ERDC Letter Report

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Evaluation of the San Jacinto Waste Pits Feasibility Study Remediation Alternatives

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Lower San Jacinto River

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Letter Report

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Dallas, TX 75202

Abstract

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

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

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

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Preface

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

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

Unit Conversion Factors

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

Summary and Conclusions

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

Site Conditions and Anchor QEA Model Evaluation

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

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

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

Permanence of Capping

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

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

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

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

Effectiveness of Capping

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

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

Effectiveness of Dredging

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

Impacts of Remediation

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

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

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

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

Project Background, Objectives and Tasks

Background

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

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

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

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

Figure 1-1 San Jacinto River Waste Pits Superfund Site

Goal and Objectives

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

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

Study Tasks

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

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

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

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

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

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

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

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

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

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

Task 10: Identify and document cases, if any, of armoring breaches or confined disposal facility breaches that may have relevance to the San Jacinto site evaluation.

Task 11: Assess the potential amount or range of sediment resuspension and residuals under the various remedial alternatives including capping, solidification, and removal.

Task 12: Identify and evaluate techniques, approaches, Best Management Practices (BMPs), temporary barriers, operational controls, and/or engineering controls (*i.e.*, silt curtains, sheet piles, berms, earth cofferdams, etc.) to minimize the amount of sediment resuspension and sediment residuals concentrations during and after dredging/removal. Prepare a new full removal alternative that incorporates the relevant techniques identified as appropriate.

Task 13: Assess the validity of statements made in the Feasibility Study that the remedial alternative with removal, solidification, and placing wastes again beneath the TCRA cap has great uncertainty as to implementation and that such management of the waste will result in significant releases.

Task 14: Provide a model evaluation of the full removal Alternative 6N identified in the Feasibility Study as well any new alternative(s) developed under Task 12 (Identify and evaluate techniques ...) above. Include modeling of sediment resuspension and residuals.

Task 15: Evaluate floodplain management and impact considerations of construction, considering Alternatives 3N, 5aN, 6N, and any new alternative(s) developed under Task 12, in the floodplain and floodwaters pathway and how that would impact flood control, water flow issues and obstructions in navigable waters. This includes impact on changes to potential flooding and any offsets that are needed due to displacement of water caused by construction in the floodway (height or overall footprint) including effects at the current temporary TCRA cap and any potential future remedial measures.

Task 16: Project the long-term (500 years) effects of the capping alternative (3N) compared to the full removal alternative (6N) on water quality.

Task 17: Assess the potential impacts to fish, shellfish, and crabs from sediment resuspension as a result of dredging in the near term and for the long term.

Task 18: Assess the potential for release of material from the waste pits caused by a storm occurring during a removal/dredging operation; identify and evaluate measures for mitigating/reducing any such releases.

Task 19: Estimate the rate of natural attenuation in sediment concentrations/residuals and recommend a monitoring program to evaluate the progress. Discuss the uncertainty regarding the rate of natural attenuation.

Task 2

Statement

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

Methodology

This task was performed by first reading all identified resources (*e.g.*, reports, journal papers, local sources including newspapers) that describe the hydrologic and hydraulic conditions in the Lower SJR. This information assisted in performing the requested assessment of the SJR hydrodynamic regime. Taking into account the historical scour reports for the Banana Bend area and for the SJR south of the I-10 Bridge, the evaluation of the potential river bed scour/erosion was performed by applying ERDC's LTFATE modeling system to simulate the flood conditions during the October 1994 flood which had a return period of approximately 100 years.

Hydrology and Hydrodynamics of the San Jacinto River

The lower SJR is classified as a coastal plain estuary. Dyer (1997) gives the following definition of an estuary: "An estuary is a semi-enclosed coastal body of water which has a free connection to the open sea, extending into the river as far as the limit of tidal influence, and within which sea water is measurably diluted with fresh water derived from land drainage." Land drainage is from the SJR watershed which is a 4,500 square mile area in Harris County, TX. Bedient (2013) reports that this watershed drains an average of approximately two million acre-feet (2.47 km^3) of runoff per year. The SJR connects to Galveston Bay which has open connections to the Gulf of Mexico.

The SJR Waste Pits are located in a FEMA designated floodway zone, which is essentially the 100-year floodplain for the SJR. The base flood elevation, which is the water surface elevation resulting from a 100-year flood, for the waste pits has been determined by FEMA to be 19 feet (5.8 m). The low lying Waste Pits are also subject to flooding from storm surges generated by both tropical storms (*i.e.*, hurricanes) and extra-tropical storms. Storm surges generated in the Gulf of Mexico propagate into Galveston Bay and into the Lower SJR. Storm surge modeling conducted by NOAA predicted that category 3 and 5 hurricanes that hit Galveston Bay during high tide would produce surge levels of 23 ft (7.0 m) and 33 ft (10.1 m), respectively, at the Site. In addition, eustatic sea level rise and subsidence also contributes to the vulnerability of the Site. The combined effect of sea level rise and subsidence is reflected in the 1.97 ft (0.6 m) increase in relative sea level rise recorded over the past 100 years in Galveston Bay (Brody *et al*. 2014).

The dynamic nature of the flow regime in the SJR estuary is exemplified by the flood that occurred from October 15-19, 1994. The flood was caused by rainfall that ranged from 8 to more than 28 inches during this five-day period and caused severe flooding in portions of 38 counties in southeast Texas (USGS 1995). The 100-year flood was equaled at three of the 43 streamflow gauging stations in the 29 counties that were declared disaster areas after the flow, and it was exceeded at 16 stations. The exceedance of the 100-year flood at the 16 stations ranged from a factor of 1.1 to 2.9 times the 100-year flood. In addition, at 25 of the 43 stations, the peak stages during the flood exceeded the historical maximums (USGS 1995). This flood had a 360,000 ft^3/s (cfs) (10,194 m^3/s (cms)) peak streamflow, 27.0 ft (8.2 m) peak stage, and current velocities greater than 15 ft/s (4.6 m/s) at the USGS gage station No. 08072050 on the SJR near Sheldon, TX when up to eight feet of scour was reported in the reach of the SJR south of the I-10 Bridge. However, no official documentation of this amount of scour was found during our extensive literature search. The photo on the report front cover shows the inundated Site during this flood.

As another example, Hurricane Ike, which was a category 2 hurricane, hit Galveston Bay on September 15, 2008. While this hurricane was less than a 100-year storm, it produced a large storm surge that completely inundated the Site and generated a peak flow rate of 63,100 cfs (1,787 cms) at the Lake Houston Dam. The peak stage at the USGS Station No. 08072050 during Hurricane Ike was 14.2 ft (4.33 m). Tropical Storm Allison hit the Galveston Bay area on June 10, 2001, and generated a peak flow rate at the Lake Houston Dam of 80,500 cfs (2,280 cms). USGS Station No. 08072050 was not installed until October 1, 2007, so the peak stage during Allison is not known.

Evaluation of Potential River Bed Scour

As stated previously, the evaluation of the potential river bed scour/erosion was performed by applying ERDC's LTFATE modeling system to simulate the flood conditions during the October 1994 flood. LTFATE is a multi-dimensional modeling system maintained by ERDC (Hayter *et al.* 2012). The hydrodynamic module in LTFATE is the Environmental Fluid Dynamics Code (EFDC) surface water modeling system (Hamrick 2007a; 2007b; and 2007c). EFDC is a public domain, three-dimensional finite difference model that contains dynamically linked hydrodynamic and sediment transport modules. The sediment transport module in LTFATE is the SEDZLJ sediment bed model (Jones and Lick 2001; James *et al.* 2010). A detailed description of LTFATE is given in Appendices A – C. Appendix A contains a general description of the modeling system, Appendix B contains a detailed description of EFDC, and Appendix C contains a description of SEDZLJ. The setup of LTFATE for this estuarine system is described in Task 3.

The hydrodynamic module in LTFATE was used to simulate the time period September 1 – 30, 1994 using the hydrodynamic input files generated by AQ. This simulation produced a hydrodynamic hot start file that was used to simulate the October 1 – 31, 1994 time period during which sediment transport was also simulated. The simulation showed that the Site was completely inundated during the flood (as seen on the photo on the report cover) which occurred during October 16-21, 1994. This flood was greater than the 100-year flood, and resulted from heavy rainfall in a 38-county area of southeast Texas caused by the remnants of Hurricane Rosa. A maximum of 6.0 ft (1.83 m) of scour was predicted to occur in the reach of the SJR around and a short distance downstream of the substructure of the two Interstate-10 bridges. The estimated uncertainty in this maximum scour depth is +/- 2.5 ft (0.76 m). The National Transportation Safety Board reported that based on sonar tests at "12 locations in the main channel for distances up to 130 feet south of the east-bound Interstate 10 bridge", "about 10-12 feet of scour" occurred during this flood (NTSB 1996). Buried pipelines in that reach were undermined, which means that they were buried less than 10-12 feet below the river bed. Once the pipelines are partially exposed due to scour of the overlying sediment, local scour processes would have caused enhanced scouring around the exposed pipelines, ultimately leading to their complete undermining. As such, it is highly likely that the measured 10-12 feet of scour in that vicinity was the result of river bed erosion as well as the local scour around the undermined pipelines. LTFATE only simulated river bed erosion and not local scour, so the fact that only half the amount of the measured scour was predicted to occur was not surprising.

For the simulation of the October 1994 flood, the TCRA cap was present in the model grid. The representation of the TCRA cap in the grid is described in the Task 3 report. The entire cap was submerged during portions of the simulated flood. The maximum scour depth in any grid cell within the cap boundary during this extreme event was 1.5 ft (0.70 m). The estimated uncertainty in this maximum scour depth is +/- 0.62 ft (0.19 m). An average 90 percent of the 12 inch layer of Armor Cap A material was eroded. This heavily eroded area represented approximately 3 of the 15.7 acres. However, an average of only 15 percent of the 12 inch layer of Armor Cap B and B/C materials were eroded, and none of the Armor Cap D was eroded. After the flood had passed, the net erosion depth at any location on the cap did not exceed 0.90 ft (0.28 m). The net erosion depth was calculated as the difference between the pre-flood elevation minus the post-flood elevation in each grid cell. The net erosion depth was less than the maximum scour depth because during the falling limb of the flood, deposition of sediment occurred over the entire cap. Thus, the final bed elevations at the end of flood hydrograph were higher than the minimum elevations which occurred towards the end of the rising limb of the hydrograph.

Task 3

Statement

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

Methodology

This task was performed in two steps. The first step consisted of evaluating AQ's models, which included evaluating the impact of the assumptions included in AQ's model framework for their hydrodynamic and sediment transport models, and the second step consisted of setting up ERDC's LTFATE modeling system whose framework does not contain as many assumptions. The second step was performed to quantify the differences between the two modeling systems during select high flow events. As stated previously, LTFATE is described in Appendices A – C. The work performed on this task is described below.

Evaluation of AQ's models

The model evaluation process began with the transfer of AQ's model files, including source code, scenario inputs and outputs, and calibration/validation data, and modeling reports to the EPA and the PDT. The review and evaluation of the models included evaluation of model inputs, verification of model code, and benchmarking of model results. More specifically, the methodology used in performing this evaluation was the following:

1. Modeling System Application: Review the application of the AQ models to the SJR estuarine system; specifically evaluate the procedures used to setup, calibrate and validate the models as well as the assumptions included in the AQ model framework.
2. Model Evaluation: a) Evaluate model input files (including model-data comparisons) used for calibration and validation run of both models. b) Verify that the model codes are correctly representing the simulated hydrodynamic and sediment transport processes. c) Benchmark the models by running the models using

the calibration/validation input files and comparing results with those given in AQ's Modeling Report.

Modeling System Application

The applications of the hydrodynamic and sediment transport model components of the AQ modeling system to the SJR are discussed in this section.

The application of AQ's Environmental Fluid Dynamics Code (EFDC) to the SJR model domain was thoroughly reviewed, taking into consideration the constraints of their modeling framework. Specific concerns (the first sentence for each concern is bolded) related to the application of their hydrodynamic and sediment transport models are discussed below.

The location of the downstream boundary of the model domain. As noted by several reviewers, the chosen location required the use of interpolated tidal boundary conditions. EPA's comments to AQ on this subject included the following:

> "The hydraulic regime at the confluence of the Houston Ship Channel at the SJR (Battleship Texas gauge station) is fundamentally different than that which occurs at the mouth of the SJR at Galveston Bay (Morgan's Point gauge station). While approximately symmetrical tidal currents can be expected at both the Battleship Texas and Morgan's Point gauge stations during non-event periods, the symmetry should not exist during periods of flooding. A decoupling of water surface elevations between stations is expected during flood events due to a local heightening of water surface elevation from increased freshwater flow at the mouth of the Houston Ship Channel compared to that of the more tidal-influenced, more open marine environ of Galveston Bay (*e.g.*, Thomann, 1987). Consequently, the water surface elevation response at the downgradient model domain boundary (Battleship Texas) would be significantly different than the water surface elevation response downstream at Galveston Bay (Morgan's Point) during a flood or surge event. As such, the use of data from Morgan's Point may be inappropriate for use in calibrating the subject model."

Regarding this issue, Anchor QEA (2012) states that "sensitivity analysis was conducted to evaluate the effect of using WSE data collected at

Morgan's Point on hydrodynamic and sediment transport model predictions (see Section 4.4)." In Section 4.4 it states the following:

> "Analysis of the effects of data source for specifying WSE at the downstream boundary of the model was accomplished by simulating 2002 using data collected at the Lynchburg gauge station. This year was chosen because it was the only year during which Battleship Texas State Park or Lynchburg WSE data are available and one or more high-flow events (*i.e.*, 2-year flood or greater) occurred. Cumulative frequency distributions of bed elevation changes within the USEPA Preliminary Site Perimeter for the base case and sensitivity simulations are compared on Figure 4-59. Differences in bed elevation change between the two simulations are between -2 and +2 cm over of the bed area in the USEPA Preliminary Site Perimeter (Figure 4-60, bottom panel). A one-to-one comparison of bed elevation changes for each grid cell within the USEPA Preliminary Site Perimeter is presented on Figure 4-60. Overall, the data source for specifying WSE at the downstream boundary of the hydrodynamic model has minimal effect on sediment transport within the USEPA Preliminary Site Perimeter."

The PDT disagrees with the approach used in this analysis of the effects of data source for the WSE. With the differences in the hydrodynamic regimes during floods as described by several of EPA's reviewers, the PDT disagrees with AQ's justification that is based on differences in simulated bed elevation changes within the Site. Just because the differences in bed elevation changes over a one year simulation using the two different WSE data sources were within $\pm$ 2 cm does not indicate that the circulation pattern in the estuary was correctly simulated. If it was not, then the fate of eroded contaminated sediment would be different. As such, the PDT still believes that the more appropriate boundary location would have been in the vicinity of Morgan's Point due to the NOAA tidal station (Number 8770613) at that location. This is where the downstream boundary for the LTFATE model domain was located.

Decoupled hydrodynamic and sediment transport models. The main limitation of AQ's model framework is the use of decoupled hydrodynamic and sediment transport models. This limits its applicability to flow conditions when large morphologic changes (relative to the local flow depth) due to net erosion and net deposition do not occur. Thus, it is not capable of simulating morphologic changes during large flood events, such as the previously described October 1994 flood. Anchor QEA (2012) states that "model reliability is not significantly affected by not incorporating direct feedback between the hydrodynamic and sediment transport models into the modeling framework, with approximately 8% of the bed area experiencing relative increases or decreases in potential water depth of greater than 20%." However, since these results, *i.e.*, "8% of the bed area ...", were obtained using a modeling framework that did not account for changes in bed elevation due to erosion and deposition, which means that those results are in question, they cannot be used to justify not including direct feedback into the modeling framework.

