate for the FS, and storms with return-intervals greater than 100-years result in lower velocities than some of the more frequent storms. The events that control the selection of the stable particle size are between the 10-year and 100-year events (depending on location).

As can be seen from these results, the Armor Cap D materials exceed the computed median (D_{50}) particle size with a conservative safety factor of 1.5. Therefore, the use of Armor Cap D materials on flatter slopes is an appropriate assumption for the design of the permanent cap.

4.4 Wave and Current Combinations

Outside of the surf zone, orbital velocities from waves combined with currents can increase bottom shear stresses. Combining extreme river current with extreme orbital velocity forces is considered to be very conservative because the probability of both extreme events occurring simultaneously is very low.

The armor stone is designed to resist forces due to waves breaking on the TCRA cap (i.e., waves would propagate and break on the western, central, or southern berm armor stone). Within the surf zone (the location where waves break), wave-breaking is the dominant hydrodynamic process (USACE 2006).

An example is provided below to evaluate the stability of Armor Cap D material for a combination of bottom velocities due to superimposed wave and current forces if the berm were to be overtopped.

The bottom shear stress due to the combination of waves and currents can be calculated using the quadratic stress law (Christoffersen and Jonsson 1985), as shown in the following equation:

$$\tau = \rho_w \left(C_{f,c} u_c^2 + C_{f,w} u_w^2 \right) \tag{1-2}$$

where:

τ	=	Bottom shear stress
ρ_w	=	Density of water
$C_{f,c}$	=	Bottom friction coefficient for currents
u_c	=	Maximum current velocity
$C_{f,w}$	=	Bottom friction coefficient for waves
u_w	=	Maximum bottom velocity due to waves

An example is provided below using the results for the EFDC model grid cell along the western berm with the highest computed bed shear stresses due to currents as computed by the EFDC model. In the example, the maximum bed shear stress due to flows computed by the model are added to the computed bed shear stresses due to waves, and a stable particle size is determined based on those stresses. The stable particle size is computed for the 25-year and 100-year return-interval flow events conservatively assuming that the 100-year return-interval wave occurs at the same time as these events.

For the 25-year return-interval flow event, the computed bed shear stress is 19.1 Pascals (0.399 pounds per square foot [psf]) for the model grid cell. For the 100-year return-interval flow event, the computed bed shear stress is 14.8 Pascals (0.309 psf) for the model grid cell.

The bottom friction coefficient for waves is computed using the following equation (van Rijn 1993):

$$C_{f,w} = 0.045 \left(\frac{u_w A_w}{\upsilon}\right)^{-0.2} \tag{1-3}$$

where:

$C_{f,w}$	=	Bottom friction coefficient for waves
u_w	=	Maximum bottom velocity due to waves
A_w	=	Peak orbital excursion
ν	=	Kinematic viscosity of water

Maximum bottom velocities and peak orbital excursions for the 100-year return-interval wave were computed with water depths over the western berm set equivalent to the 25-year and 100-year return-interval flow events using the Linear Wave Theory Module in ACES. Based on this analysis, the estimated bed shear stress due to waves is 5.39 Pascals (0.113 pcf) for the 25-year event and 0.581 Pascals (0.0121 pcf) for the 100-year event. The shear stresses due to waves are higher for the 25-year return-interval flow event as compared with the 100-year return-interval flow event because the water depths over the berm are lower. Table 4-2 summarizes the results of this analysis.

The stable median diameter (D_{50}) for particles subject to a given shear stress can be estimated based on the approach described by Shields (1936). The correlation between shear stress and particle size presented below represents the point at which the subject particle begins to move or "rock" on the bed and does not necessarily imply significant transport of particles of this size. In addition, Shields' work is based on a bed of uniform particles and does specifically account for the increased stability resulting from a well-graded armor layer constructed from a range of angular particles, thus the use of the Shields model is conservative compared to actual conditions at the site.

$$\tau_{*c} = \frac{\tau_c}{(\gamma_s - \gamma) D_{50}} \tag{1-4}$$

where:

τ_{*c}	=	Critical shear stress parameter (pcf)
τ_c	=	Critical shear stress (threshold of motion; pcf)
γ_s	=	Specific weight of the particle (pcf)
γ	=	Specific weight of the water
D_{50}	=	Median particle size (feet)

Shields provides a plot of dimensionless critical shear stress versus a dimensionless Reynolds number. This graphical representation, commonly known as the Shields diagram, is widely used to determine a general relationship for incipient motion. Rouse (1939) fitted a mean curve to the zone of these data points, above which particles are considered to be in motion, and showed that at higher values of the Reynolds number (i.e., coarse sediments/larger grain sizes, and/or fully turbulent flow), the critical shear stress parameter approaches a constant value of 0.060. Since then, others have proposed more conservative values for the critical shear stress parameter, ranging from 0.039 by Laursen (1963) to 0.045 by Yalin and Karahan (1979).

Rearranging Equation 1-4 above to solve for median particle size, and substituting a specific weight of 165 pcf for natural materials such as the Armor Cap D materials (and assuming that the wave event occurs during a freshwater flow event) and a conservative critical shear stress parameter of 0.039, yields the following relationship:

$$D_{50} = \frac{\tau}{4} \tag{1-5}$$

The maximum combined bed shear stresses for combined waves and currents for the 25-year and 100-year return-interval events are 0.511 pcf and 0.322 pcf, respectively. The median particle size (D_{50}) to resist the combined waves and currents ranges between 1.0 and 1.5 inches using this method, which is substantially lower than the median particle size of 10 inches for Armor Cap D material.

Table 4-2

Summary of Combined Forces from Currents and Waves

Flood Flow Return-Interval	Forces from Currents			Forces from Waves					Combined Forces	
	Maximum Depth-Averaged Velocity Computed by EFDC Model (m/s)	Maximum Shear Stress Computed by EFDC Model (Pa)	Maximum Shear Stress Computed by EFDC Model (psf)	Peak Orbital Velocity Computed in ACES (m/s)	Peak Orbital Excursion Computed in ACES (meters)	$C_{f,w}$	Computed Shear Stress For Waves (Pa)	Computed Shear Stress For Waves (psf)	Combined Shear Stress due to Waves and Currents (Pa)	Combined Shear Stress due to Waves and Currents (psf)
25-year	2.03	19.1	0.399	0.725	0.248	0.0102	5.39	0.113	24.5	0.511
100-year	2.15	14.8	0.309	0.180	0.0610	0.0179	0.581	0.0121	15.4	0.322

Notes:
ACES = Automated Coastal Engineering System
$C_{f,w}$ = Bottom friction coefficient for waves
m/s= meters per second
Pa = Pascals
psf = pounds per square foot