Floodplain areas. Anchor QEA (2012) states that "Floodplain areas (*i.e.*, areas that only get inundated during high flow events) were incorporated into the rectangular numerical grid to adequately represent extreme events in the vicinity of the USEPA Preliminary Site Perimeter." However, more of the floodplain should have been included in other portions of the model grid to correctly represent the flows throughout the estuarine system during the extreme floods simulated during the 21-year model simulation, *e.g.*, the October 1994 flood. The 100-year floodplain was represented in the LTFATE model grid.

Two-Dimensional depth averaged model. It states in Section 2.3 of Anchor QEA (2012) that "the two-dimensional, depth-averaged hydrodynamic model within EFDC was used, which is a valid approximation for the non-stratified flow conditions that typically exist in the San Jacinto River". No salinity data are presented to support this assumption. Stating that models of other estuaries in Texas have used depth-averaged hydrodynamic models is not an acceptable technical justification for this assumption.

Use of hard bottom in the HSC and in the upper reach of the SJR. Regarding this issue, EPA commented that "a justification for assuming the sediment bed was hard bottom in the SJR channel downstream of Lake Houston Dam and in the HSC shall be added to the report. How far downstream in the river channel was a hard bottom assumed? In addition, the report shall comment on potential impacts of these assumptions on sediment and contaminant transport processes in proximity to the Superfund site." In response, the following text was added to Section 4.2.2:

"‥ the numerical grid was extended up to Lake Houston for hydrodynamic purposes (*i.e.*, to ensure that the tidal prism of the San Jacinto River is properly represented in the model). The sediment bed was specified as hard bottom in this portion of the San Jacinto River because: 1) no significant dioxin bed sources exist within this region (see Section 5.2.5.2); and 2) sparse data were available for specifying bed properties (*i.e.*, there is a large uncertainty in bed type and composition). Thus, specification of the sediment bed in the San Jacinto River channel between the dam and Grennel Slough as cohesive or non-cohesive (*i.e.*, erosion and deposition fluxes were calculated) was not necessary to meet the objectives of this study." This justification seems technically justifiable. However, the discussion of sensitivity analyses results along the San Jacinto River does not take into account the hard bottom assumed for this river between the Lake Houston dam and Grennel Slough. For example, in the second paragraph of Section 5.3.3.2.1 it states "due to flux from sediments [porewater diffusion and erosion]". These processes do not occur to a hard bottom. The appropriate portions of Section 5.3.3.2.1 should have been rewritten (as stated in two previous reviews of this report) to account for the fact that, for example, porewater diffusion, sediment bed mixing, and erosion do not occur in the hard bottom reach. In addition, the procedure used to make "slight adjustments ‥ to the water column concentrations during calibration to avoid "double counting" of contaminant inputs" needs to be more thoroughly described.

Regarding the hard bottom assumption for the Houston Ship Channel (HSC), the report states the following:

"With respect to the HSC, specifying the sediment bed as hard bottom was valid because sufficient data were available to specify water column chemical concentrations within the HSC (see Section 5.2.3). It is not necessary to simulate erosion and deposition processes in the HSC because water column chemical concentrations in the HSC can be specified using data, which is all that is necessary for the chemical fate and transport model. Simulating erosion and deposition fluxes within the HSC would not have improved the predictive capability of the chemical fate and transport model within the USEPA Preliminary Site Perimeter."

These explanations are not justifiable, at least not without quantifying the effects of this assumption using a sensitivity analysis. It states that water column chemical concentration data are available for the HSC. Are there data for all 21 years of the model simulation? While the assumption that "simulating erosion and deposition fluxes within the HSC would not have improved the predictive capability of the chemical fate and transport model within the USEPA Preliminary Site Perimeter" may be valid, a sensitivity test should have been run to quantitatively justify this assumption.

Delineation of the sediment bed. It states in Section 4.2.2 of Anchor QEA (2012) that the sediment bed in a given area was specified as cohesive if the median particle diameter, D_{50}, is less than 250 μm and if the combined clay and silt content is greater than 15 percent. Unless the fraction of clay size sediment is the majority of the combined clay and silt content, it is unlikely if sediment with only these two criteria are cohesive in behavior. More justification needs to be given to support this assumption as it would definitely have an impact on the erosion and transport of sediment in the SJR estuary.

Calibration of the hydrodynamic model. The comparison of measured and simulated depth-averaged velocities shown in Figures 3-23 – 3-25 indicates that the model is under predicting the maximum velocities during both ebb and flood tides, but more so during the latter. In particular, the poor agreement seen during the period July 3 – 4 indicated the model did not accurately represent the combined tidal and riverine flows during this high flow event. The impact that the location of the downstream boundary in the AQ model had on these comparisons is not known. This was investigated using the LTFATE model. Based on these comparisons of the simulated versus measured velocity times series, the PDT does not completely agree with the last sentence in this section that states 'the calibration and validation results demonstrate that the model is able to simulate the hydrodynamics within the Study Area with sufficient accuracy to meet the objectives of this study'.

Calibration of the sediment transport model. How were the two qualitative conclusions made in the last two sentences of the fourth paragraph of Section 4.3 ("Overall, the model predicts net sedimentation with reasonable accuracy' and 'The general pattern of net sedimentation is qualitatively consistent with known characteristics of the Study Area') arrived at? The PDT comes to a different conclusion when examining the comparisons shown in Figs. 4-24 and 4-25, especially for two of the three stations within EPA's Preliminary Site Perimeter. It seems that the model does not predict net sedimentation with reasonable accuracy. This conclusion remains the same even after reading the discussion of the effect of spatial scale on model results in the last paragraph in Sec 4.5. Finally, what are the known characteristics of the Study Area that are mentioned in the last sentence?

Other factors/processes not represented in the modeling. These include the following: wind waves and the effects of barges and propwash on sediment resuspension at the Site. The text that was added to Section 4.1 of Anchor QEA (2012) explaining why wind-wave resuspension is not simulated is valid for non-storm conditions. However, it should have been evaluated in the sensitivity analysis for simulated storm conditions. Regarding the effects of barges and propwash, it is noted that AQ commented that "The potential effects of ship and barge traffic on sediment transport within the USEPA Preliminary Site Perimeter will be evaluated during the Feasibility Study."

Model Evaluation – Hydrodynamic Model

The AQ hydrodynamic model for the SJR was benchmarked for model output integrity and reliability. These verification and benchmarking tasks were intended to ensure that the hydrodynamic model correctly simulates the riverine and estuarine circulation in the SJR estuary. The evaluation consisted of the following three steps:

1. Model inputs were reviewed to verify consistency with what is documented in Anchor QEA (2012). As a component of this, model-data comparisons were performed for the hydrodynamic input files to insure that the correct parameterizations were used in the model.

2. Model output integrity was verified for selected simulations by recompiling the AQ source code, re-running these simulations with the generated executable, and comparing the model results from these simulations to the model results provided by AQ.

3. Verification of model calculations was accomplished by reviewing model outputs. This review focused on model calculations that were specific to the SJR model domain.

Verification of Model Inputs

Model inputs for bathymetry, inflows, and downstream tidal boundary conditions are based on site-specific data. The goal of the review was to insure the inputs were correctly specified in the model input files. All the hydrodynamic input files were checked, and no problems were identified. Specifically, the input files which described the computational grid were checked to insure the SJR model grid was correctly represented, and the bathymetric data included in the files were correct. Selected model simulation input files, including flow and stage boundary condition files, were also checked for consistency. No inconsistencies were found during these checks, so the model inputs for the hydrodynamic model were successfully verified.

Verification of Model Calculations

The hydrodynamic model for the SJR is based on the EFDC model, which is an open source model supported by EPA Region 4, and which has been applied to many rivers, estuaries, other water bodies worldwide. The AQ version of EFDC was compiled on a Windows computer using the FORTRAN Compiler for Windows by Intel and on a Linux server using the Intel FORTRAN Compiler for LINUX. These recompilations were performed to verify that the AQ version of EFDC could be successfully compiled on different computers using different operating systems (*i.e.*, Windows and Linux). The results obtained using the code executable received from AQ were identical (to within machine precision) with the results obtained using the two recompiled codes. The recompiled code run on the Windows computer was run in full debug mode, but no runtime errors occurred. The conclusion from this task is that the AQ version of EFDC was successfully verified.

Benchmarking of Model Outputs

The 21-year hydrodynamic model simulation was benchmarked to insure that model outputs provided by AQ were reproduced. This simulation was performed using the recompiled code on a Windows computer. The 21-

year simulation was successfully completed without any runtime errors, and comparisons of the output from this simulation with that produced using the code executable provided by AQ were identical (to within machine precision). The conclusion from this task is that the AQ version of EFDC was successfully benchmarked.

Model Evaluation - Sediment Transport Model

The AQ sediment transport model was benchmarked for model output integrity and reliability. These verification and benchmarking tasks were intended to ensure that the sediment transport model correctly simulates the represented sediment transport processes. The evaluation consisted of the following three steps:

1. Model inputs were reviewed to verify consistency with what is documented in Anchor QEA (2012). As a component of this, model-data comparisons were performed for the sediment transport input files to insure that the correct parameterizations were used in this model.
2. The model output integrity was verified for selected simulations by recompiling the AQ source code, re-running these simulations with the generated executable, and comparing the model results from these simulations to the model results provided by AQ.
3. The verification of model calculations was accomplished by reviewing model outputs. This review focused on model calculations that were specific for the SJR modeling system.

Verification of Model Inputs

The following sediment transport model inputs are based on site-specific data, and should be consistent across all model simulations.

- Effective particle diameter for each size class
- Cohesive resuspension parameters (τ_{cr}, A, n)
- D90 (used for skin friction calculation)
- D50 (used for initial grain size distribution calculations, as well as other sediment transport calculations)
- Initial grain size distribution
- Dry bulk density

The verification of model inputs for the sediment transport model used consisted of the following components:

1. The values used for the input parameters listed above were reviewed to insure they were within the expected ranges, *i.e.*, ranges of these parameters reported in the literature. The values of all these model inputs used in the sediment transport modeling fell within the expected ranges and/or were the same as given in Anchor QEA (2012).

2. All of the input files for the sediment transport model were checked to verify that the values of the parameters listed above were consistently used. This check revealed that the same values were used for these parameters in all the input files.

3. The time series of solids loading for the sediment transport model were plotted using the model input time series to identify any unusual or outlying solids load inputs. No problems were noted, and the time series were as described in Anchor QEA (2012).

In conclusion, no inconsistencies or incorrect values were found during these checks, so the model inputs for the sediment transport model were successfully verified.

Verification of Model Calculations

The various processes and rate calculations included in the sediment transport model (*e.g.*, settling speed, probability of deposition, resuspension rate) all feed into the computation of the erosion and deposition fluxes for each particle size class in each grid cell at every model time step. Along with velocity and water surface elevation time series for every grid cell that are calculated by the hydrodynamic model, calculated time series of the erosion and deposition fluxes along with the resulting time series of water column concentrations of suspended sediment in every grid cell are passed to the contaminant transport and fate model. These hydrodynamic and sediment transport time series are used to drive the contaminant model. Considering that the transport and fate of highly hydrophobic chemicals (such as PCBs) that are mostly sorbed to particulate organic matter (POM), and that varying fractions of POM are typically adsorbed to sediment particles, in particular clay and silt size particles, the fate of hydrophobic chemicals are typically governed to a significant degree by the transport and fate of these solids. As such, verification of the calculations of erosion and deposition fluxes of solids in the model is essential.

The calculations of the sediment transport model were checked using the following two tasks:

1. The model code was reviewed to verify that the sediment transport model computes erosion and deposition fluxes correctly.

2. Values of the following parameters and variables that were used in the calculation of erosion and deposition fluxes were printed out during a model run to verify that correct values for the parameters being used in the calculations and that variables (*e.g.*, near-bed suspended sediment concentration) were being calculated correctly.

    a. Deposition flux components: settling speeds of the sediment size classes, probabilities of deposition, and near-bed suspended solid concentrations.

    b. Erosion flux components: critical shear stresses, erosion rate for the non-cohesive solid classes, and the erosion rate for the cohesive size class.

The finding from the first task was that the model code was correctly calculating the specified erosion and deposition fluxes, and the findings from the second task were that a) the correct parameter values were being used, and b) the correct values of relevant variables were being calculated by the model. Therefore, the conclusion from this task is that the sediment transport related calculations performed by AQ's sediment transport model were successfully verified.

Benchmarking of Model Outputs

The 21-year sediment transport simulation was benchmarked to insure that model outputs provided by AQ were reproduced. This simulation was performed using the recompiled code on a Windows computer. The 21-year simulation successfully finished without any runtime errors, and comparisons of the output with that produced using the code executable provided by AQ were identical (to within machine precision). The preliminary conclusion from this task is that the AQ sediment transport model was successfully benchmarked.

Application of LTFATE

Model Setup

Model Domain

The model domain (highlighted in blue) chosen for LTFATE is shown in Figure 3-1. As seen, the downstream boundary is adjacent to Morgan's Point, and includes the 100-year floodplain (FEMA designated floodway zone) as identified by FEMA.

Model Grid

Figures 3-2 and 3-3 show zoomed in views of the orthogonal curvilinear model grid in proximity to the Site and the downstream boundary at Morgan's Point. The average grid sizes at the Site and at the downstream boundary are 18m by 18m and 50m by 65m, respectively. The average deviation angle from orthogonal for the entire grid is 3.7 degrees, which is acceptable and insures that mass loss of water and transported constituents due to too large a degree of non-orthogonality does not occur.

Bathymetry Data

The same bathymetry data used by AQ (as documented in Appendix A in Anchor QEA (2012) were used in constructing the LTFATE grid.

Boundary Conditions

The same boundary conditions used by AQ in their hydrodynamic and sediment transport models were used in LTFATE. For the hydrodynamic model, the measured water surface elevations at the NOAA tidal station at Morgan's Point were applied to all the wet cells across the downstream open water boundary. The simulated freshwater inflows to the SJR estuary from Lake Houston and the bayous along the Houston ship channel (HSC) represented in the AQ model were also included in LTFATE. The same salinity boundary conditions were used as were used by AQ. Due to the lack of salinity data over the water depth at the downstream boundary, the LFATE model was run in a two-dimensional, depth-averaged mode like AQ's model.