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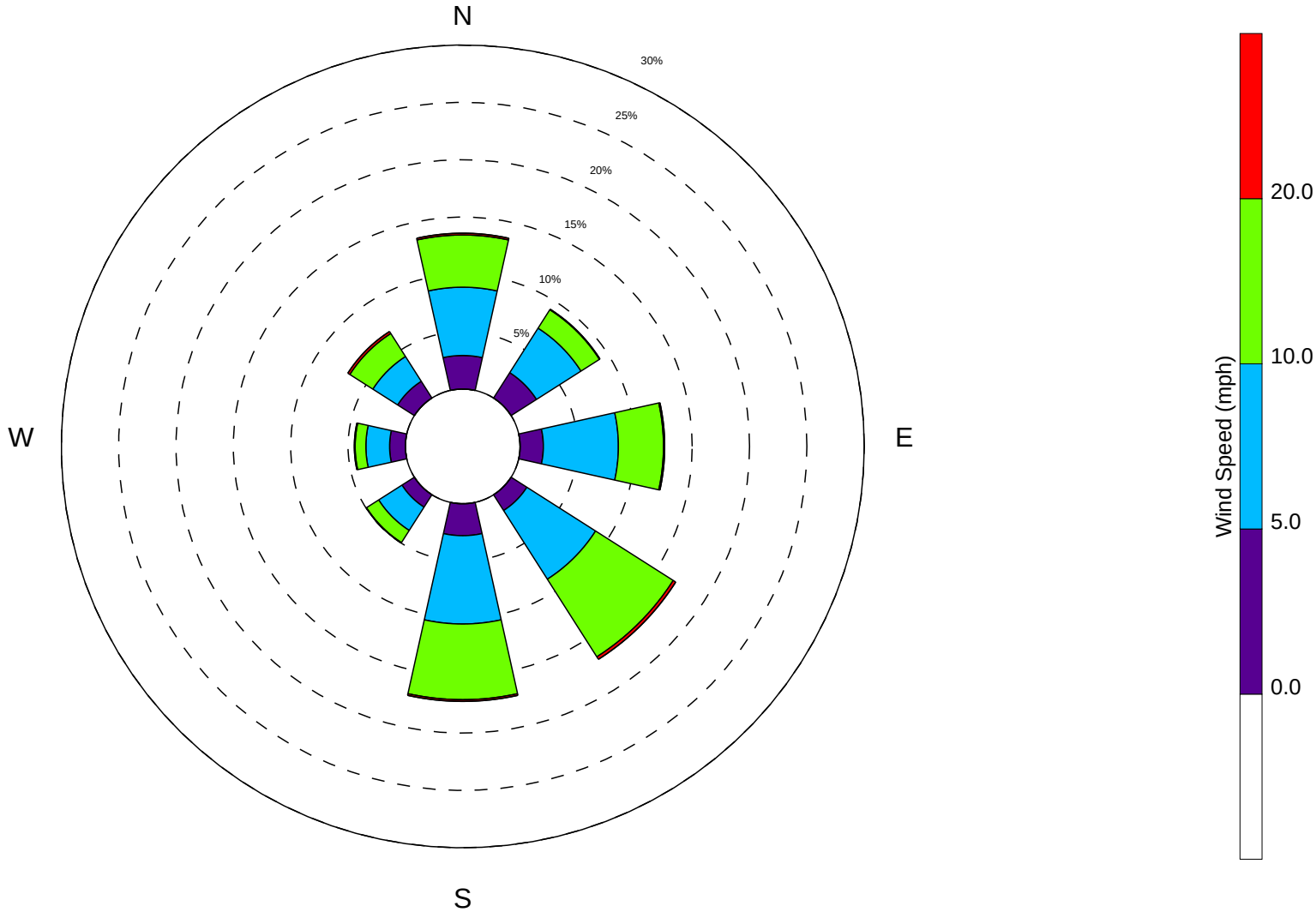
FIGURES



Maximum Recorded Wind Speed: 63.3 mph

Calm Winds 14.07%

Figure 1

Wind Rose Diagram

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San Jacinto River Waste Pits Superfund Site

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Figure 2
Fetch Distances
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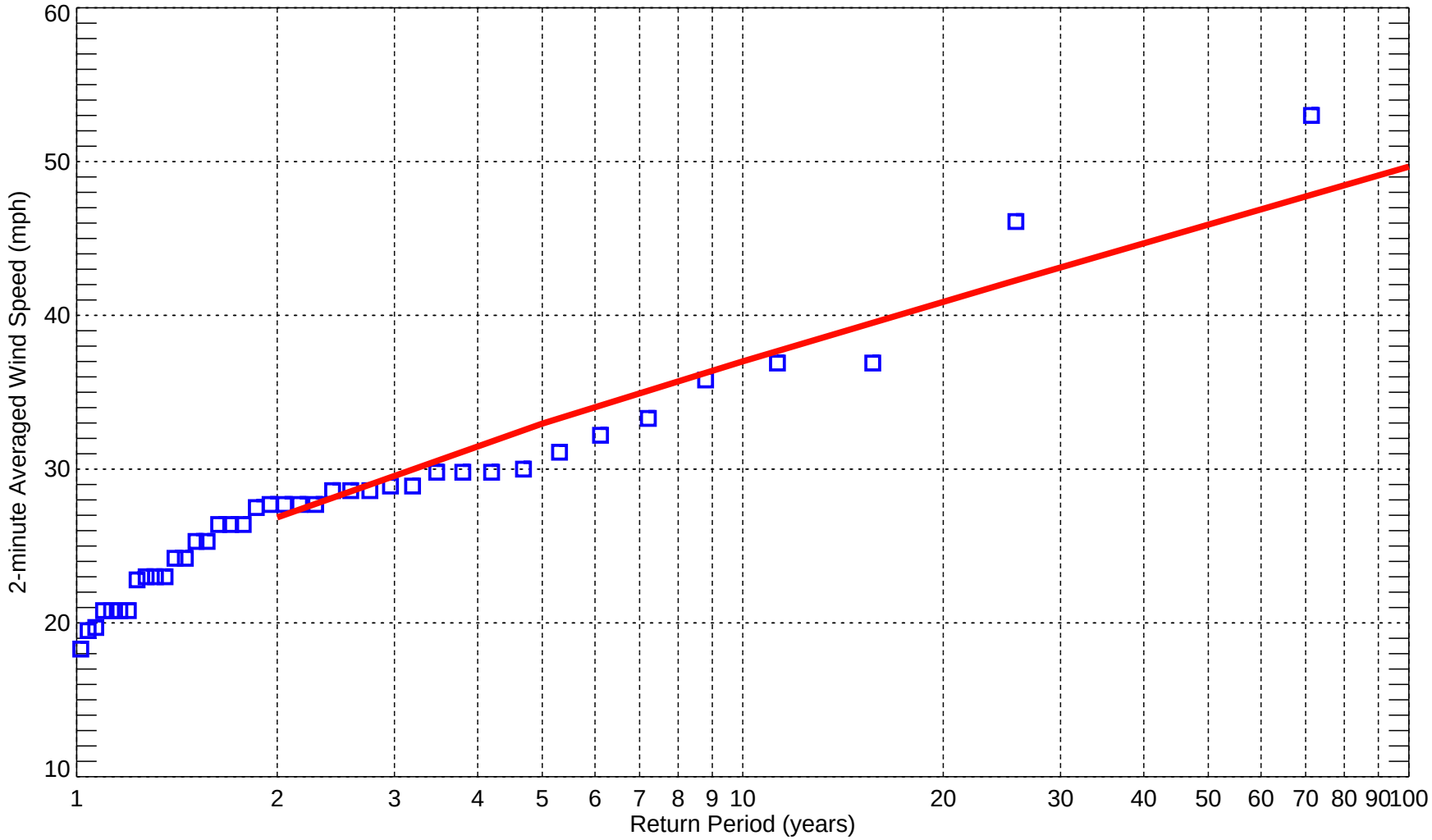
San Jacinto River Waste Pits Superfund Site