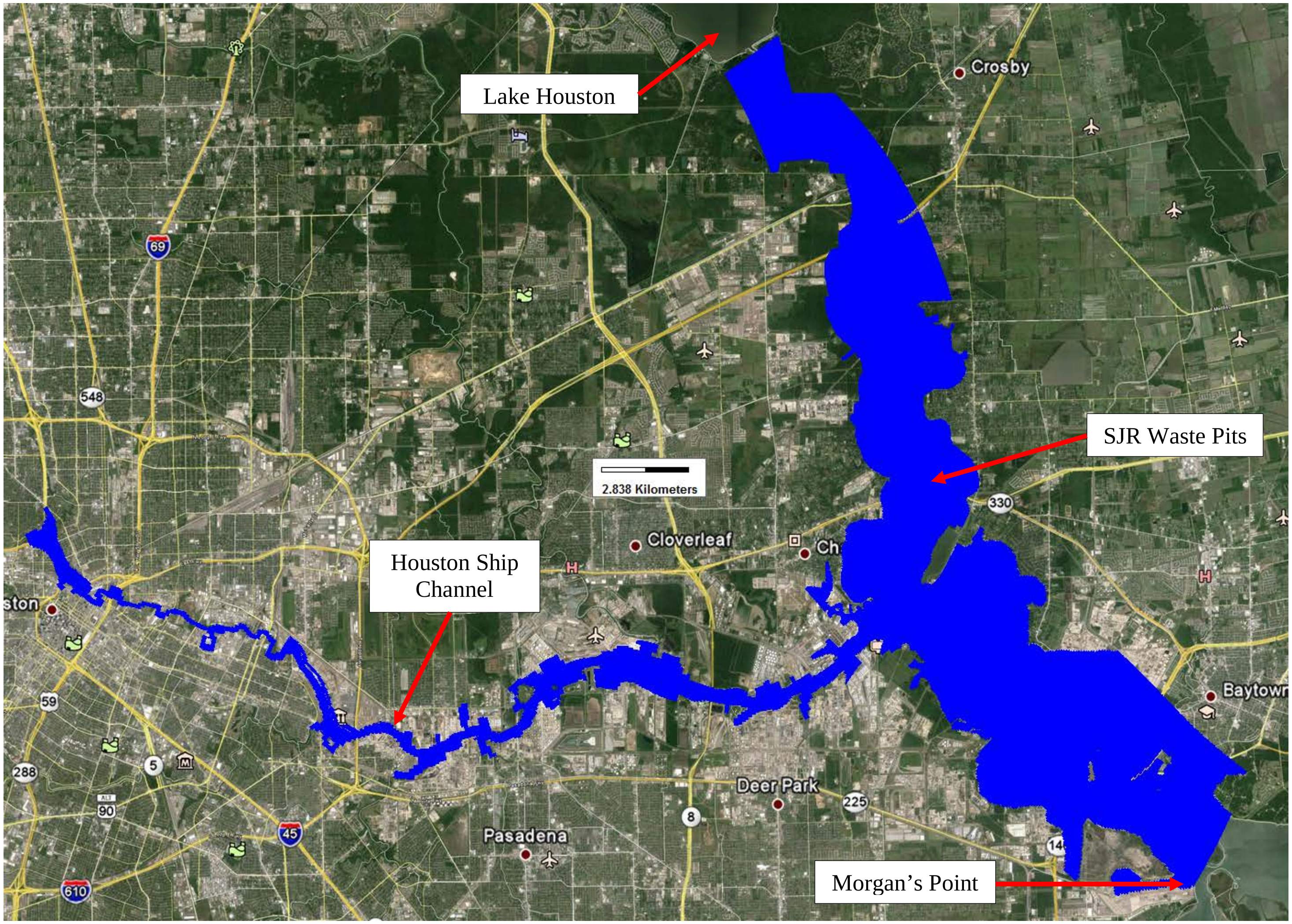


Figure 3-1 LTFATE San Jacinto River Model Domain

Figure 3-2 Grid in Proximity to the SJR Waste Pits Site

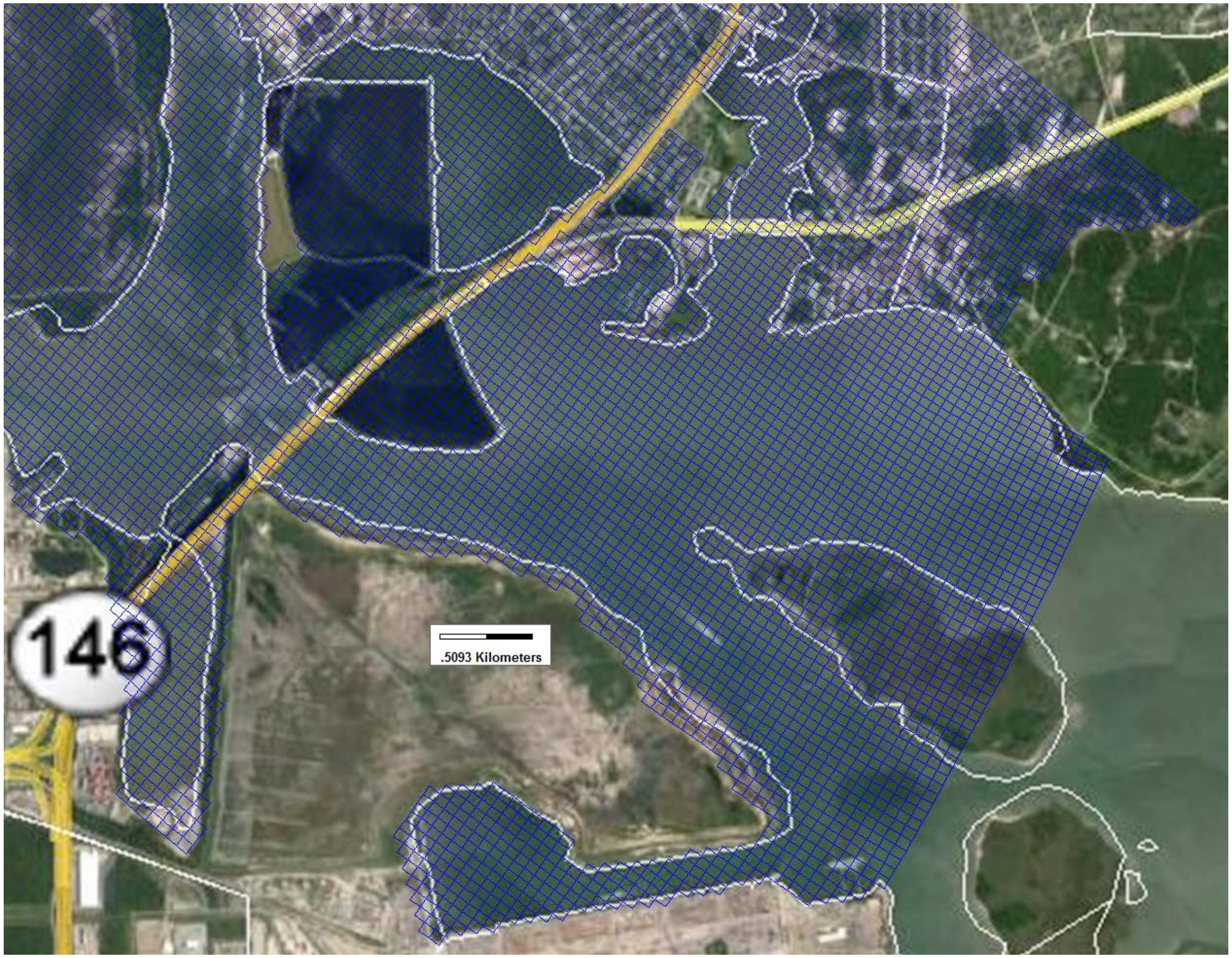


Figure 3-3 Grid in Proximity to the Downstream Boundary

Initial Sediment Bed

In specifying the initial sediment bed, the same four sediment size classes that AQ used were used in the SEDZLJ module in LTFATE. One difference between AQ's version of SEDZLJ and that used in LTFATE is that in the latter, the grid cells are not defined as being either cohesive or noncohesive and then not allowed to change during the model simulation as in the AQ version. In the LTFATE version, whether the surficial sediment is cohesive or noncohesive in behavior is determined for every active (*i.e*., wet) grid cell during each time step. This enables the changing nature of natural sediment beds due to the varying composition of suspended sediment as well as sediment being transported as bedload to be represented. It was assumed that floodplain cells have an initial hard bottom, *i.e*., they cannot erode. However, sediment is allowed to deposit on inundated floodplain cells, and the deposited sediment is allowed to resuspend if the bed surface of these cells is subjected to a high enough bed shear stress while the floodplain cell is wet. This is also different from the methodology used by AQ as their model does not allow sediment being carried in suspension to deposit on cells (whether they are floodplain or wet cells) that have a hard bottom.

To represent the TCRA cap, the 196 grid cells that are located within cap boundaries were assigned the Armor Cap material designated in Figure 6-1 (Armor Cap As-Built) in Anchor QEA (2012). The D_{50} sizes and thicknesses used in the grid cells are 3, 6, 6, 8 and 8 inches for the Armored Cap A (recycled – 12 inches thick), Cap B/C (recycled – 12 inches thick), Cap C (natural– 12 inches thick), Cap D (natural – 18 inches thick), and Cap D (natural – 24 inches thick), respectively.

Model Debugging

To insure that both the hydrodynamic and sediment transport modules in LTFATE were setup correctly and no runtime errors occurred, the model was run in full debug mode (Using the Intel FORTRAN compiler) for three days. The reason that it was run for only three days is that the compile code runs much slower in debug mode than it does in optimized mode.

Simulated Processes

The differences between LTFATE and AQ's sediment transport model are the following: 1) Bedload transport is simulated in LTFATE but not in AQ's sediment transport model; 2) The effect of bottom slope on bedload transport and erosion rates is accounted for in LTFATE but not in AQ's sediment transport model. The methodology described by Lick (2009) to include the effect of bed slope on erosion rates and bedload transport is incorporated in the LTFATE version of SEDZLJ. The bed slopes in both the x- and y-directions are calculated, and scaling factors are applied to the bed shear stress, erosion rate, and bedload transport equations. A maximum adverse bed slope is specified that prevents bedload transport from occurring up too steep an adverse slope.

Calibration of the Hydrodynamic and Sediment Transport Models

The same data sets used to calibrate the AQ hydrodynamic model (ADCP surveys conducted June 13 – July 7, 2010 and May 10 – July 13, 2011) were used to calibrate LTFATE. To date, the optimum agreement in the simulated and measured water levels and depth-averaged velocities was achieved using a globally averaged value of 0.1 cm for z_o = effective bed roughness that represents to total bottom roughness due to both skin friction and form drag. The root-mean-square error (RMSE), which represents the standard deviation of the model error, in the water surface elevations for the 2010 and 2011 periods were 4.05 cm and 4.55 cm, respectively. The RMSE error in the depth-averaged velocities for the 2010 and 2011 periods were 0.12 m/s and 0.11 m/s, respectively. These results were comparable to the calibration results obtained by AQ, and were deemed satisfactory to perform the modeling related tasks in which LTFATE was used (as opposed to AQ's models) to perform the modeling. A refinement of the hydrodynamic model calibration using the ADCP data collected by the USGS in proximity to the SJR Waste Pits in February 2015 and delivered to the EPA and the ERDC PDT in May 2015 is still underway. At this time, it is not anticipated that any significant changes to the model calibration will be necessary.

Likewise, the same data AQ used to calibrate their sediment transport model was used to calibrate LTFATE, with the main metric being the net sedimentation rate. The calibration of the sediment transport model in

LTFATE again yielded comparable results to those obtained by AQ's model. Specifically, the same 16 year period (1995 -2010) that AQ ran for calibrating their sediment transport model was run using LTFATE. The same range of net sedimentation rates (NSR) inside the SJR site perimeter (i.e., 0 to 1 cm/yr) was obtained using LTFATE as it was using AQ's model, and both models showed a small area of net erosion along the eastern boundary of the site. Taking into account the uncertainties in the LTFATE modeling performed, both models yielded similar NSR results to those shown in Figures 4-22 and 4-23 in Anchor QEA (2012).

Evaluation of Assumptions in AQ's Model Framework

The results from the evaluation of the impact of the assumptions included in AQ's model framework for their hydrodynamic and sediment transport models are presented in this section. The major items identified in the *Modeling System Application* section under **Evaluation of AQ's Models** were evaluated, and the findings are presented below.

The location of the downstream boundary of the model domain

As noted previously, the chosen location for the downstream boundary in AQ's models required the use of interpolated tidal boundary conditions. The effect of driving the hydrodynamic model using interpolated boundary conditions was evaluated by examining the differences between the water surface elevations and current velocities at the Site predicted by the two models over a lunar month. The average difference in water surface elevations was 5 cm, and the average difference in current magnitudes and directions were 3 cm/s and less than 5 degrees. These small differences are well within the uncertainty envelope of the hydrodynamic model when applied to a complex estuary such as the SJR. As expected, the differences in these parameters became significant in proximity to the location of AQ's boundary as well as in the eastern end of the Houston Ship Channel. This comparison quantified that the location of AQ's boundary was located sufficiently far from the SJR Site so as to not impact the results of either their sediment transport or contaminant transport models in proximity to the Site.

Decoupled hydrodynamic and sediment transport models

The main limitation of AQ's model framework is the use of decoupled hydrodynamic and sediment transport models. This does result in the AQ model predicting smaller amounts of net erosion and higher amounts of net deposition since the effect of changes in bed elevations due to erosion and deposition is not accounted for in the decoupled hydrodynamic model that AQ uses. As a result, more uncertainty should be attached to morphologic changes predicted by their sediment transport model. This higher level of uncertainty, along with the higher level of uncertainty associated with their hydrodynamic model results since the latter does not account for bed elevation changes (and therefore changes in water depths) during a model run, should be propagated into the uncertainty associated with the results from their contaminant transport model since the latter is driven to a large degree by the results from both the hydrodynamic and sediment transport models. While the quantification of this uncertainty is beyond the scope of this study, one of the consequences is that the use of decoupled hydrodynamic and sediment transport models often yield higher quantities of net deposition. The latter, when used in the contaminant transport model, usually result in faster decreases in concentrations of COCs in the sediment bed than actually occur. The latter is caused by the deposition of sediment with lower COC concentrations on top of the contaminated sediments, thus causing the average concentrations in the bed to decrease due to the mixing of the surficial sediments by bioturbators, etc.

Floodplain areas

The actual 100-year floodplain that was represented in the LTFATE model grid produced a better representation of the flooded conditions at occur in the SJR estuary during extreme riverine floods and tropical storm induced storm surges than that represented by AQ's models. However, the maximum flow velocities in proximity to the SJR Waste Pits simulated by LTFATE for an out-of-bank event were slightly lower than those simulate by AQ's model since the flood was more confined to the river/channel in AQ's model than in LTFATE.

Two-Dimensional depth averaged model

Due to the lack of vertical salinity data to be able to quantify the degree of salinity-induced stratification and the combination of hydrologic conditions and tidal flows during which at least partially stratified flows occur in the SJR estuary, it was decided to run LTFATE in the depth-average mode like AQ did with their models. Thus, both models assumed that the SJR estuary was well mixed, so it was not possible to quantify the impact of this assumption. This assumption is thought to have negligible impact on the predicted sediment transport during a severe event such as a flood or storm surge because the combined energy from the waves and wind-, river- and tide-generated flows would be more than sufficient to vertically mix the water column.

Use of hard bottom in the HSC and in the upper reach of the SJR

The effect of this assumption in AQ's model framework was tested by determining the differences in the composition and thickness of the sediment bed at the SJR Site as predicted by AQ's models and LTFATE in which a hard bottom was not assumed in these two waterways. The differences were within the range of uncertainty associated with these models. The uncertainty associated with the limited sediment data in these waterways that were used to specify the sediment bed properties in LTFATE was included in this analysis. As a result, this assumption was not found to have a significant impact on the results obtained by AQ's models.

Task 4

Statement

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

Methodology

It is standard to evaluate the effects of uncertainties in model inputs using a sensitivity analysis. Thus, this task was performed by expanding on the sensitivity analyses performed by AQ with their models. A review of the analysis that AQ performed is given below, followed by a critique of their analysis, and then a description of the expanded sensitivity analysis being performed for this task is given.

AQ Sensitivity Analysis

The sensitivity analysis performed by AQ evaluated the effects of varying input parameters for both the sediment transport model and the hydrodynamic model. These analyses are summarized below.