Annual Maximum Winds
Fisher-Tippett Type 1 (FT-1) Distribution

Figure 3

Return Interval Wind Speeds (North)
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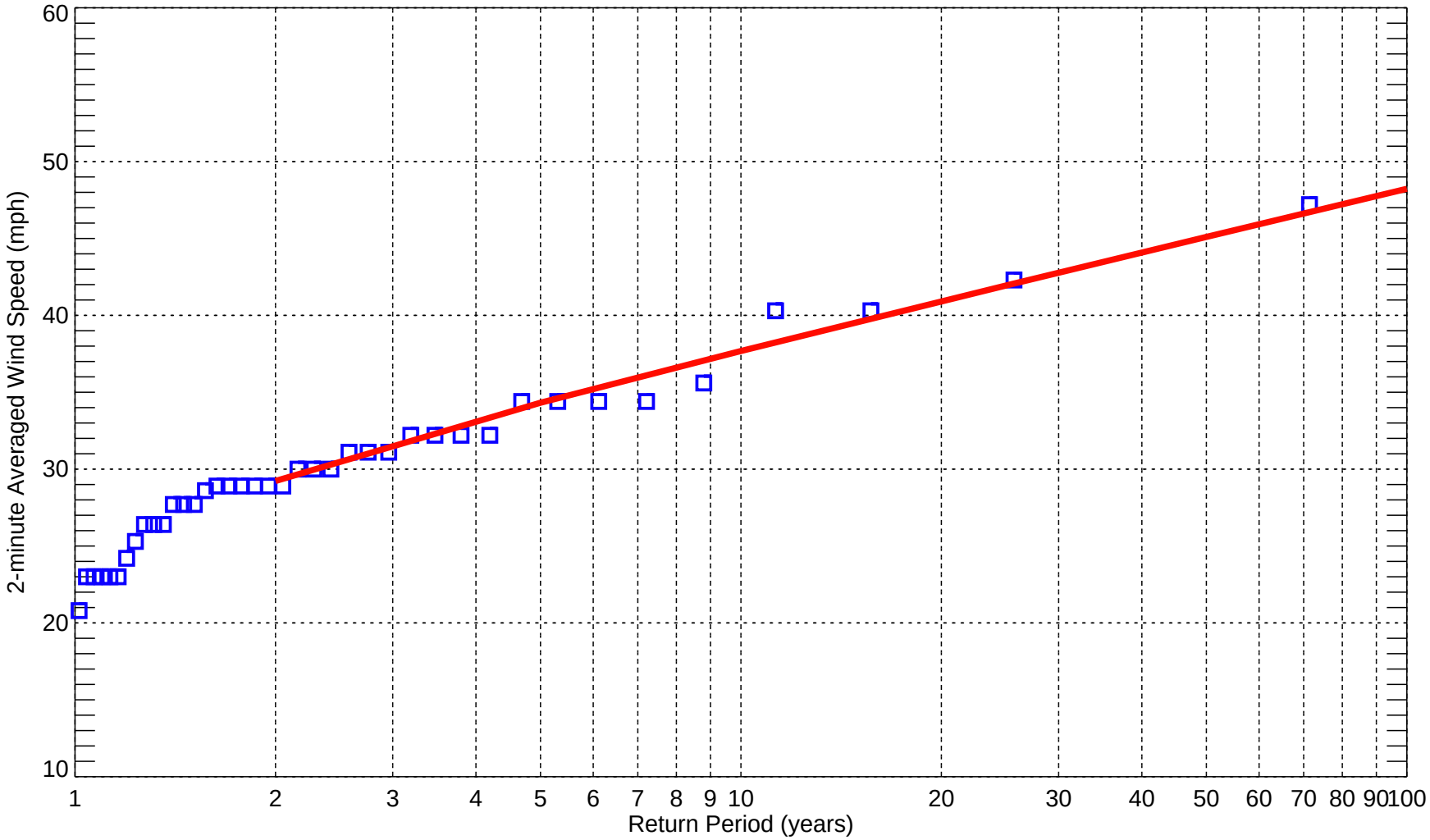
San Jacinto River Waste Pits Superfund Site

The wind record is from 1973 to 2012 at the George Bush Intercontinental Airport.



Annual Maximum Winds
Fisher-Tippett Type 1 (FT-1) Distribution

Figure 4

Return Interval Wind Speeds (Northwest)
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San Jacinto River Waste Pits Superfund Site

The wind record is from 1973 to 2012 at the George Bush Intercontinental Airport.

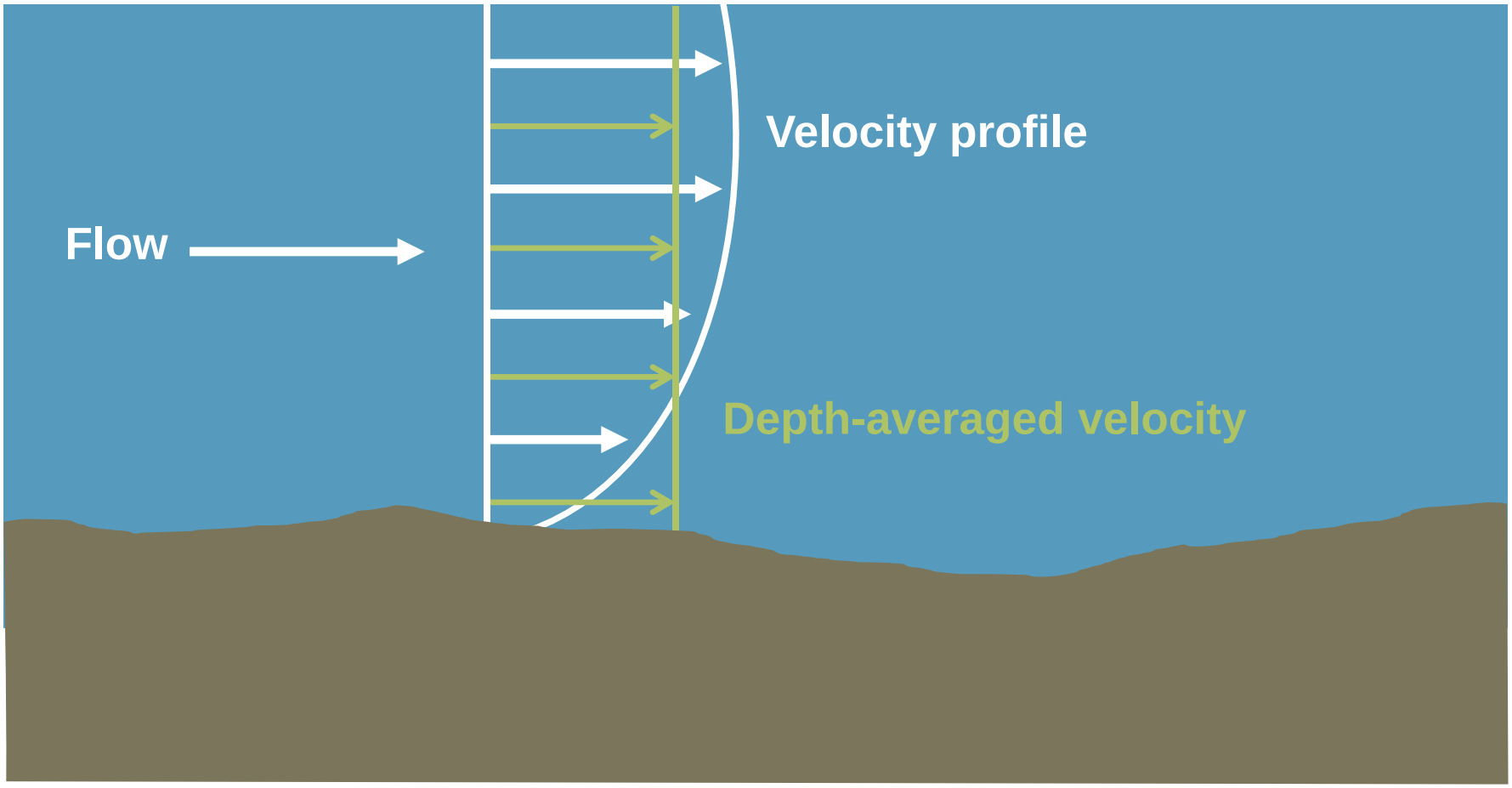

Figure 5
Depth-averaged Velocity Description
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Figure 6
High-Flow Simulation Plot Locations
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San Jacinto River Waste Pits Superfund Site

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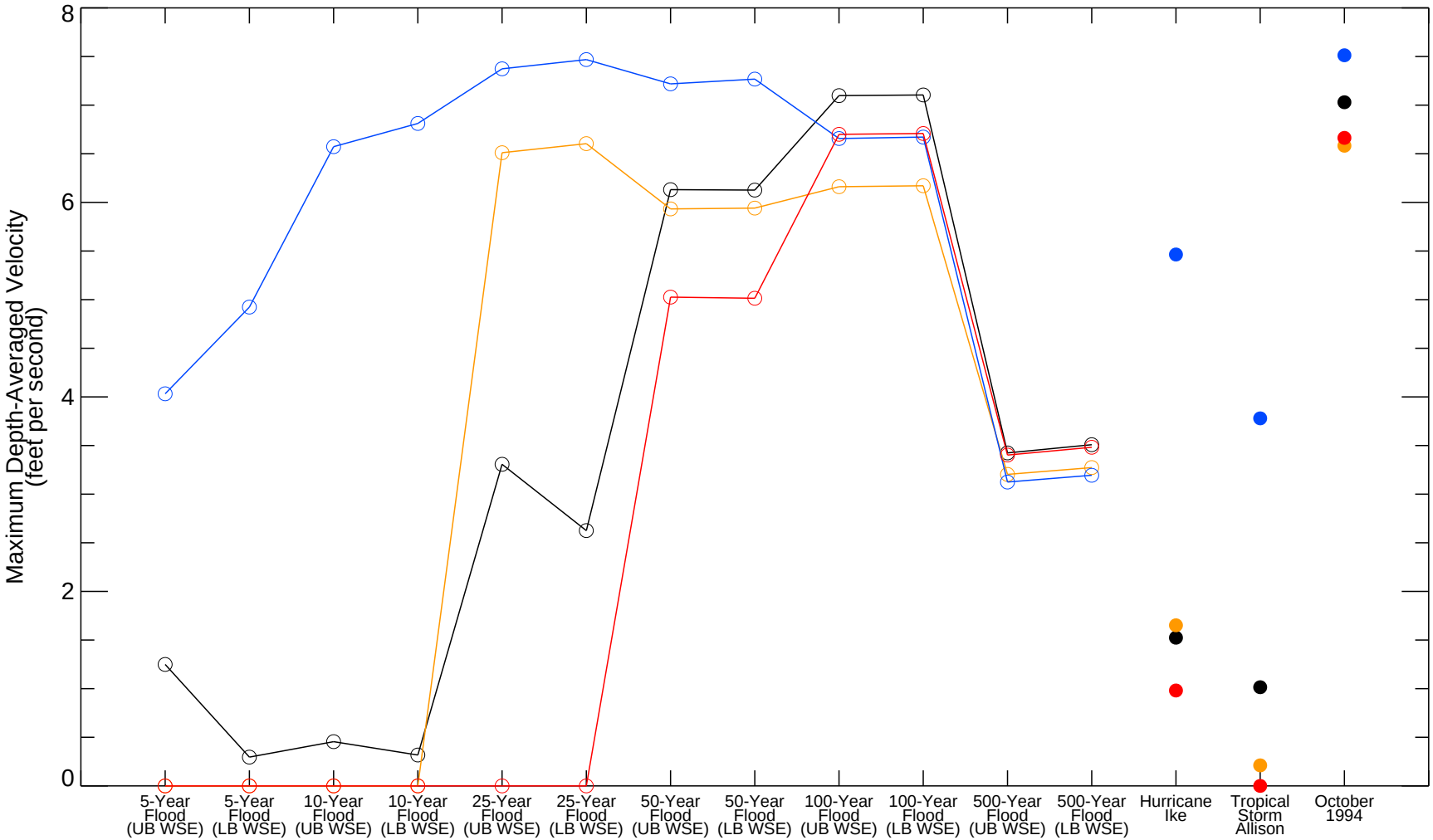

- Western Berm
- Northern Face
- Eastern Cell
- Central Berm

- High-Flow Event Simulation
- Historical Event Simulation

Figure 7

Maximum Depth-Averaged Velocity During High-Flow Simulations
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San Jacinto River Waste Pits Superfund Site

Note: The water surface elevations at the downstream boundary are denoted with UB WSE and LB WSE to represent upper-bound and lower-bound conditions, respectively.