The sensitivity analysis performed by AQ evaluated the effects of varying the following sediment transport model input parameters: erosion rates, incoming sediment load at the Lake Houston Dam, and the effective bed roughness as quantified by the value of D_{90}. The latter was only increased by a factor of two, whereas the incoming sediment load was varied by $\pm$ 2. Both changes are with respect to the base case simulation. Lower and upper-bound parameters that were based on the erosion rate ratio values for the Sedflume cores, with the lower-bound being Core SJSD010 and the upper-bound being Core SJSF003. AQ evaluated the effects of possible interactions among the three input parameters using a factorial analysis. The latter produced eight model simulations that accounted for all of the possible combinations of the upper and lower bounds of the three parameters. The results of these eight model simulations were compared “using the sediment mass balance for the Study Area as the metric for quantitative comparison”. Figure 4-44 in Anchor QEA (2012) shows the predicted sediment mass balance for the entire model domain over the 21-year model simulation, and the trapping efficiency was determined to be

17 percent. Trapping efficiency is calculated as the percentage of the incoming sediment load that is deposited in the model domain. Seven of the eight sensitivity simulations had positive trapping efficiencies, *i.e.*, they were net depositional over the 21-year simulation period, whereas one of the simulations was net erosional so no trapping efficiency was calculated for that simulation. The seven positive trapping efficiencies ranged from 6 to 24 percent (see Figure 4-49 in Anchor QEA (2012)). AQ also presents comparisons of the gross erosion rate, the gross deposition rate, and the rate of net change for the entire model domain and the Site Perimeter, respectively, in Figures 4-50 and 4-51 for the base case and eight sensitivity simulations. Their findings from these sensitivity simulations were the following: 1) Changes in the upstream sediment load had the largest effect on the net deposition over the 21-year simulation; and 2) The effects on both net erosion and net deposition due to the variations in erosion rate parameters and the effective bed roughness were of similar magnitude, and most importantly, were significantly less than the effect from varying the incoming sediment load from Lake Houston.

The sensitivity analysis performed by AQ evaluated the effects of varying the following hydrodynamic model input parameters: channel bathymetry in the vicinity of Grennel Slough, water inflow at the Lake Houston Dam, salinity at the downstream boundary, and the water surface elevation (WSE) at the downstream boundary. The effects of these input parameters on both the hydrodynamic and sediment transport models were determined by simulating conditions for 2008 (during which Hurricane Ike occurred) for both the base case (using the original input parameters) and the sensitivity model runs. The differences between the base case and the different sensitivity runs were quantified by determining the differences in bed elevation changes within the Site Perimeter at the end of the one-year model simulations. Results from this analysis are described next.

The channel bathymetry in the vicinity of Grennel Slough was modified by eliminating two areas that created a cutoff in the channel due to spatial interpolation of the bathymetric data. Analysis of the model simulation of 2008 found that the original bathymetry that contained the two cutoffs had negligible effect on the hydrodynamics and sediment transport within the Site.

As discussed in Anchor QEA (2012), the water releases at the Lake Houston Dam were estimated for the period of the 21-year simulation prior to July 1996. The impact of the method used to estimate the inflows into the SJR on the model results was evaluated by using the same method to estimate the inflows for 2008 and running the models for that year. The results from this analysis revealed that the method used for estimating the inflows prior to July 1996 had relatively minor effects on the sediment transport simulations within the Site perimeter.

A constant salinity of 16 psu was used at the downstream boundary for the 21-year simulations. The effect of the salinity value used for the downstream boundary on sediment transport simulations at the Site was investigated by simulating 2008 using both a salinity boundary condition of 16 and 0 psu. These two simulations were compared and negligible impacts on the sediment transport results were found. This is not a surprising result when using a depth-averaged model.

The effect of the WSE used at the downstream boundary was investigated in the following manner. The year 2002 was simulated using the WSE obtained from data collected at the Morgan’s Point tidal gauge station as well as using the WSE data collected at the Battleship Texas State Park/Lynchburg station. The bed elevation changes for each grid cell within the Site Perimeter were compared between these two model simulations, and minimal differences were found. Thus, AQ concluded that the WSE data used at the downstream boundary in their model did not have a significant impact on the sediment transport results in proximity to the Site.

Critique of the AQ Sensitivity Analysis

Overall, the sensitivity analysis performed by AQ is the best method for attempting to put bounds on the uncertainty in results obtained from any transport and fate modeling study. The use of trapping efficiency as a metric for quantifying the results from the sensitivity analysis is thought to be somewhat limited in its usefulness. However, the finding that the largest source of uncertainty in the sediment transport modeling is the estimated sediment loading from the Lake Houston Dam is not surprising. As the USGS commented in their review, “to improve the model, better sediment load information from Lake Houston Dam is necessary.” However, having more accurate sediment loading data may or may not improve the model's ability to predict sediment transport in the SJR estuary. This same thought is conveyed in USGS's comments 29 and 37.

As discussed in Task 3, it is the opinion of the PDT that the largest source of uncertainty is the application of a model framework that does not account for morphologic feedback between the sediment transport and hydrodynamic models to a water body such as the SJR. The SJR estuary is subjected to aperiodic large hydrologic events, *i.e.*, floods and hurricanes, such as the three significant events that occurred during the 21-year simulation period, during which significant sediment transport and large scale scour and sedimentation occurred in certain portions of the estuary. The unquantified uncertainty in applying a non-morphologic modeling system to such a system limits the usefulness of the sensitivity analysis performed using the non-morphologic models. In addition, the other issues discussed in Task 3, *e.g*., inclusion of the 100-year floodplain in the model grid, location of the downstream boundary, definition used to classify sediment as cohesive, use of a hard bottom in the HSC, etc., are believed to further increase the uncertainty in the model results. A better model framework to use at the SJR would have been the one that AQ used in simulating primarily noncohesive sediment transport in the Tittabawassee River, Michigan in which a quasi-linkage routine was added between the sediment transport and hydrodynamic models. In both water bodies, the magnitude of the morphologic changes is within one order of magnitude of the water depths, thus necessitating the linkage between the hydrodynamic and sediment transport models.

Expanded Sensitivity Analysis

In an attempt to better quantify the uncertainty associated with the model framework and the other issues listed above and in Task 3, an expanded sensitivity analysis is being performed as a component of this project. It is being performed using the LTFATE modeling system that was setup to represent the SJR estuary model domain. A description of the methodology used in performing the expanded sensitivity analysis is described next.

The effects of changes in the following parameters on results with the LTFATE modeling system were investigated using a sensitivity analysis approach similar to the factorial analysis methodology used by AQ:

- Simulation of bedload
- Different classification of cohesive sediment
- Sediment loadings at the Lake Houston Dam
- Use of a non-hard bottom in the HSC and upper SJR

Table 4-1 lists the nine sensitivity simulations that were run, with Run 1 representing the Base Case (defined as that being closest to AQ's model setup). The September – November 1994 time period was used for these nine model runs. While many different simulation periods could have been used for this analysis, including the 21-year period that AQ used, the extreme event of record was chosen to differentiate the differences among these nine sensitivity simulations under this extreme event during which the sediment load being transported through this estuary was enormous. The inclusion of the 100-year floodplain in the model grid and the use of the dynamically linked hydrodynamic model and sediment transport model option in LTFATE were used in all nine sensitivity simulations.

Table 4-1.
Sensitivity Simulations

Sensitivity Run	Bedload Simulated	Different cohesive sediment classification	Inflow sediment loadings	Hard bottom in the HSC and upper SJR
1	No	No	AQ	Yes
2	No	Yes	AQ	Yes
3	No	No	Upper Bound	Yes
4	No	No	Lower Bound	Yes
5	No	No	AQ	No
6	Yes	No	AQ	Yes
7	Yes	Yes	AQ	Yes
8	Yes	Yes	AQ	No
9	Yes	Yes	Upper Bound	No

Using a similar approach to that used by AQ, the sediment mass balance inside the northern impoundments was used as the metric for the quantitative comparison of the results of the nine sensitivity simulations.

Figure 4-1 shows the results from the three month simulation for the nine sensitivity runs. The numbers (1 through 9) at the top of each bar are the sensitivity run numbers shown in Table 4-1. As expected, all nine simulations showed negative net bed elevation changes (*i.e.*, net erosion) over this three month period. The plotted net bed elevation changes represent the spatially averaged values for the portion of the grid inside the northern impoundments. Net bed elevation change is defined as the difference in bed elevation in a given grid cell from that at the beginning of the simulation to that at the end. As such, the net bed change does not represent the maximum depth of erosion that occurred during the simulated three months. In all cases, the maximum erosion depth was about twice that of the net change. The net change was smaller due to the net deposition that occurred at the site for the period of the model simulation that followed the peak of the 100-year flood.

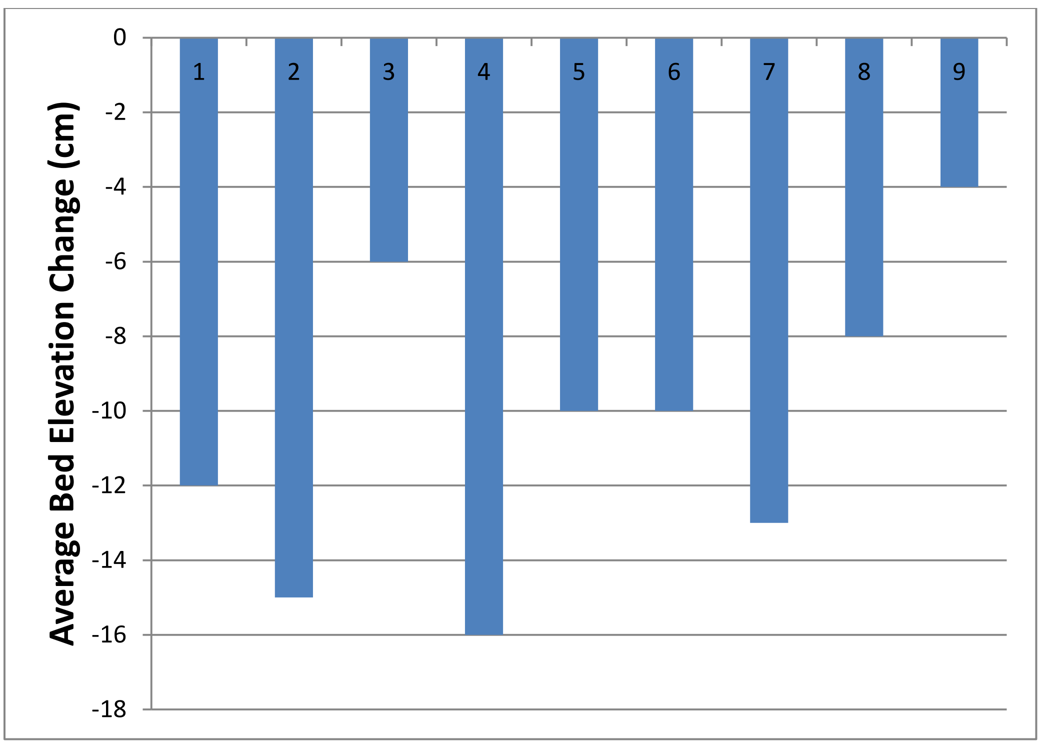


Figure 4-1 Average Change in Bed Elevation within the Northern Impoundments for the nine Sensitivity Simulations

These nine sensitivity simulations agreed with the conclusions reached by AQ in their model sensitivity analysis. For example, as seen by comparing Runs 3 and 4, decreases in the upstream sediment load causes more net erosion due to less sediment being transported to the SJR estuary, which in turn results in smaller quantities of sediment being deposited at the Site following the simulated flood. In addition, the following conclusions were developed from the results shown in Figure 4-1.

- The use of a hard bottom in the upper SJR also decreases the sediment load transported downstream, thus resulting a higher amount of net erosion (as seen by comparing Runs 1 and 5).

- The simulation of bedload transport of the noncohesive sediment size classes is seen to slightly decrease the amount of net erosion (as seen by comparing Runs 1 and 6). The reason for this is that bedload transport increases the quantity of sediment that is simulated to be transported to the site, and the lower flow velocities within the boundaries of the Site result in net deposition of the sediment transported as bedload.

- The used of AQ's cohesive sediment classification in their version of the SEDZLJ layered sediment bed model results in less net erosion than the traditional cohesive sediment classification used in the SEDZLJ model in LTFATE (as seen by comparing Runs 6 and 7). This is because AQ's cohesive sediment classification results in the bed surface being more resistant to eroding forces than that used in LTFATE.

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

Task 5 and Task 6

Statements

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

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

Background

Design and construction of the existing TCRA cap was divided into three sections, each of which has different cap components. The Western Cell is generally above the water line; the Eastern Cell is mostly covered with less than 5 ft (1.5 m) of water; and the Northwestern Area is mostly in greater than 10 ft (3.0 m) of water. The Western Cell cap is composed of a geotextile filter, a geomembrane, a protective geotextile cushion and armor stone. The Eastern Cell has a geotextile filter and armor stone. The Northwestern Area has predominantly granular filter blended with armor stone. These three sections were further subdivided into subsections with varying armor stone. The cap is presently built with some slopes steeper than 1V:3H. The thicknesses of the armor stone is at least twice the D_{50} of the stone. The armor stone is sized for limited movement during storm events having a return period of up to 100 years. The capped sediment consists predominantly of a soft, compressible, organically rich sludge.

Western Cell

The Western Cell should largely be physically stable provided that all surfaces have a slope flatter than 1V:3H, all areas of potential high bottom shear stress with a slope steeper than 1V:5H are covered in natural stone, the design bottom shear stresses are properly modeled, and no significant localized deformations occur to disrupt the geomembrane. Soft sediments were solidified/stabilized prior to cap construction. The design and construction followed standard practice for land-based operations. The geotextiles were overlapped and geomembrane seams were welded. The armor stone, geotextiles and geomembrane effectively isolates environmental receptors from the contaminated sediment. The geotextiles used in the design provide adequate protection for the geomembrane to prevent puncture and to provide long-term chemical isolation. The geomembrane will control infiltration, seepage and tidal pumping along with their associated dissolved and colloidal transport of contaminants. The geomembrane also controls diffusion and resuspension, effectively isolating the contaminants. No groundwater transport in the sediment under the cap across the site is anticipated based on the topography of the region, location of the site, and permeability of the sediment.

The long-term reliability of the Western Cell can be improved by providing greater resistance to armor stone movement. Flattening of slopes steeper than 1V:3H and providing a gradual transition between the slopes are recommended to increase the factor of safety and provide for long-term stability. Increasing the armor stone size by two inches is also recommended to provide stability during the most severe hydrodynamic and hydrologic events.

Eastern Cell

The Eastern Cell should largely be physically stable provided that all surfaces have a slope flatter than 1V:3H, all areas of potential high bottom shear stress with a slope steeper than 1V:5H are covered in natural stone, the design bottom shear stresses are properly modeled, and no significant localized deformations occur to disrupt the geotextile. The design and construction followed standard practice for water-side operations. The geotextiles were overlapped and secured in place during placement of the armor cap. The geotextiles were rolled out and advanced gradually during armor cap placement to maintain their positioning. The armor stone and geotextile effectively isolates environmental receptors from the contaminated sediment. The Eastern Cell does not contain a geomembrane to control resuspension and the advective and diffusive fluxes of contaminants. However, being submerged in relatively flat environs without regional surficial groundwater upwelling, no significant advective flux is anticipated to provide transport of dissolved or colloidal contaminants.

A small quantity of porewater with dissolved and colloidal contaminants would have been expelled in the short term following the cap placement from consolidation and compression of the sediment under the pressure loading imposed by the armor cap. This contaminant mass release would have been very small compared to the resuspension releases prior to capping, but likely to be several times greater than the diffusive releases during the same period. Resuspension of contaminated particles is not expected because the geotextile will provide a filter to control particle movement and prevent translocation of the capped sediment to the surface. Therefore, contaminant transport would be restricted to porewater expulsion and diffusion. The releases from the armor cap would not pose concerns for toxicity and bioaccumulation because the releases would be much less than background releases outside the cap where resuspension of particles with sorbed contaminant is on-going along with diffusion.