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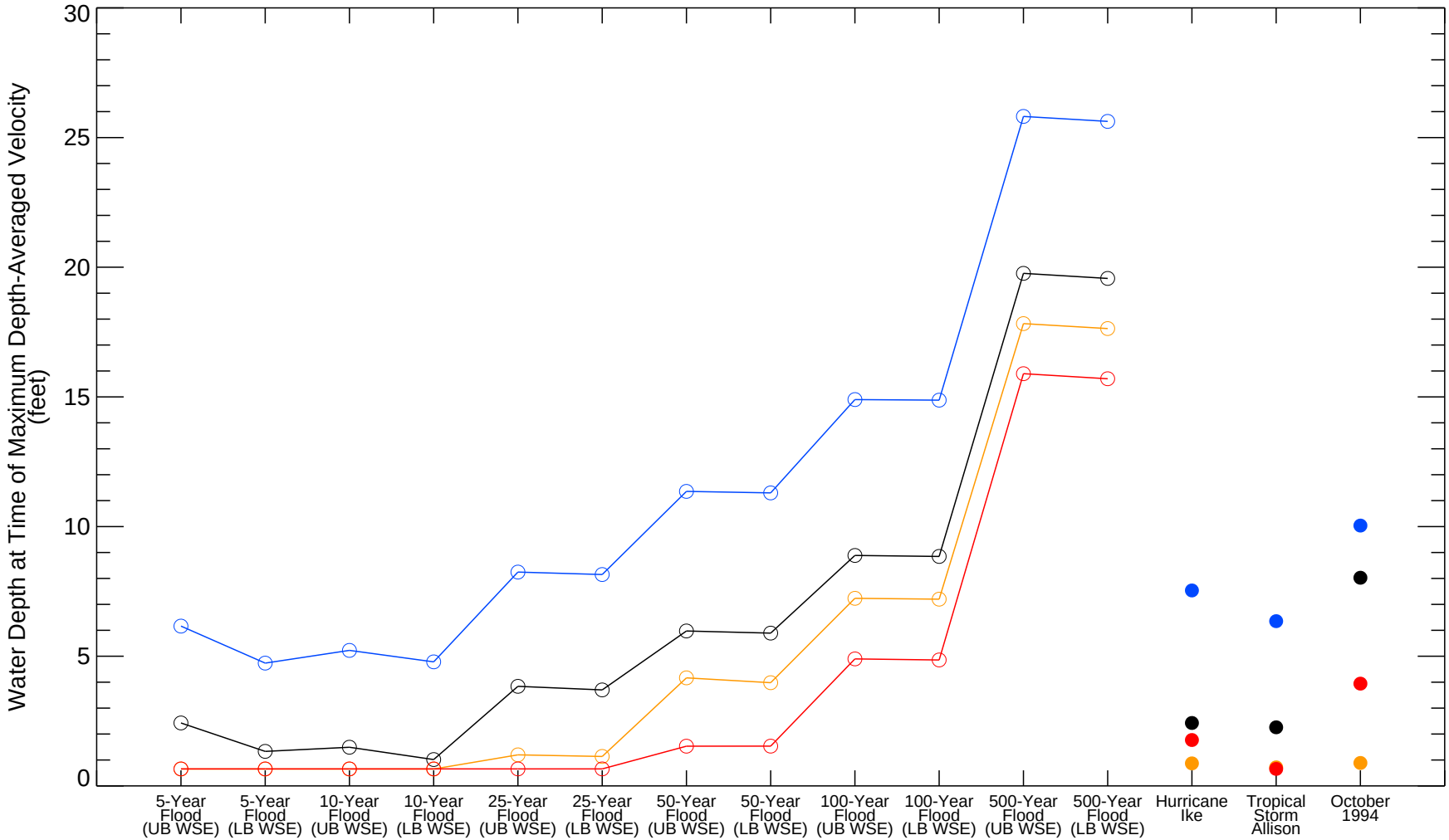

- Western Berm
- Northern Face
- Eastern Cell
- Central Berm

- High-Flow Event Simulation
- Historical Event Simulation

Figure 8

Water Depth During High-Flow Simulations
Draft Feasibility Study - Appendix B: Hydrodynamic Cap Modeling
San Jacinto River Waste Pits Superfund Site

Note: The water surface elevations at the downstream boundary are denoted with UB WSE and LB WSE to represent upper-bound and lower-bound conditions, respectively.

HS - \\HOUL-HSAMAHA\D_Drive\San_Jacinto\Analysis\Long_Term_SedTran\Model_Outputs\FS_High_Flow\high_flow_event_xy_plot_130618.pro Mon Jul 29 10:36:30 2013

DRAFT FEASIBILITY STUDY REPORT APPENDIX C: REMEDIAL ALTERNATIVE COST DEVELOPMENT

SAN JACINTO RIVER WASTE PITS SUPERFUND SITE

SAN JACINTO FEASIBILITY STUDY ALTERNATIVES

	ALT 1	ALT 2	ALT 3	ALT 4	ALT 5a	ALT 5b	ALT 6a	ALT 6b
Elements:	- TCRA Cap OMM	- Institutional Controls - MNR - TCRA Cap OMM	- Institutional Controls - MNR - Permanent Cap - Permanent Cap OMM	- Institutional Controls - MNR - Permanent Cap - Partial Solidification - Permanent Cap OMM	- Institutional Controls - MNR - Permanent Cap - Partial Removal; Disposal - Permanent Cap OMM	- Institutional Controls - MNR - Permanent Cap - Partial Removal; Incinerate - Permanent Cap OMM	- Institutional Controls - MNR - Full Removal; Disposal	- Institutional Controls - MNR - Full Removal; Incinerate
CONSTRUCTION ITEMS								
Mobilization/Demobilization and Setup								
Mobilization/Demobilization			$ 118,000	$ 920,000	$ 2,180,000	$ 11,630,000	$ 10,340,000	$ 63,730,000
Environmental Protection and Erosion Control			$ 50,000	$ 100,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000
Construction, Payment and As-Built Surveys			$ 50,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000
Construction Materials Testing			$ 15,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000
Silt Curtain					$ 100,000	$ 100,000	$ 100,000	$ 100,000
Permanent Cap Construction								
Additional Armor Rock Placement			$ 671,000	$ 671,000	$ 671,000	$ 671,000		
Treatment								
Temporary Sheet Pile Installation				$ 520,000				
In Situ Solidification				$ 1,599,000				
Sheet Pile Dewatering				$ 535,000				
Excavation and Disposal								
Upland TCRA Cap Excavation				$ 275,000	$ 275,000	$ 275,000	$ 275,000	$ 275,000
Inwater TCRA Cap Excavation				$ 196,000	$ 196,000	$ 196,000	$ 1,957,000	$ 1,957,000
Land-based Sediment Excavation					$ 556,000	$ 556,000	$ 556,000	$ 556,000
Water-based Sediment Excavation/Dredging					$ 322,000	$ 322,000	$ 9,582,000	$ 9,582,000
TCRA Cap Wash Water Treatment & Disposal				$ 155,000	$ 155,000	$ 155,000	$ 540,000	$ 540,000
Offsite Haul & Disposal of TCRA Cap (Subtitle D)				$ 682,000	$ 682,000	$ 682,000	$ 2,376,000	$ 2,376,000
Stabilization of Sediment prior to Shipment					$ 210,000	$ 210,000	$ 6,249,000	$ 6,249,000
Offsite Incineration & Disposal of Sediment						$ 67,140,000		$ 379,350,000
Offsite Haul & Disposal of Sediment (Subtitle C)					$ 8,243,000		$ 46,576,000	
Offsite Haul & Disposal of Sediment (Subtitle D)						$ 4,103,000		$ 23,183,000
Dredge Residuals Cover/Backfill					$ 1,599,000	$ 1,599,000	$ 477,000	$ 477,000
Permanent Cap Replacement								
Replacement Cap Geotextile				$ 83,000	$ 83,000	$ 83,000		
Replacement Cap Armor Stone A				$ 665,000	$ 665,000	$ 665,000		
Replacement Cap Armor Stone C/D				$ 550,000	$ 550,000	$ 550,000		
NON-CONSTRUCTION COST ITEMS								
Engineering Design			$ 150,000	$ 250,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000
Construction Administration/Observation			$ 150,000	$ 250,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000
Long Term Costs								
Long Term Cap Monitoring	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ 500,000		
Long Term Natural Recovery Monitoring	$ -	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000
Long Term Cap Maintenance	$ 450,000	$ 450,000	$ 225,000	$ 225,000	$ 225,000	$ 225,000		
TOTAL OPINION OF PROBABLE COST								
Subtotal (Construction + Non-Construction)	$ 1,000,000	$ 1,200,000	$ 2,200,000	$ 8,600,000	$ 18,300,000	$ 90,700,000	$ 80,100,000	$ 489,500,000
Contingency (30%)	$ 300,000	$ 400,000	$ 700,000	$ 2,600,000	$ 5,500,000	$ 27,200,000	$ 24,000,000	$ 146,900,000
TOTAL Opinion of Probable Cost	**$ 1,300,000**	**$ 1,600,000**	**$ 2,900,000**	**$ 11,200,000**	**$ 23,800,000**	**$ 117,900,000**	**$ 104,100,000**	**$ 636,400,000**