The diffusive flux of contaminants from the capped area is very small compared to resuspension releases of contaminated particulates prior to capping; however, the diffusive releases from the sediment are largely unimpeded by the cap. The armor cap material does not have a significant quantity of organic carbon to retard contaminant transport in the short term; however, sedimentation will increase the organic content in the armor as new materials deposit in the pore space between the armor stones. In addition, the large pore structure of the armor cap material would permit a large exchange of water within the cap, preventing the formation of a concentration gradient to slow the diffusion in the short term until the pore spaces are filled with new deposits. Results of cap pore water testing by D. Reible on the TCRA cap using solid phase micro extractions (SPMEs) was generally unable to detect any contaminants of interest in the cap pore water. Nevertheless, addition of an amendment like AquaGate™ or SediMite™ to fill the pore spaces and provide activated carbon to sequester the contaminants could further reduce the potential contaminant releases from diffusion throughout the life of the cap. A product like AquaGate™ or Aquablok™ would also provide added protection from erosion by providing cohesion between granular particles upon infiltration, swelling and filling the large pores of the Armor Cap C and D materials, and perhaps also the pores among the recycled concrete particles of the Armor Cap A and B/C materials following raining of the AquaGate™ particles onto the armor cap materials.

Thin armor caps with a geotextile placed on an organic sediment having a flat slope such as the cap built in most of the Eastern Cell would be subject to disruption by gas generation. The geotextile resists gas transmission at low pressures due to its air entry properties. Over time the geotextile may become clogged by fine-grained deposition and biological excretions. The generated gas pressures may build to a point where local disturbances of submerged caps less than 24 inches thick may occur.

The long-term reliability of the Eastern Cell can be improved by providing greater resistance to armor stone movement. Flattening of slopes steeper than 1V:3H and providing a gradual transition between the slopes are recommended to increase the factor of safety and provide for long-term stability. Increasing the armor stone size by two inches is also recommended to provide stability during the most severe hydrodynamic and hydrologic events. Increasing the thicknesses of sections of the cap that are continuously submerged to at least 24 inches is recommended to avoid localized disruptions of the armor cap.

Northwestern Area

The design and construction of the cap in the Northwestern Area is very different than the other two cells and does not provide the same level of confidence in its long-term stability and performance. The area is largely capped with twelve inches of non-uniform recycled concrete blended with granular filter material at a ratio of 4:1. The D_{50} of the recycled concrete was specified to be 3 inches (7.6 cm). Slopes within the Northwestern Area are as steep as 1V:2H. The cap was placed in layers proceeding from deep water to shallow water, following standard construction practices for water-side operations.

Placement of recycled concrete with a blended filter on slopes steeper than 1V:3H, and perhaps as flat as a 1V:5H slope, promotes separation of the sand-sized particles and perhaps gravel-sized particles from the larger concrete particles. The finer particles would have a tendency to move down the slope before coming to rest, coarsening the cap on the upper portion of the slopes and reducing the effectiveness of the filter on the upper slope. Without a filter being placed on soft sediments (having low bearing capacity) prior to placement of the armor material, the larger particles of recycled concrete would embed themselves in the sediment and promote mixing of the cap with the sediment, thereby limiting the isolation of the sediment. Use of a blended filter would tend to be less effective on very soft sediments than a separate granular filter.

Additionally, the weight of the armor stones and cap may be sufficient to extrude very soft sediment through the large pores between armor stone unless a sufficient quantity of properly sized filter media is in place. To ensure physical stability of the cap, the cap and blended filter should be placed on a slope no greater than 1V:3H, and preferably 1V:5H. It is likely that the filter is inadequate in places and additional capping media will be needed to upgrade the cap performance and prevent future sediment exposure.

Mixing of the sediment with the capping media and inadequate filtration due to loss of the finer fraction of the capping media (sands and perhaps gravel) due to separation during placement may allow exposure of the sediments to the water column, leading to releases by resuspension of sediment particles in addition to diffusion and porewater expulsion. Additionally, bioadvection of sediment may translocate sediment particles to the surface where the sediment can be resuspended. Burrowing to a depth of 12 to 15 inches (30.5 to 38.1 cm) may be expected in the absence of a geotextile or a geomembrane. Thickening the cap in the Northwestern Area and providing adequate filter media to restrict translocation of sediment particles would virtually eliminate the potential resuspension releases.

Regardless of whether resuspension releases occur, there are potential contaminant releases by diffusion, porewater expulsion, tidal pumping and groundwater seepage. Like the Eastern Cell, the Northwestern Area does not contain a geomembrane to control the advective and diffusive flux of contaminants. However, being submerged in relatively flat environs without regional surficial groundwater upwelling without regional surficial groundwater upwelling, no significant advective flux by groundwater seepage is anticipated to provide transport of dissolved or colloidal contaminants. A small quantity of porewater with dissolved and colloidal contaminants would have been expelled in the short term following the cap placement from consolidation and compression of the sediment under the pressure loading imposed by the armor cap. This contaminant mass release would have been very small compared to the resuspension releases prior to capping, but likely to be several times greater than the diffusive releases during the same period. Therefore, contaminant transport is restrictive to porewater expulsion and diffusion. The diffusive flux of contaminants from the capped area is very small compared to resuspension releases of contaminated particulates prior to capping; however, the diffusive releases from the sediment are largely unimpeded by the cap. The releases from the armor cap would not pose concerns for toxicity and bioaccumulation because the releases would be much less than background releases outside the cap where resuspension of particles with sorbed contaminant is on-going along with diffusion.

The armor cap material does not have a significant quantity of organic carbon to retard contaminant transport. In addition, the large pore structure of the armor cap material would permit a large exchange of water within the cap by tidal pumping, preventing the formation of a concentration gradient to slow the diffusion. Cap pore water testing by D. Reible on the TCRA cap using solid phase micro extractions (SPMEs) was generally unable to detect any contaminants of interest in the cap pore water. Nevertheless, addition of an amendment like AquaGate™ or SediMite™ could further reduce the potential contaminant releases from diffusion by the addition of activated carbon to sequester the contaminants and restrict the exchange of water within the cap. The activated carbon could provide *in situ* treatment of sediment particles mixed into the cap during placement or bioadvected after placement, limiting resuspension releases as well as diffusive and advective releases from the cap in the Northwestern Area where the filter may not be performing as well as desired, allowing some intermixing of cap material with the sediment. A product like AquaGate™ or Aquablok™ would also provide added protection from erosion by providing cohesion between granular particles and filling the pores of the recycled concrete of the Armor Cap A material. The long-term releases from the armor cap are presented in Task 16. The predictions in Task 16 show that an intact cap would not pose concerns for toxicity and bioaccumulation because the peak releases by diffusion would be much less than the releases from an exposed sediment having a contaminant concentration equal to the PCL where resuspension of particles with sorbed contaminant would be on-going along with diffusion.

The long-term reliability of the Northwestern Area can be improved by providing greater resistance to armor stone movement. Flattening and coarsening of slopes steeper than 1V:3H and providing a gradual transition between the slopes are recommended to increase the factor of safety and provide for long-term stability. Alternatively, ribbing with larger stone or terracing could be used to stabilize the slope while restricting the resulting cap thickness and slope length. The Armor Cap A material is unlikely to be stable under the most severe hydrodynamic and hydrologic events. Increasing the armor stone size to a D_{50} of 6 inches (15 cm), and probably larger in shallow water, would be needed to prevent erosion during the most severe hydrodynamic and hydrologic events.

Conclusions

- To ensure physical stability of the cap and prevent migration of blended filter material from migrating down the slope, the cap and blended filter in the Northwestern Area should be placed on a slope no greater than 1V:3H, and preferably 1V:5H.
- The size of the armor stone in the most vulnerable areas of the cap should be increased by 2 to 3 inches in diameter. This is especially true in the Northwestern Area.
- Thickening the cap in the Northwestern Area would virtually eliminate the potential resuspension releases by bioturbation. Maintenance of an adequate filter between the contaminated sediment and the armor stone is critical to control contaminant releases. Use of a product like Aquablok™ could fill the voids between armor stone and seal the cap, restricting erosion of the armor stone and blended filter media.
- Thickening of the cap in the Eastern Cell is needed to control disruption of the geotextile and consequently the armor cap by gas generation. A minimum of 24 inches of armor cap thickness is needed.
- Addition of an amendment like AquaGate™ or SediMite™ could further reduce the potential contaminant releases from diffusion or advection by the addition of activated carbon to sequester the contaminants and restrict the exchange of water within the cap. However, diffusive releases should be quite small regardless and very little advection is predicted. Results of cap pore water testing by Reible on the TCRA cap using SPMEs support these conclusions.

Task 7

Statement

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

Methodology

The methodology used to assess the long-term reliability of the cap is given below.

1) Evaluate bed shear stresses generated by the October 1994 flood.

2) Estimate the erosion potential resulting from the time series of these bed shear stresses.

3) To evaluate potential scour of the cap due to propwash generated by ship traffic in proximity to the cap the following methodology should be used: a) detailed information on ship traffic (*e.g.*, average ship power, size, draft, propeller(s) diameter and type (*i.e.*, ducted or non-ducted), ship speed) are needed; b) develop an empirical propwash relationship using available ship information; c) calculate the bed shear stress using the method given by Maynord (2000); and d) calculate potential bed erosion using the method given by Maynord (2000).

4) The following events were also qualitatively evaluated as part of the assessment of the long-term reliability:

    a. Cap undermining caused by toe erosion.

b. Erosion of the cap cause by movement of the armor rock across the surface of the cap during a large flood and the possible erosion of the substrate material below the cap.

c. Changes in river flow dynamics and channel morphology during a high flow event caused by a major flood or hurricane.

Uncertainty Discussion

The uncertainty regarding this assessment of the long-term reliability and effectiveness of the existing cap will first be discussed. It is the PDT's professional judgment that the uncertainty inherent in any quantitative analysis technique used to estimate the long-term (500 years) reliability of the cap is very high. This includes the empirical analyses developed by, among others, Blaauw and van de Kaa (1978), Maynord (2000), and Lam *et al.* (2011) to estimate the potential scour of the cap due to propwash generated by ship traffic since a lot of the site data needed to perform this analysis were not available. The estimated uncertainty associated with the propwash analysis is at a minimum ± one order of magnitude. So, if the estimate of propwash-induced scour is 10 cm, then than range of uncertainty would be from 1 cm to 100 cm or more. This estimate of the uncertainty takes into account the lack of a complete data set for the Site and the uncertainty in the different methods themselves. Estimation of the impact of propwash on the cap will be further discussed below. The uncertainty associated with estimates of the impact of the three processes listed under the forth bullet above on the long-term reliability of the cap would be at least as large.

Impact of Floods

Simulation of the hydrodynamics and sediment transport during a three month period (September – November 1994) that includes the 100-year flood event was performed using LTFATE. This included calculation of the maximum bed shear stresses at the Site during the peak of that flood. Estimation of the 500-year reliability of the cap should include multiple 100-year (or bigger) flood/storm events in the analysis. Different types of events, for example a 100-year flood on the SJR and a 100-year hurricane, are going to impact the SJR Waste Pits Site differently.

The three month simulation of the 100-year flood yielded a net erosion of the finer material on the cap (with a D_{50} = 3 inches), with the maximum net erosion in any cell being less than 11 inches. During the portion of the simulated time period that started when the maximum scour occurred, there was a partial recovery of the eroded sections of the cap, *i.e.*, net deposition occurred in those sections. Once the flood wave began to decelerate, which occurred before the flow reached its peak, the load of sediment being carried by the flow began to decrease. The deposition rate during this portion of the flood hydrograph was much greater than the long-term net sedimentation rate (NSR). The latter was estimated in Task 19 to be approximately 1.3 cm/yr ± 0.8 cm/yr at the Site. This is why the average change in bed elevation of the active grid cells within the Site boundary over the three month simulation was just slightly greater than half of the maximum change in bed elevation (when the depth of scour was maximum). Assuming that any localized damage to a portion of the cap was repaired following a major flood or storm event, then it is not unreasonable to assume that in between several significant flood events over the duration of 500 years, the mean bed elevation at the Site will approach the pre-flood mean bed elevation.

Impact of Propwash

Concerns of local citizens regarding the increase of barge activity near the SJR Waste Pits Site are well known. The concerns as the PDT understand them are: 1) barges are anchored on top of the area north of the Site, 2) propwash from tug boats disturbing the northwest portion of the Site, and 3) propwash from tug boats disturbing the area north of the Site that has contamination from previous runoff events.

As discussed above, the quantitative analysis of estimating the impact of propwash on the cap involves a detailed study requiring an enormous amount of data and model development. Ziegler *et al.* (2014) describe such an effort in their discussion of the modeling they performed to simulate sediment transport processes in ship berthing areas in Mitchell Bay. Included in their model framework is a propwash model that they developed and applied as a component of their modeling study. What Ziegler *et al.* did not perform in their study was a detailed uncertainty analysis to be able to at least estimate the uncertainty in the results obtained from their new propwash model. However, they did perform a limited but very informative sensitivity analysis for the propwash model.

With regard to this study, a propwash model was developed, tested and coupled to LTFATE. This is described in detail in Appendix D. However, the data needed to fully utilize the propwash module consists of the history of vessel movements in the SJR, especially near the Site, the types (e.g., tugboats, tankers, container ships), sizes, and drafts of the vessels; the diameter, applied horsepower, depths of the propeller shafts, and number of propellers on each of the vessels; the vessel speeds and paths, and the times when the vessels pass close to the Site. This would be an enormous database, but it was not available to EPA or the PDT. As such, only a simplistic analysis could be performed. The results from this analysis, described in Appendix D, is that propwash induced scour would only damage the cap if the vessel, e.g., tugboat, moved directly over the cap during a flood event when the water depth over the cap might be deep enough to permit the tug to do so. Methods to prevent this for happening are described in Tasks 8 and 9, e.g., installing pilings around the cap.

Impact of Toe Erosion and Cap Undermining

The possibility of wave- and current-induced toe erosion that might lead to undermining of a portion of the cap would be greatly reduced if the recommended reductions in some of the cap side slopes are implemented. Enhancement of the armor rocks around the toe of the submerged cap would also lessen the possibility of toe erosion and undermining.

Impact of Storm Surges

A storm surge event was modeled during this study. It was decided to simulate Hurricane Ike, which was a ‘wet’ hurricane. Ike impacted the Galveston Bay and SJR estuary in September 2008. The most severe event simulated as a component of this task was the hypothetical synoptic occurrence of Hurricane Ike and the October 1994 flood. The results from both these model simulations are presented in this section

For simulating the impact of Hurricane Ike on the SJR Site, the model domain for LTFATE had to be expanded to include Galveston Bay to be able to simulate the propagation of the storm surge into the SJR estuary. The expanded model domain is shown in Figure 7-1. A Cartesian grid with 131,989 120m by 120m size grid cells was constructed. The time period simulated was June – September 2008. The first 2.5 months of these four months was used to spin-up the hydrodynamic model. A sediment transport model run for the last 1.5 months was hot started (for the hydrodynamic model) using the output from the spin-up simulation. Wave modeling was performed, using a one-hour time step, for the same 1.5 months using the CMS-Wave model. This modeling is described in Appendix E. The time series of wave heights, periods and directions were read during the LTFATE model run and used to calculate the current- and wave-induced bed shear stresses in the SEDZLJ sediment bed model.

The results during the peak of the storm surge at the Site showed that the sections of the TCRA Cap (mainly in the Northwestern Area and the southwestern area of the Eastern Cell) using Cap Armor A material (D_{50} = 3 inches) were completely eroded. The two sections using Cap Armor D (D_{50} = 10 inches) were only eroded an average of 15 percent of the 12 and 24 inches thicknesses. The sections using Cap Armor material B/C and C (D_{50} = 6 inches) incurred an average maximum erosion of more than 70 percent. Thus, approximately 60 percent (11 acres) of the 15.7 acre impoundment incurred severe erosion.

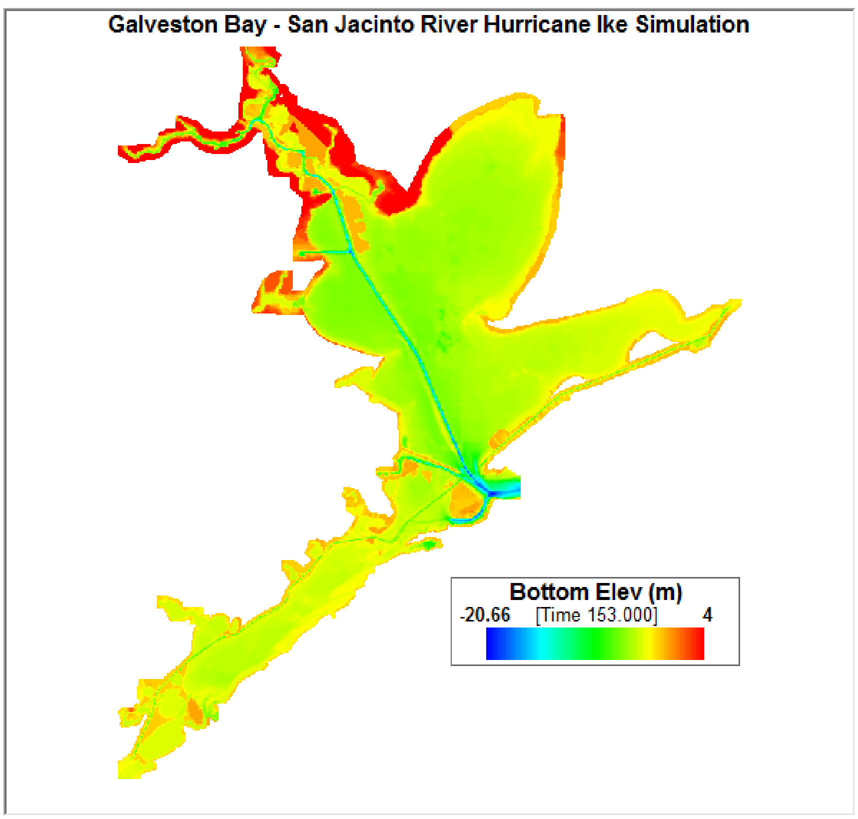


Figure 7-1Expanded LTFATE Model Domain used to simulate Hurricane Ike

The most severe event simulated as a component of this task was the hypothetical synoptic occurrence of Hurricane Ike and the October 1994 flood, with a peak discharge of approximately 11,000 cms (390,000 cfs) occurring at the time of the peak storm surge height at the Site. The maximum scour depth in any grid cell within the cap boundary during this hypothetical extreme event was 2.4 ft (0.73 m). The results during the peak of the storm surge at the Site showed that the sections using Cap Armor A (D_{50} = 3 inches) were completely eroded, while the sections using Cap Armor D (D_{50} = 10 inches) were only eroded more than 12 inches in about 25 percent of those sections. The sections using Cap Armor B/C and C (D_{50} = 6 inches) incurred a maximum erosion of more than 9 inches in about 85 percent of those areas. Thus, approximately 80 percent (12.5 acres) of the 15.7 acre impoundment was simulated to incur severe erosion, and an estimated 170 g of 2,3,7,8-TCDF (which was the only dioxin/furan congener modeled) would be resuspended. Replacement of all the Cap Armor materials with a median size of at least D_{50} = 12 inches would be needed to greatly reduce the amount of scour that occurs during such an extreme event.

Impact of Substrate Material Erosion

The modeling performed of the October 1994 100-year flood event demonstrated that there was no substantial erosion of the TCRA Cap's substrate material. However, there was substantial erosion of the Cap's substrate material during the most severe event simulated (described in the previous paragraph). The maximum erosion of the substrate material occurred in the section of the Cap where Cap Armor A was used, where up to 6 inches of this material was eroded. In this analysis, it was assumed that the geotextile underneath the Cap Armor A material would be completely removed by the overlying high flows.

Impact of Armor Rock Erosion

The modeling performed of the October 1994 100-year flood event demonstrated that there should be no dislodgement and subsequent movement of large armor rock across the surface of the cap during that event. This is based on the bed shear stresses calculated in the grid cells within the cap boundary. None of those bed shear stresses were high enough to dislodge and then transport the armor rock as bedload across the surface of the cap. However, there was dislodgement and movement of the large armor rock (Cap Armor D) during the most severe event simulated (described above).

Impact of Changes in River Morphology

Changes in channel planform morphology due to bank erosion, shoreline breaches, etc. during a high flow event caused by a major flood or hurricane is beyond the ability of existing sediment transport models to simulate. However, the LTFATE modeling performed did account for changes in morphology in the SJR estuary due to erosion and deposition.

Impact of Subsidence

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

Reliability of Geotextile and Other Materials

Geotextiles and geomembranes when protected from UV light have been demonstrated to have design lives of hundreds of years, which should be more than sufficient to maintain separation in lieu of the anticipated deposition which should bury the armor cap completely in less than a hundred years.

Natural stone has the durability to provide long-term stability with the limited forces exerted on the stones in the SJR environment. The durability of recycled concrete is less reliable than natural stone. Recycled concrete is subject to more rapid breakdown by freeze thaw forces, but freeze thaw occurrences in submerged placement areas in the SJR would be rare. Recycled concrete is not as hard as natural stone and would be more abraded, but there are no identified natural mechanisms available to abrade the concrete. Recycled concrete also has less tensile strength than natural stone, but again there are no anticipated mechanisms to put the recycled concrete in tension. Consequently, both armor materials are expected to have long-term durability.

As is further discussed in Task 10, the damage of the western berm of the Western Cell that occurred in 2012 was not due to erosion. The failure was caused by sloughing off the geotextile when the berm became submerged due to loss of friction resulting from the loss of effective weight and the resulting decrease of the friction angle. The recycled concrete slipped down the slope until it achieved a stable slope. The slope in locations was steeper than 1V on 1H, while a stable slope would have been closer to 1V on 1.6H. The design slope was 1V on 2H, but it was not enforced during construction at all points (locally). The slope was confirmed only on a more global basis (the slope as a whole rather than all points on the slope).

Task 8

Statement

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

Methodology

An assessment of the potential sediment losses from a barge strike was performed, and the short-term and long-term impacts potential impacts on the water column and ecological resources were evaluated.

Frequency of Barge Accidents/Strikes

Incidents involving barges are relatively infrequent. Annually in the U.S., approximately 20 grounding of barges, 22 collisions, and four incidents of barges being set adrift occur with medium to high severity, causing damages in excess of $50,000 (USCG 2013). An additional eight times as many low severity incidents occur annually. Most of the strikes occur during high flow or storm conditions while some result from equipment failures or errors. The size of the U.S. fleet of tugboats and towboats is about 4000 and the number of barges is over 27,000 (GlobalSecurity.org 2011). Therefore, there is about a 1 in 100 probability of a given pushboat or barge tow having a significant strike in a year or a 1 in 12 probability of a minor strike in a year, considering the effects of potential flooding and severe weather. However, the probability of striking a particular location such as the San Jacinto cap instead of the shoreline, nearby islands or bridge pilings would be a small fraction of that total probability, but perhaps as much as 25% of total probability considering the proximity of barge operations, yielding an effective probability of 1 in 400 for a significant strike in a year per pushboat or barge tow or 1 in 50 for a low severity impact strike in a year per pushboat or barge tow. Given the probability of multiple pushboats and barge tows being present in the vicinity year round due to nearby barge operations, the chance of a strike is about three times as great as that of an individual pushboat or barge tow, yielding an effective probability of 1 in 130 for a significant strike in a year or 1 in 15 for a low severity impact strike in a year. This would equate to 4 significant strikes and about 30 low severity strikes over a 500-year period. These probabilities are likely high because empty barges and pushboats would pass over the cap during large flooding events when the hydrodynamics would predict a sizable portion of the flow passing over and near the cap. Many of the strikes during high flow or flood events, when many of the accidents occur, would only strike the berms at the site and would not significantly disrupt the armor cap, requiring minor repairs.

Impacts of Barge Strikes

Background

The potential impacts of barge strikes vary greatly with the nature and location of the barge strike. River barges have 1V:3H sloped bows, flat bottoms and square sides that affect the nature and extent of damage to the cap which would be dependent on the angle of the attack and the slope of cap at the point of impact. Typical dimensions are 200'L x 35'W x 13'D. Empty barges have a draft of 1.5 ft while loaded barges have a draft of 8 to 11 ft. Therefore, a number of scenarios were examined for various locations of the site under both normal flow and high water flow conditions for Alternative 3N.

Under normal flow conditions, the water depth varies across the site such that the cap may be a couple of feet above the water level in the Western Cell, may be more than 15 feet below the water surface in the Northwestern area, and generally between 0 and 4 feet below the water surface in the Eastern Cell except in the northeastern portion of the cell where appears to be the remnants of an old channel. Only about 10 percent of the site has an elevation less than -6 ft NAVD88. Under flooding conditions, the entire site can be underwater. A flood with a 5-year or 10-year return period would have a river stage of 5 ft NAVD88, while floods with 25-year, 50-year and 100-year return periods would have predicted stages of about 8 ft, 11 ft and 14 ft NAVD88 at the site, respectively (Table 4-4 Draft Final Interim Feasibility Study Report – Appendix B: Hydrodynamic Cap Modeling, San Jacinto River Waste Pits Superfund Site, March 2014).

The interiors of the Western and Eastern Cells are relatively flat; slopes are generally about 1 to 3 percent. Slopes are very steep on the cell berms and shorelines including the Northwestern area adjacent to the Western Cell, as much as 1V:2H. In the old channel area northeast of the Western Cell slopes are steep ranging from 10 to 15% or about 1V:6H to 1V:10H.

Scenarios

Barge impact conditions can be broken into scenarios based on flow condition, bottom slope, and water depth. Additional conditions that would affect the impacts are barge loading, angle of impact and contaminant concentration. Normal flow conditions persists about 99 percent of the time and therefore should be representative of the time when common low severity impacts should occur (estimated to be about once in 50 years, not more frequent than once in 15 years). Water depths under normal flow conditions greatly restrict the conditions and locations where a strike may occur. Additionally, the currents are generally quite small in areas of moderate to very high contamination; therefore, erosion of exposed significantly contaminated sediment from barge strikes is not expected under normal flow conditions, allowing armor cap repairs without significant loss of contaminants.

Normal Flow Scenarios

Scenario 1 – Steep bottom slope (steeper than 1V:5H<5 feet), shallow water (< 5 feet). This condition occurs along the outside of the western berm of the Western Cell, the eastern side of the center berm and inside of southern berm of the Eastern Cell. Only the northern end of the center berm would be particularly susceptible to being struck by the nearby barge operations. Similarly, significant currents that could transport a free or disabled barge pass the same locale. The other sections of berm are in dead zones and circulation areas outside the main flow channels. The water depth is too shallow for the capped berms to be struck by anything other than an unloaded barge. If the berm were struck at an angle which would be most likely, a small section of the toe of the berm could be dislodged. This would expose very little sediment and potentially cause some sloughing of the existing berm, but would not pose the same risk when the berm is modified to a 1V:5H slope as planned in Alternative 3N. The impact of a barge strike under this scenario is probably very small. No control measures for barge strikes should be needed for this scenario.

Scenario 2 – Steep bottom slope (steeper than 1V:5H), deep water (>5 feet). This condition occurs only in the Northwestern Area in a 500-ft long reach of steep armor that would be particularly susceptible to being struck by the nearby barge operations. Local currents are suitable to promote a barge strike in this area from a free or disabled barge emanating from the local barge operations. The water depth is too deep for the slope to be struck by anything other than a loaded barge; a loaded barge would strike at mid-slope and potentially gouge a seam several feet wide and up to 100 feet long in the armor if the cap is struck obliquely. This potentially could cause sloughing of armor on the upper half of the slope, exposing as much as several thousand square feet of highly contaminated sediment under its existing slope of 1V:2H. However, this area of the armor cap will be modified to a 1V:3H slope as described in Alternative 3N, which will thicken the cap and improve the stability of the slope and limit the sloughing and sediment exposure to perhaps five hundred square feet.

If the barge were to strike the slope head-on, which is a potential mode of action because the currents run up the slope in portions of this area, the barge would ride up the slope until the barge is grounded or beached. The grounded barge would shear the armor layer and push armor up the slope during grounding and pull armor down the slope during barge removal, exposing perhaps as much as a thousand square feet of the sediment. The weight of the barge would drive the bottom of the armor cap under the barge into the sediment and promote mixing with the cap. Additionally, the weight of the barge on the top of the slope may induce a slope failure, pushing out the toe and uplifting sediment at the toe and exposing additional sediment.

The dominant impact of the scenario would be the renewed exposure of highly contaminated sediment since very little erosion of the exposed sediment would be expected under normal flow conditions. As such, the impact of a barge strike under this scenario is probably only moderate. The barge strike would require armor cap maintenance to limit contaminant loss and prevent sediment erosion under high flow conditions. Control measures should be considered for 500-ft reach in the Northwestern Area.

<u>Scenario 3 – Mild to moderate (flatter than 1V:5H) bottom slope, shallow water (<5 feet).</u> This condition occurs throughout much of the interior of the Eastern Cell and along the northern end of the site, including north of the Western Cell in the Northwestern Area. Only the northern and easternmost sections of the Eastern Cell and the area immediately north of the Western Cell would be particularly susceptible to being struck by the nearby barge operations due to the currents. Of these sections only the

northern end of the center berm and the area directly north of the Western Cell would have highly contaminated sediments. The other sections of the Eastern Cell are in dead zones and circulation areas outside the main flow channels. The water depth is too shallow to be struck by anything other than an unloaded barge. The only strike potential is grounding or beaching of the barge. The grounded barge would shear the armor layer and push some of the armor material ahead of the barge up the slope during grounding and pull some armor down the slope during barge removal, exposing perhaps as much as a thousand square feet of the sediment for moderate slopes and as little as several hundred square feet for mild slopes. The weight of the barge would drive the bottom of the armor cap under the barge into the sediment and promote mixing with the cap. The impact of a barge strike under this scenario is probably very small. No control measures for barge strikes should be needed for this scenario except for the area directly north of the Western Cell and the area north and east of the northern end of the center berm. The control measures for Scenario 2 should also provide protection for these areas although it could be enhanced to provide better protection farther to the east of the northern end of the center berm.