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Client: IPC & MIMC
Project: San Jacinto Feasibility Study
Project No.: 090557-01.03

Prepared by: Renee Robertson
Date: 08-30-13
Reviewed by: John Laplante

Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 1 and 2 - Institutional Controls, MNR, and OMM

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	0	LS	$ -	$ -
0002	Environmental Protection and Erosion Control	0	LS	$ 100,000.00	$ -
0003	Construction, Payment and As-Built Surveys	0	LS	$ 100,000.00	$ -
0004	Construction Materials Testing	0	LS	$ 15,000.00	$ -
Subtotal (Construction Lump Sum Items):					$ -
CONSTRUCTION UNIT COST ITEMS					
0005	Additional Armor Rock Placement	0	TON	$ 110.00	$ -
Subtotal (Construction Unit Cost Items):					$ -
CONSTRUCTION TOTAL:					$ -
ROUNDED TOTAL:					**$ -**
NON-CONSTRUCTION COSTS					
0006	Engineering Design	1	LS	10%	$ -
0007	Construction Administration/Observation	1	LS	10%	$ -
0008	Long Term Cap Monitoring	20	EA	$ 25,000.00	$ 500,000.00
0009	Long Term Natural Recovery Monitoring	0	EA	$ 40,000.00	$ -
0010	Cap Maintenance	6	LS	$ 75,000.00	$ 450,000.00
NON-CONSTRUCTION TOTAL:					$ 950,000.00
PROJECT TOTAL					$ 950,000.00
PROJECT ROUNDED TOTAL:					**$ 1,000,000.00**
30% Contingency					**$ 1,300,000.00**

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Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 1 and 2 - Institutional Controls, MNR, and OMM

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	0	LS	$ -	$ -
0002	Environmental Protection and Erosion Control	0	LS	$ 100,000.00	$ -
0003	Construction, Payment and As-Built Surveys	0	LS	$ 100,000.00	$ -
0004	Construction Materials Testing	0	LS	$ 15,000.00	$ -
Subtotal (Construction Lump Sum Items):					$ -
CONSTRUCTION UNIT COST ITEMS					
0005	Additional Armor Rock Placement	0	TON	$ 110.00	$ -
Subtotal (Construction Unit Cost Items):					$ -
CONSTRUCTION TOTAL:					$ -
ROUNDED TOTAL:					**$ -**
NON-CONSTRUCTION COSTS					
0006	Engineering Design	1	LS	10%	$ -
0007	Construction Administration/Observation	1	LS	10%	$ -
0008	Long Term Cap Monitoring	20	EA	$ 25,000.00	$ 500,000.00
0009	Long Term Natural Recovery Monitoring	5	EA	$ 40,000.00	$ 200,000.00
0010	Cap Maintenance	6	LS	$ 75,000.00	$ 450,000.00
NON-CONSTRUCTION TOTAL:					$ 1,150,000.00
PROJECT TOTAL					$ 1,150,000.00
PROJECT ROUNDED TOTAL:					**$ 1,200,000.00**
30% Contingency					**$ 1,560,000.00**

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Client: IPC & MIMC
Project: San Jacinto Feasibility Study
Project No.: 090557-01.03

Prepared by: Renee Robertson
Date: 08-30-13
Reviewed by: John Laplante

Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 3 - Permanent Cap

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	1	LS	$ 118,000.00	$ 118,000.00
0002	Environmental Protection and Erosion Control	1	LS	$ 50,000.00	$ 50,000.00
0003	Construction, Payment and As-Built Surveys	1	LS	$ 50,000.00	$ 50,000.00
0004	Construction Materials Testing	1	LS	$ 15,000.00	$ 15,000.00
Subtotal (Construction Lump Sum Items):					*$ 233,000.00*
CONSTRUCTION UNIT COST ITEMS					
0005	Additional Armor Rock Placement	6,100	TON	$ 110.00	$ 671,000.00
Subtotal (Construction Unit Cost Items):					*$ 671,000.00*
CONSTRUCTION TOTAL:					$ 904,000.00
ROUNDED TOTAL:					**$ 1,000,000.00**
NON-CONSTRUCTION COSTS					
0006	Engineering Design	1	LS	150,000.00	$ 150,000.00
0007	Construction Administration/Observation	1	LS	150,000.00	$ 150,000.00
0008	Long Term Cap Monitoring	20	EA	$ 25,000.00	$ 500,000.00
0009	Long Term Natural Recovery Monitoring	5	EA	$ 40,000.00	$ 200,000.00
0010	Cap Maintenance	3	LS	$ 75,000.00	$ 225,000.00
NON-CONSTRUCTION TOTAL:					$ 1,225,000.00
PROJECT TOTAL					$ 2,129,000.00
PROJECT ROUNDED TOTAL:					**$ 2,200,000.00**
30% Contingency					**$ 2,860,000.00**

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Project: San Jacinto Feasibility Study
Project No.: 090557-01.03