<u>Scenario 4 – Mild to moderate (flatter than 1V:5H) bottom slope, deep water (>5 feet).</u> This condition occurs only in the Northwestern Area and in the Eastern Cell north of the center berm and east of the Northwestern Area, which would be particularly susceptible to being struck by the nearby barge operations. Local currents are suitable to promote a barge strike in this area from a free or disabled barge emanating from the local barge operations. These areas would have generally lowly to moderately contaminated sediments. The water depth is too deep for the slope to be struck by anything other than a loaded barge. The only strike potential is grounding or beaching of the barge. The grounded barge would shear the armor layer and push some of the armor material ahead of the barge up the slope during grounding and pull some armor down the slope during barge removal, exposing perhaps as much as a thousand square feet of the sediment for moderate slopes and as little as several hundred square feet for mild slopes. The weight of the barge would drive the bottom of the armor cap under the barge into the sediment and promote mixing with the cap. The impact of a barge strike under this scenario is probably very small. No control measures for barge strikes should be needed for this

scenario. The control measures for Scenario 2 would provide adequate protection for this area.

Flood Scenarios

Under flood scenarios, the water depths would tend to be 3 to 13 feet greater than under normal flow conditions. This would essentially eliminate any shallow water conditions except for the berms and shoreline; however, the potential for erosion of impacted areas becomes much greater. As such, no concerns would arise from the presence of unloaded barges except for potential strikes of the berms or shoreline, posing little to no risks. Grounding a barge during flood conditions presents much greater impacts than during normal flow periods because if the flood waters recede before the barge is removed, barge removal operations will become much more difficult and additional equipment may need to traffic over the armor cap to lighten the barge load or lift the barge off the armor cap. One uncertainty in this evaluation is the impact of flood conditions on nearby barge operations. If barge operations were suspended during all flood conditions or during just high return period floods (greater than 15 years) and no loaded barges are maintained in the area, then the risks become much smaller.

<u>Scenario 5 – Steep bottom slope (steeper than 1V:5H), shallow water (normally <5 feet).</u> This condition occurs along the outside of the western berm of the Western Cell, the eastern side of the center berm and inside of southern berm of the Eastern Cell. Only the northern end of the center berm would be particularly susceptible to being struck by the nearby barge operations, but the outside of the western berm of the Western Cell could also be struck under severe flood events. Similarly, significant currents that could transport a free or disabled barge pass both locales. The other sections of berm would be protected by the susceptible berms or would not be susceptible based on the current direction. The water depth is too shallow for the capped berms to be struck by anything other than an unloaded barge, except under severe flood conditions (greater than at least a 50-year return period). Loaded barges would likely be grounded before reaching the berms, but could become grounded on the berms under very sever flood events. Contact with the berm would be at the top, which would probably dislodge the top of the berm. This would create a 40-ft wide notch with a depth of 1 to 2 ft and expose very little sediment. The

impact of a barge strike under this scenario is probably very small. No control measures for barge strikes should be needed for this scenario.

Scenario 6 – Steep bottom slope (steeper than 1V:5H), deep water (>5 feet). This condition occurs only in the Northwestern Area in a 500-ft long reach of steep armor that would be particularly susceptible to being struck by the nearby barge operations. Local currents are suitable to promote a barge strike in this area from a free or disabled barge emanating from the local barge operations. However, under all but the low return period flood conditions (<15-year return period) the water depth is too deep for the slope to be struck by an unloaded or loaded barge. At worst, a loaded barge would strike near the top of the slope and would ride up the slope and become grounded. The grounded barge would shear the armor layer and push armor up the slope during grounding and pull armor down the slope during barge removal, exposing perhaps only several hundred square feet of the sediment. The weight of the barge would drive the bottom of the armor cap under the barge into the sediment and promote mixing with the cap. Additionally, the weight of the barge on the top of the slope may induce a slope failure since the 1V:3H slope has somewhat low factor of safety. The slope failure would push out the toe and dislodge sediment at the toe and expose additional sediment. The dominant impact of the scenario would be the renewed exposure of highly contaminated sediment and potential erosion of the exposed sediment due to the high flow conditions. The impact of a barge strike under this scenario is probably low due to small disturbance area. The barge strike would require armor cap maintenance to limit contaminant loss and prevent sediment erosion under high flow conditions. Control measures for the 500-ft reach in the Northwestern Area should be considered as presented in Scenario 2.

Scenario 7 – Mild to moderate (flatter than 1V:5H) bottom slope, shallow water (normally <5 feet). This condition occurs throughout much of the interior of the Eastern Cell and along the northern end of the site, including north of the Western Cell in the Northwestern Area. Only the northern and easternmost sections of the Eastern Cell and the area immediately north of the Western Cell would be particularly susceptible to being struck by the nearby barge operations due to the currents. Of these sections only the area directly north and northeast of the northern end of the center berm and the area directly north of the Western Cell would have highly contaminated sediments. The other sections of the Eastern Cell would be protected by the center berms or would not be susceptible based on the current direction. Under flooding conditions the water depth would be too deep to be struck by anything other than a loaded barge. The only strike potential is grounding or beaching of the barge. The grounded barge would shear the armor layer and push some of the armor material ahead of the barge up the slope during grounding and pull some armor down the slope during barge removal, exposing perhaps as much as a thousand square feet of the sediment for moderate slopes and as little as several hundred square feet for mild slopes. The weight of the barge would drive the bottom of the armor cap under the barge into the sediment and promote mixing with the cap. The worst-case impact of a barge strike under this scenario is the potential loss of up to about 50 cubic yards of susceptible highly contaminated areas because there is a significant potential for erosion of the exposed sediment during the high flow conditions of flooding events. The 50 cubic yards would represent less than 0.05 percent of the contaminated sediment, and it would be widely dispersed and diluted with the suspended solids of the flood waters. No control measures for barge strikes should be needed for this scenario, except for the area directly north of the Western Cell and the area north and east of the northern end of the center berm. The control measures for Scenario 2 would also provide protection for these areas, although it could be enhanced to provide better protection farther to the east of the northern end of the center berm as presented in Scenario 3.

<u>Scenario 8 – Mild to moderate (flatter than 1V:5H) bottom slope, deep water (>5 feet).</u> This condition occurs only in a small portion of the Northwestern Area and in the Eastern Cell north of the center berm and east of the Northwestern Area, which would be particularly susceptible to being struck by the nearby barge operations. Local currents are suitable to promote a barge strike in this area from a free or disabled barge emanating from the local barge operations. These areas would have generally lowly to moderately contaminated sediments. The water depth is generally too deep for the slope to be struck by even a loaded barge, except in the small portion of the Eastern Cell. The only strike potential is grounding or beaching of the barge. The grounded barge would shear the armor layer and push some of the armor material ahead of the barge up the slope during grounding and pull some armor down the slope during barge removal, exposing perhaps as little as several hundred square feet. The weight of the barge would drive the bottom of the armor cap under the

barge into the sediment and promote mixing with the cap. Erosion of the exposed sediment during the high flow conditions of flooding events would be expected to occur but the contamination is only low to moderate. Therefore, the impact of a barge strike under this scenario is probably very small. No control measures for barge strikes should be needed for this scenario.

Control Measures for Barge Strikes

Pilings could be installed on 30-ft spacing along a 500-ft long reach just west of the Western Cell and Northwestern Area and also north of the Northwestern Area to prevent barge strikes by runaway barges or disabled pushboats. Other areas can be protected by signage to advise barge operators and boaters to stay clear of the cap.

Summary

The probability of a significant strike or grounding of a barge, which would expose contaminated sediment in up to 1 percent of the capped area or up to 0.1 percent of the contamination, is very low, likely less than 1 in 400 in any given year. A low severity strike would be expected to occur no more often than about once every fifty years on average, but its impact would be limited to several hundred square feet, less than 0.1% of the area, that could be readily repaired with minor releases, less than 0.005% of the contaminants.

Strikes pose significant impacts only from loaded barges and only in proximity of the Northwestern Area. Strikes on the present 1V:2H or the proposed upgraded 1V:3H slope could cause sloughing from gouging and displacement of armor and slope instability from grounding due to the added loadings on the slope from the grounded weight of the barge, exposing a sizeable area of highly contaminated sediment. Low to moderate impacts can occur in the same area from the grounding of an empty barge on the mildly sloped area above the steep slope. This would expose a relatively small area having high levels of contamination in the area immediately north of the Western Cell and directly north and east of the northern end of the center berm. The impacts of strikes during high flow flood conditions are much greater due to potential erosion of exposed sediment; however, flood conditions also increases the likelihood of barge accidents but reduces the likelihood of a strike on the cap because the water depth would be great enough to allow barges to pass over the cap without striking it. Strike protection control measures, such as pilings, caissons or a wall, could be used in a 500- to 700-ft reach along the base of the slope in the deep water (15 feet) of the Northwestern Area. These control measures could prevent all but very low impact strikes.

Task 9

Statement

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

Background

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

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

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

Available Engineering and Institutional Controls

Land Use Controls

Land Use Controls (LUCs) are often used at remediation sites to provide protection from exposure to contaminants. LUCs may be implemented as interim protection at sites where remediation is ongoing, or to manage residual contamination (ITRC 2008). LUCs include both engineering controls (ECs) and institutional controls (ICs). Institutional controls are defined by EPA as “non-engineered instruments, such as administrative and legal controls, that help to minimize the potential for human exposure to contamination and/or protect the integrity of a response action” (EPA, 2010). Engineering controls are physical controls that prevent exposure such as fences, barriers, signage, capping or containment. Both ICs and ECs can be used stand-alone, or can be used in conjunction with other ICs or ECs.

Institutional Controls

There are several categories of ICs, including governmental controls, proprietary controls, enforcement and permit tools, and informational devices. Governmental controls, enforced by state or local government, may include bans on harvesting fish or shellfish, zoning restrictions, ordinances, statutes, building permits, or other restrictions. Zoning may be used by local governments to designate land use for specific purposes. Government ordinances or permits may also restrict or control land uses, and outline specific requirements before authorizing certain activities (*e.g.*, building codes, drilling permit requirements). Some local ordinances place controls on access to or use of certain areas within a property. Groundwater management zones may also be used to prohibit certain groundwater uses (ITRC 2008).

Proprietary controls are based on real property law (EPA 2000). Enforceability of proprietary controls should be evaluated under applicable (state) law. Some proprietary controls are enforceable upon execution, others upon the sale or transfer of property. Examples include easements, covenants, and conservation easements. Easements are rights over the use of another’s property, and include negative easements which limit uses that would otherwise be lawful. Access easements are sometimes used to ensure current and future property owners allow property access to operate, monitor, or maintain ECs or ICs. Covenants are agreements between the landowner and others connected to the land. They are typically used to establish an IC when property is transferred to another party. Use restrictions/ statutes/ environmental covenants are state statutes that provide owners of a contaminated property with authority to establish use restrictions. Conservations easements are state statutes that establish easements to conserve property or natural resources. Enforcement and permit tools include permits, administrative orders, and consent decrees which are enforceable by state or federal agencies. Most enforcement agreements are binding on only the signatories and do not bind subsequent owners. Examples include administrative orders which are issued by an environmental regulatory agency directing property owners to perform (or not perform) certain actions. Consent decrees document an administrative or judicial court's approval of the settlement of an enforcement case filed in court. These typically specify actions to be taken (or not to be taken) by the settling parties. Permits are implemented by an environmental regulatory agency and may require compliance with a statutory or regulatory provision that may impact the reuse of the property (ITRC 2008).

Informational devices provide information to the public about risks from contamination and generally are not legally enforceable. Informational devices include deed notices, state registries of hazardous waste sites, and advisories. Deed notices are filed in public land records with the property deed that provide information about potential health risks from contamination left on the property. State registries of hazardous waste sites also contain information about contaminated properties. Some state laws provide that the use of the property cannot be changed without state approval. Advisories warn the public of potential risks associated with using contaminated land surface water or groundwater, generally issued by public health agencies (ITRC 2008).

In addition to the legal mechanisms mentioned above, the Uniform Environmental Covenants Act (UECA) is a model statute that can be adopted into law by each individual state or territory (EPA 2010). The UECA provides legal framework to create, modify, enforce and terminate a valid real estate instrument (environmental covenant or IC) to restrict use of contaminated real estate or impose obligations under state law and precluded the application of traditional common law doctrines that might otherwise hinder the validity or enforcement of ICs adopted under state property law or other mechanisms (ITRC 2008). The UECA provides a legal mechanism to ensure LUCs can be readily found, maintained, and enforced over time.

EPA (2000) suggests layering ICs, using different types of ICs at the same time to enhance protectiveness. Applying ICs in series may help ensure both short- and long-term effectiveness. Using ICs in conjunction with physical barriers (ECs) to limit access is also recommended.

The three most common types of ICs at sediment sites include fish consumption advisories and commercial fishing bans, waterway use restrictions, and land use restriction/structure maintenance agreements (EPA 2005).

Fishing advisories, restrictions or bans on fishing (including shell fishing) are typical ICs. Commercial fishing bans are government controls that ban commercial fishing for specific species or sizes of fish or shellfish (EPA 2005). Rather than a complete ban, advisories may be placed on certain locations and types of fishing. Advisories inform the public that they should not consume fish from an area or should limit the number of fish meals consumed over a specific time period. Advisories and bans are usually established by state departments of health and can be administered through signs, pamphlets or other outreach materials. Warning signs should be in the language of the local community including new immigrants, and require periodic inspection and maintenance. Monitoring, enforcement and communication with local or state authorities are required. Consumption advisories are not enforceable controls and may have variable effectiveness (EPA 2005). Surveys of anglers are often helpful to evaluate whether they consume the fish they catch and whether restrictions are effective (ASTSWMO 2009). EPA's Fish Advisory Program compiles a national listing of fish advisories through its Office of Science and Technology.

Institutional controls may also be needed to protect the integrity of the remedy. Land use restrictions may be needed at near-shore or upland sites to limit or eliminate construction activities, digging or other activities that may disturb the contaminated materials. A deed restriction or notice may be adequate for an upland property, but for in-water remedies, restrictions may be more difficult due to ownership issues. Nearshore areas can, in some cases, be privately owned out to the end of piers. If privately owned, traditional ICs such as proprietary controls or enforcement tools can be considered. Federal, state and local laws place restrictions on and require permits for dredging, filling, or other construction activities in the aquatic environment. ICs may also be implemented through coordination through existing permitting processes (EPA 2005).

Restrictions on vessel traffic to establish no-wake zones or restrictions against anchoring may be necessary to protect a cap. Restrictions on easements for installation of utilities and other in-water construction may also be needed, and should be placed on navigational charts. Navigational buoys or warning flags can be used to help warn boaters (ASTSWMO 2009). Changing the navigation status of a waterway may also be necessary. Deauthorization or reauthorization of federally authorized navigation channels to a different width or depth would be required. The state may have authority to change harbor lines or the navigation status (EPA 2005).

Management

Application of LUCs require planning to a) evaluate what types of ICs are appropriate, b) determine responsible parties for various activities, c) estimate costs, and d) identify issues that may impact effectiveness. When selecting ICs, it should be considered how the controls fit into the overall remedy, and whether it can be realistically implemented. A number of activities may be needed to implement various ICs including drafting and signing documents to establish ICs or arranging technical or legal support (EPA 2010). There may be both short- and long-term expenses associated with implementation and management of LUCs. Some funding mechanisms to cover the cost associated with maintaining and monitoring LUCs include stewardship fees, oversight fees, and trust funds (ITRC 2008).

LUCs require effective management to ensure long-term effectiveness. Both institutional and engineering controls require regular monitoring and maintenance. Enforcement may be needed if ICs are breached or not properly implemented. Enforcement actions vary from state to state, but may include penalties, loss of liability protection, and lawsuits (ITRC 2008). Some states have developed tracking systems to identify LUCs in place, although the nature of the systems varies from state to state. The

UECA provides mechanisms for states to develop and maintain a registry of sites with ICs.

More detailed information on institutional controls as applied to Superfund sites, Brownfields, underground storage tanks, federal facilities and RCRA site cleanups is provided by EPA (2005, 2010).