Prepared by: Renee Robertson
Date: 08-30-13
Reviewed by: John Laplante

Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 4 - Partial Solidification

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	1	LS	$ 920,000.00	$ 920,000.00
0002	Environmental Protection and Erosion Control	1	LS	$ 100,000.00	$ 100,000.00
0003	Construction, Payment and As-Built Surveys	1	LS	$ 100,000.00	$ 100,000.00
0004	Construction Materials Testing	2	LS	$ 15,000.00	$ 30,000.00
Subtotal (Construction Lump Sum Items):					*$ 1,150,000.00*
CONSTRUCTION UNIT COST ITEMS					
0005	Additional Armor Rock Placement	6,100	TON	$ 110.00	$ 671,000.00
0006	Remove TCRA Riprap - Land Based	5,000	CY	$ 55.00	$ 275,000.00
0007	Remove TCRA Riprap - Water Based	1,900	CY	$ 103.00	$ 196,000.00
0008	Wash TCRA Riprap; Treat and Dispose	310	TON	$ 500.00	$ 155,000.00
0009	Dispose TCRA Riprap - Subtitle D	12,400	TON	$ 55.00	$ 682,000.00
0010	Temporary Sheet Pile	800	LF	$ 650.00	$ 520,000.00
0011	Sheet Pile Dewatering	107	DAY	$ 5,000.00	$ 535,000.00
0012	In situ Solidification	53,300	CY	$ 30.00	$ 1,599,000.00
0013	Replace Geotextile	20,500	SY	$ 4.05	$ 83,000.00
0014	Replace Armor Rock A	9,000	TON	$ 73.90	$ 665,000.00
0015	Replace Armor Rock C/D	5,000	TON	$ 110.00	$ 550,000.00
Subtotal (Construction Unit Cost Items):					*$ 5,931,000.00*
CONSTRUCTION TOTAL:					$ 7,081,000.00
ROUNDED TOTAL:					**$ 7,100,000**
NON-CONSTRUCTION COSTS					
0016	Engineering Design	1	LS	250,000.00	$ 250,000.00
0018	Construction Administration/Observation	1	LS	250,000.00	$ 250,000.00
0019	Long Term Cap Monitoring	20	EA	$ 25,000.00	$ 500,000.00
0020	Long Term Natural Recovery Monitoring	5	EA	$ 40,000.00	$ 200,000.00
0021	Cap Maintenance	3	LS	$ 75,000.00	$ 225,000.00
NON-CONSTRUCTION TOTAL:					$ 1,425,000.00
PROJECT TOTAL					$ 8,506,000
PROJECT ROUNDED TOTAL:					**$ 8,600,000.00**
30% Contingency					**$ 11,180,000.00**

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Project No.: 090557-01.03

Prepared by: Renee Robertson
Date: 08-30-13
Reviewed by: John Laplante

Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 5a - Partial Removal with Haz Waste Disposal

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	1	LS	$ 2,180,550.00	$ 2,180,000.00
0002	Environmental Protection and Erosion Control	1	LS	$ 200,000.00	$ 200,000.00
0003	Construction, Payment and As-Built Surveys	1	LS	$ 100,000.00	$ 100,000.00
0004	Construction Materials Testing	2	LS	$ 15,000.00	$ 30,000.00
Subtotal (Construction Lump Sum Items):					*$ 2,510,000.00*
CONSTRUCTION UNIT COST ITEMS					
0005	Silt Curtain	1	LS	$ 100,000.00	$ 100,000.00
0006	Additional Armor Rock Placement	6,100	TON	$ 110.00	$ 671,000.00
0007	Remove TCRA Riprap - Land Based	5,000	CY	$ 55.00	$ 275,000.00
0008	Remove TCRA Riprap - Water Based	1,900	CY	$ 103.00	$ 196,000.00
0009	Wash TCRA Riprap; Treat and Dispose	310	TON	$ 500.00	$ 155,000.00
0010	Dispose TCRA Riprap - Subtitle D	12,400	TON	$ 55.00	$ 682,000.00
0011	Water-based Excavation/Dredging	7,000	CY	$ 46.00	$ 322,000.00
0012	Land-based Excavation	46,300	CY	$ 12.00	$ 556,000.00
0013	Sediment Residuals Cover/Backfill	53,300	CY	$ 30.00	$ 1,599,000.00
0014	Sediment Stabilization prior to Shipment	7,000	CY	$ 30.00	$ 210,000.00
0015	Incineration	0	TON	$ 900.00	$ -
0016	Haul & Disposal of Sediment to Subtitle C Landfill	74,600	TON	$ 110.50	$ 8,243,000.00
0017	Replace Geotextile	20,500	SY	$ 4.05	$ 83,000.00
0018	Replace Armor Rock A	9,000	TON	$ 73.90	$ 665,000.00
0019	Replace Armor Rock C/D	5,000	TON	$ 110.00	$ 550,000.00
Subtotal (Construction Unit Cost Items):					*$ 14,207,000.00*
CONSTRUCTION TOTAL:					$ 16,717,000.00
ROUNDED TOTAL:					**$ 16,800,000.00**
NON-CONSTRUCTION COSTS					
0020	Engineering Design	1	LS	$ 300,000	$ 300,000.00
0021	Construction Administration/Observation	1	LS	$ 300,000	$ 300,000.00
0022	Long Term Cap Monitoring	20	EA	$ 25,000.00	$ 500,000.00
0023	Long Term Natural Recovery Monitoring	5	EA	$ 40,000.00	$ 200,000.00
0024	Cap Maintenance	3	LS	$ 75,000.00	$ 225,000.00
NON-CONSTRUCTION TOTAL:					$ 1,525,000.00
PROJECT TOTAL					$ 18,242,000.00
PROJECT ROUNDED TOTAL:					**$ 18,300,000.00**
30% Contingency					**$ 23,790,000.00**

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Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 5b - Partial Removal with Incineration

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	1	LS	$ 11,630,550.00	$ 11,630,000.00
0002	Environmental Protection and Erosion Control	1	LS	$ 200,000.00	$ 200,000.00
0003	Construction, Payment and As-Built Surveys	1	LS	$ 100,000.00	$ 100,000.00
0004	Construction Materials Testing	2	LS	$ 15,000.00	$ 30,000.00
Subtotal (Construction Lump Sum Items):					*$ 11,960,000.00*
CONSTRUCTION UNIT COST ITEMS					
0005	Silt Curtain	1	LS	$ 100,000.00	$ 100,000.00
0006	Additional Armor Rock Placement	6,100	TON	$ 110.00	$ 671,000.00
0007	Remove TCRA Riprap - Land Based	5,000	CY	$ 55.00	$ 275,000.00
0008	Remove TCRA Riprap - Water Based	1,900	CY	$ 103.00	$ 196,000.00
0009	Wash TCRA Riprap; Treat and Dispose	310	TON	$ 500.00	$ 155,000.00
0010	Dispose TCRA Riprap - Subtitle D	12,400	TON	$ 55.00	$ 682,000.00
0011	Water-based Excavation/Dredging	7,000	CY	$ 46.00	$ 322,000.00
0012	Land-based Excavation	46,300	CY	$ 12.00	$ 556,000.00
0013	Sediment Residuals Cover/Backfill	53,300	CY	$ 30.00	$ 1,599,000.00
0014	Sediment Stabilization prior to Shipment	7,000	CY	$ 30.00	$ 210,000.00
0015	Incineration	74,600	TON	$ 900.00	$ 67,140,000.00
0016	Haul & Disposal of Sediment to Subtitle D Landfill	74,600	TON	$ 55.00	$ 4,103,000.00
0017	Replace Geotextile	20,500	SY	$ 4.05	$ 83,000.00
0018	Replace Armor Rock A	9,000	TON	$ 73.90	$ 665,000.00
0019	Replace Armor Rock C/D	5,000	TON	$ 110.00	$ 550,000.00
Subtotal (Construction Unit Cost Items):					*$ 77,207,000.00*
CONSTRUCTION TOTAL:					$ 89,167,000.00
ROUNDED TOTAL:					**$ 89,200,000.00**
NON-CONSTRUCTION COSTS					
0020	Engineering Design	1	LS	$ 300,000	$ 300,000.00
0021	Construction Administration/Observation	1	LS	$ 300,000	$ 300,000.00
0022	Long Term Cap Monitoring	20	EA	$ 25,000.00	$ 500,000.00
0023	Long Term Natural Recovery Monitoring	5	EA	$ 40,000.00	$ 200,000.00
0024	Cap Maintenance	3	LS	$ 75,000.00	$ 225,000.00
NON-CONSTRUCTION TOTAL:					$ 1,525,000.00
PROJECT TOTAL					$ 90,692,000.00
PROJECT ROUNDED TOTAL:					**$ 90,700,000.00**
30% Contingency					**$ 117,910,000.00**

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Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 6a - Full Removal with Haz Waste Disposal

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	1	LS	$ 10,337,700.00	$ 10,340,000.00
0002	Environmental Protection and Erosion Control	1	LS	$ 200,000.00	$ 200,000.00
0003	Construction, Payment and As-Built Surveys	1	LS	$ 100,000.00	$ 100,000.00
0004	Construction Materials Testing	2	LS	$ 15,000.00	$ 30,000.00
Subtotal (Construction Lump Sum Items):					*$ 10,670,000.00*
CONSTRUCTION UNIT COST ITEMS					
0005	Silt Curtain	1	LS	$ 100,000.00	$ 100,000.00
0006	Additional Armor Rock Placement	0	TON	$ 110.00	$ -
0007	Remove TCRA Riprap - Land Based	5,000	CY	$ 55.00	$ 275,000.00
0008	Remove TCRA Riprap - Water Based	19,000	CY	$ 103.00	$ 1,957,000.00
0009	Wash TCRA Riprap; Treat and Dispose	1,080	TON	$ 500.00	$ 540,000.00
0010	Dispose TCRA Riprap - Subtitle D	43,200	TON	$ 55.00	$ 2,376,000.00
0011	Water-based Excavation/Dredging	208,300	CY	$ 46.00	$ 9,582,000.00
0012	Land-based Excavation	46,300	CY	$ 12.00	$ 556,000.00
0013	Sediment Residuals Cover	15,900	CY	$ 30.00	$ 477,000.00
0014	Sediment Stabilization prior to Shipment	208,300	CY	$ 30.00	$ 6,249,000.00
0015	Incineration	0	TON	$ 900.00	$ -
0016	Haul & Disposal of Sediment to Subtitle C Landfill	421,500	TON	$ 110.50	$ 46,576,000.00
0017	Replace Geotextile	0	SY	$ 4.05	$ -
0018	Replace Armor Rock A	0	TON	$ 73.90	$ -
0019	Replace Armor Rock C/D	0	TON	$ 110.00	$ -
Subtotal (Construction Unit Cost Items):					*$ 68,588,000.00*
CONSTRUCTION TOTAL:					$ 79,258,000.00
ROUNDED TOTAL:					**$ 79,300,000.00**
NON-CONSTRUCTION COSTS					
0020	Engineering Design	1	LS	$ 300,000	$ 300,000.00
0021	Construction Administration/Observation	1	LS	$ 300,000	$ 300,000.00
0022	Long Term Cap Monitoring	0	EA	$ 25,000.00	$ -
0023	Long Term Natural Recovery Monitoring	5	EA	$ 40,000.00	$ 200,000.00
0024	Cap Maintenance	0	LS	$ 75,000.00	$ -
NON-CONSTRUCTION TOTAL:					$ 800,000.00
PROJECT TOTAL					$ 80,058,000.00
PROJECT ROUNDED TOTAL:					**$ 80,100,000.00**
30% Contingency					**$ 104,130,000.00**

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Client: IPC & MIMC
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Reviewed by: John Laplante

Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 6b - Full Removal with Incineration

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	1	LS	$ 63,731,250.00	$ 63,730,000.00
0002	Environmental Protection and Erosion Control	1	LS	$ 200,000.00	$ 200,000.00
0003	Construction, Payment and As-Built Surveys	1	LS	$ 100,000.00	$ 100,000.00
0004	Construction Materials Testing	2	LS	$ 15,000.00	$ 30,000.00
Subtotal (Construction Lump Sum Items):					*$ 64,060,000.00*
CONSTRUCTION UNIT COST ITEMS					
0005	Silt Curtain	1	LS	$ 100,000.00	$ 100,000.00
0006	Additional Armor Rock Placement	0	TON	$ 110.00	$ -
0007	Remove TCRA Riprap - Land Based	5,000	CY	$ 55.00	$ 275,000.00
0008	Remove TCRA Riprap - Water Based	19,000	CY	$ 103.00	$ 1,957,000.00
0009	Wash TCRA Riprap; Treat and Dispose	1,080	TON	$ 500.00	$ 540,000.00
0010	Dispose TCRA Riprap - Subtitle D	43,200	TON	$ 55.00	$ 2,376,000.00
0011	Water-based Excavation/Dredging	208,300	CY	$ 46.00	$ 9,582,000.00
0012	Land-based Excavation	46,300	CY	$ 12.00	$ 556,000.00
0013	Sediment Residuals Cover	15,900	CY	$ 30.00	$ 477,000.00
0014	Sediment Stabilization prior to Shipment	208,300	CY	$ 30.00	$ 6,249,000.00
0015	Incineration	421,500	TON	$ 900.00	$ 379,350,000.00
0016	Haul & Disposal of Sediment to Subtitle D Landfill	421,500	TON	$ 55.00	$ 23,183,000.00
0017	Replace Geotextile	0	SY	$ 4.05	$ -
0018	Replace Armor Rock A	0	TON	$ 73.90	$ -
0019	Replace Armor Rock C/D	0	TON	$ 110.00	$ -
Subtotal (Construction Unit Cost Items):					*$ 424,545,000.00*
CONSTRUCTION TOTAL:					$ 488,605,000.00
ROUNDED TOTAL:					**$ 488,700,000.00**
NON-CONSTRUCTION COSTS					
0020	Engineering Design	1	LS	$ 300,000	$ 300,000.00
0021	Construction Administration/Observation	1	LS	$ 300,000	$ 300,000.00
0022	Long Term Cap Monitoring	0	EA	$ 25,000.00	$ -
0023	Long Term Natural Recovery Monitoring	5	EA	$ 40,000.00	$ 200,000.00
0024	Cap Maintenance	0	LS	$ 75,000.00	$ -
NON-CONSTRUCTION TOTAL:					$ 800,000.00
PROJECT TOTAL					$ 489,405,000.00
PROJECT ROUNDED TOTAL:					**$ 489,500,000.00**
30% Contingency					**$ 636,350,000.00**

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