ICs Used at Other Sites

A number of contaminated sediment sites have established institutional controls. At the Lake Hartwell Superfund Site, South Carolina, fish consumption advisories are in effect, and were implemented by posting warning signs and distribution of printed material to educate the public (EPA 1994, Magar *et al.* 2009). Fish and/or shellfish advisories are also used at the Lavaca Bay Point Comfort site in Texas (fish and shellfish), Wyckoff/Eagle Harbor, Washington, (Magar *et al.* 2009), and Marathon Battery Corporation, New York (blue crab) (EPA 2008). At Fox River, Wisconsin, fish advisories are in place to prevent ingestion of PCB-contaminated fish above 50 ppb, along with MOUs to prevent anchoring, dredging, dragging, or construction over sediment caps (Tetra Tech *et al.* 2012, Ridenour 2014). At Palos Verdes Shelf, California, a fish advisory is also in place, along with a commercial catch ban for white croaker. Components of the IC plan include public outreach and education, monitoring, and enforcement (EPA 2009, Ridenour 2014).

The Commencement Bay, Nearshore/Tideflats, Tacoma, WA also has fish consumption advisories in place to warn the public about the danger of consuming shellfish, which are relayed by placement of multi-lingual signs. The institutional control plan for the site (Washington State DNR 2007) describes the controls to be put in place as well as the responsibilities of the various entities involved. In addition to shellfish warnings, other ICs specified at Commencement Bay include restrictive covenants, and control of marine vessel navigation and anchoring through the use of no-anchor zones, and waterway navigational markers and signs regarding prohibited activities, vessel size and speed. A system is also in place to notify appropriate entities as to changes in conditions or unauthorized anchorage or trespassing. Restrictions on issuing leases, easements, rights-of-entry and use authorizations are also in place which require notification, and restrict State-owned aquatic land (SOAL) authorizations for commercial shellfish harvest in capped areas. SOAL authorizations are to include terms specifying the provisions of the Consent Decree including prohibited activities such as any activity that alters the cap, piling removal/installation, dredging/excavation and anchoring.

ICs at Pine Street Canal are specified to limit future land use, excluding residential uses and uses involving the care of children, and activities which may interfere with ongoing investigations or might cause recontamination or change hydrogeologic conditions and migration of contaminated groundwater. Excavation greater five feet is prohibited, along with the use of ground water for drinking water purposes or installation of well and any activity that may disturb the integrity of an engineering control (Burlington Land Records 2004).

In addition to the fish consumption advisory for blue crab (recommending consumption of no more than six per week), the Marathon Battery Corp. site has established ICs including deed restrictions barring excavation deeper than 15 feet, construction or use of groundwater wells, and any activity that may disturb the marsh soil cover (EPA 2008). The institutional controls for Allied Paper, Inc./Portage Creek/Kalamazoo River prohibit construction or use of wells to extract ground water, activities that may disturb the integrity of an engineering control or result in release of hazardous substances, or limit future land use (Michigan DNRE 2010).

Application of ICs and ECs to San Jacinto River Waste Pits Site

General information on ICs at contaminated sediment sites has been provided. The latest draft feasibility study (FS) (Anchor QEA 2014) lists seven potential alternatives for the final remedy including:

- Alternative 1N – No further action,
- Alternative 2N – ICs and Monitored Natural Recovery (MNR)
- Alternative 3N – Permanent cap, ICs, MNR
- Alternative 4N – Partial solidification/stabilization (S/S), permanent cap, ICs, MNR
- Alternative 5N – Partial removal, permanent cap, ICs, MNR
- Alternative 5aN – Partial removal of materials exceeding the protective concentration level (PCL), permanent cap, ICs, MNR

- Alternative 6N – Full removal of materials > PCL, ICs, MNR

Alternatives 4N, 5N, 5aN and 6N involve removal of some, or all, of the existing TCRA cap, which would expose contaminated sediments during construction. For Alternatives 4N, 5N and 5aN, the cap would be reconstructed and improved after either removal or treatment of the sediments in the affected area. Cap improvements are also included for Alternative 3N. Alternative 6N does not include cap reconstruction as it calls for removal of sediments exceeding PCL across the entire TCRA area.

All alternatives except for Alternative 1N call for implementation of additional ICs. The recommended ICs described in the FS would be used to: alert property owners of the presence of subsurface materials exceeding PCLs, describe the need for protective equipment and training if excavation of subsurface materials exceeding PCLs is required, describe management requirements for any excavated soils or sediment exceeding PCLs, describe the need to restore the armored cap following any disturbance, and establish limitations on dredging and anchoring within the footprint of the armored cap by requesting that the U.S. Coast Guard District Commander establish a regulated navigation area (Anchor QEA 2014).

Some land use controls are already in place. An advisory (ADV-49) is in place regarding consumption of fish and blue crab on the San Jacinto River (Anchor QEA 2014). Controls were implemented at the site with the TCRA armored cap installation, which is itself an engineering control. Also, a perimeter fence was installed around the perimeter of the impoundments, including a second phase of fencing installed across neighboring property to address unauthorized access that had been observed (Anchor QEA 2012). Warning signs, No Trespassing signs and USEPA Project Identification signs were installed as part of the TCRA and remain in place and are subject to ongoing monitoring and maintenance. A series of 29 buoys (25 ball float, and four regulatory) were installed along the perimeter of the Eastern Cell to warn passing vessels to keep out of the SJRWP area; though not specified, it is assumed the buoys were removed post-construction. Fifteen warning signs on steel posts in 3 ft x 3 ft concrete block are posted around the perimeter of the impoundments to be visible to passing vessels.

It appears the existing land-side fencing and warning signs provide sufficient notification and access control. Monitoring should continue to ensure these measures are maintained as long as there continues to be a risk from on-site contaminants. Security measures were implemented during TCRA cap construction, including a manned security guard shack, roving security patrol, installation of security cameras, and requirement of visitors to sign in at a security checkpoint (Anchor QEA 2012). The security equipment was demobilized upon completion. Upon commencement of further construction activities, security measures should be reinstated to protect against unauthorized entry.

It is unclear whether water-side perimeter controls are sufficient. Access to the site by boat is currently constrained to the north, west, south, and southeast by industrial use and navigational hazards (Anchor QEA 2014). As stated, warning signs on steel posts are in place to warn passing vessels. During construction, Alternatives 4N and 5aN call for sheet pile barriers, and Alternatives 5N and 6N include the use of a silt curtain as measures to control resuspension. Warnings posted outside of these measures should deter vessel traffic during construction. More robust engineering controls to restrict vessel traffic over the long term could be considered such as the use of caissons, or vessel exclusion barriers. The FS suggested a five-foot high submerged rock berm outside the perimeter of the Permanent Cap to protect from potential vessel traffic for alternatives involving the Permanent Cap (3N, 4N, 5N, 5aN). Shallow areas can be isolated using steel cable or chain with appropriate marine and land-based signage and markers to prevent vessel access. The long-term need for such measures depends on the selected alternative, and the extent to which contamination is left on-site, and the need to protect a cap. The ICs discussed in the FS included the need to establish limitations on dredging and anchoring within the footprint of the Armored Cap (Anchor QEA 2014). This would be needed for all alternatives until such time as resulting concentrations are shown to be acceptable.

According to the FS, propeller wash from tug boat operations associated with the SJRF operations could disturb sediments in the Upland Sand Separation Area, but the existing TCRA cap and proposed Permanent Cap would resist such erosive forces (Anchor QEA 2014). Alternative 6N would not result in a Permanent Cap, but instead would be covered with 6 inches of clean cover. The clean cover will not be stable when subjected to prop wash. If residual concentrations are not sufficiently low, a no-wake zone may need to be established for Alternative 6N, as well as for the Upland Sand Separation Area. Additionally, both the clean cover and residuals would be subject to erosion under high flow conditions. Since the residuals may contain as much as 5% of the contaminant mass removed by removal in the wet (dredging), a stable cover would be needed in these areas. An armored cap with a granular filter could be considered for Alternative 6N to provide stability and control long-term releases.

A TxDOT Agreement was put into place during TCRA construction in which TxDOT is required to receive a three-day notice before commencement of construction activities, and requires TxDOT to be provided notice should any future construction disturb sediments in the San Jacinto River. However, procedures are not currently in place to alert future landowners of the TCRA Site to the potential risks of exposing the capped sediment (Anchor QEA 2014). There are also no current restrictions on dredging or anchoring at the site. As called for in the alternatives including the ICs described in the FS, additional measures are needed to alert future property owners of the presence of subsurface materials exceeding PCLs and management requirements for any excavated soils or sediment exceeding PCLs. Enforcement tools such as administrative orders can be used to direct current property owners to perform certain actions such as implementing ICs (including management of excavated soils or sediment). However, most enforcement agreements are not transferred to new owners when the land is sold. Proprietary controls such as covenants may be needed to establish an IC when the property is transferred to another party. Informational devices such as a deed notice could be used to provide information about health risks from contamination left on the site to future property owners. State registries of hazardous waste sites also contain information about contaminated properties. For the nearshore areas or the upland area of the southern impoundment, more traditional ICs may be considered such as land use restrictions against construction, excavation, or other disturbances that may expose contamination. Zoning may be used to restrict land use to industrial purposes or to prohibit groundwater uses. According to the FS, groundwater is not a significant source of dioxins or furans (Anchor QEA 2014), and thus groundwater use restrictions may not be necessary. The intent of Alternative 6N is full removal of all materials exceeding PCLs for protection of the hypothetical recreational visitor, potentially allowing for less restricted future use of the property. If successful, future controls may not be necessary. However, if dredging residuals leave a layer of material exceeding PCLs, ICs will be needed to alert property owners. Easements will need to be in place both during construction and in the future to allow monitoring and maintenance of ECs.

Several of the Alternatives (3N, 4N, 5N, 5aN, 6N) will require staging areas to store clean fill material or armor stone, and areas to dewater and treat excavated cap material and contaminated sediment. The size of the staging areas depends on the alternative and the extent of the removal. Engineering and institutional controls will be needed for the staging areas if contaminated material is to be stored there. Perimeter fencing and warning signs will be needed. Silt fences will be necessary to control surface water runoff, along with coverage of stockpiled contaminated materials. The dust control measures (sprinkling) that were used during construction of the TCRA cap may be necessary to minimize dust generation from land activities and application of Portland cement.

As stated in the FS, ICs would be used to describe the need for protective equipment and training if excavation of subsurface materials exceeding PCLs is required. During the TCRA Cap construction, due to the likelihood of coming in contact with dioxin-contaminated waste, workers in the Exclusion Zone were required to have 40-hour HAZWOPER certification and Level D personal protective equipment. The same procedures would need to be implemented for any of the alternatives (4N, 5N, 5aN, 6N) involving potential exposure of contaminated material.

Summary of Recommended ICs and ECs for San Jacinto River Waste Pits Site

The recommended ICs described in the FS cover the three most common types of ICs at sediment sites include fish consumption advisories and commercial fishing bans, waterway use restrictions, and land use restriction/structure maintenance agreements (EPA 2005). The recommended ICs apply to all alternatives since sediment or dredging residuals that will exceed the PCLs will be left in place following the remediation. The recommended ICs are (Anchor QEA 2014):

1. Alert property owners of the presence of subsurface materials exceeding PCLs.
2. Describe the need for protective equipment and training if excavation of subsurface materials exceeding PCLs is required.
3. Describe management requirements for any excavated soils or sediment exceeding PCLs.
4. Describe the need to restore the armored cap following any disturbance.
5. Establish limitations on dredging, construction, dragging and anchoring within the footprint of the armored cap by requesting that the U.S. Coast Guard District Commander establish a regulated navigation area.
6. Maintain advisory (ADV-49) that is in place regarding consumption of fish and blue crab on the San Jacinto River. Maintain multi-lingual signage and public outreach activities until the tissue concentrations meet risk goals.
7. Maintain the perimeter fence that was installed around the perimeter of the impoundments, including a second phase of fencing installed across neighboring property to address unauthorized access that had been observed.
8. Maintain Warning signs, No Trespassing signs and USEPA Project Identification signs that were installed as part of the TCRA and remain in place.

Additionally, deed restrictions should be established to restrict issuing leases, easements, rights-of-entry and use including any activity that alters the cap or fill including the drilling of wells.

Task 10

Statement

Identify and document cases, if any, of armoring breaches or confined disposal facility breaches that may have relevance to the San Jacinto site evaluation.

Findings

After an extensive literature review, there appear to be no documented cases of any armored cap or armored confined disposal facility (CDF) breaches. However, there have been many occurrences of breaches and slope failures of armored dikes, jetties, and breakwaters, with some of those structures confining dredged material. These typically occurred due to ineffective filtering between the armor and core material, insufficient armor sizing for wave action velocities, and steep side slopes allowing rock to be more easily displaced. Ineffective filtering exists when the filter media is not properly sized, allowing finer sediment from below the filter layer to pass through the filter and be washed through the armor stone. Ineffective filtering allows loss of the foundation and undermining of the armor stone, ultimately resulting in failure. Table 10-1 briefly describes several cases including a description of the site, the cause of the breach, and if any repairs were made to the structure. The cases shown in Table 10-1 represent varying situations that may be of some relevance to the San Jacinto site investigation because the site is adjacent to a well-traveled waterway with significant wave action due to navigation, is subject to large storm events that may cause large inflows of water from overtopping the CDF, and has armored slopes with synthetic material acting as a filter or liner that is susceptible to tears that allow erosion to degrade the system. None of the listed cases completely breached or failed and were discovered by routine inspections. Repairs and rehabilitation measures, when documented, were easily made.

The three modes of armor failure presented above apply as well to the San Jacinto River Waste Pits TCRA armor cap. There is potentially ineffective filtering between the armor stones and the sediment in the Northwestern Area. The blended media filter used in the Northwestern Area may have not been fine enough or placed uniformly enough to prevent fine sediment from migrating into the armor cap. A cap defect that appeared in the

Table 10-1. Descriptions of Armor Breaches and Failures				
Site Name/ Location	**Site Details**	**Breach/Failure**	**Rehabilitation/Repairs**	**References**
Cox Creek DMCF, MD	Reactivated facility originally built in 1960's. Consists of a containment dike roughly 5000 ft stabilized with concrete vats and slabs.	Original armoring was not sufficient in protecting against erosion from wave energy. Before rehabilitation, side slopes had eroded to 1:1	Rehabilitation from 2002 - 2006 included stabilizing the dike before replacing armor stone.	Kotulak *et al*. (2007)
Chicago CDF, Calumet Harbor, IL	17-ha nearshore CDF with a rubble mound dike constructed of a core of limestone, a synthetic membrane liner along the inside face to prevent excess migration of fine dredged material solids through the dike as it is filled, and armor stone.	The fluctuating levels during and after construction revealed that the liner was ineffective due to tears resulting from punctures during the placement of the armor stone or from the limestone core.	A sand blanket was selected as the appropriate corrective action and placed along the inside face of the dike. Further fine grained material was placed along the inside face of the dike to improve the effectiveness.	Savage (1986), Palermo, *et al.* (2000)
Port Chehalis Revetment, WA	South jetty originally built in 1929, reconstructed between 1935 & 1939 and has been improved over the years by the addition of 6 groins and a revetment wall connecting the groins.	Routinely incurs damage from winter storm wind and waves as well as overtopping resulting in erosion of the core material and the settlement and displacement of the armor.	Major rehabilitation in 1972 reinforced groins A-D, F and added groin E. Emergency repairs were made to groin E and the revetment wall after a winter storm caused significant damage in 1999. In 2010, erosion to the revetment was repaired by the addition of Class V stone and Class I filter stone. In 2013, proactive measures were taken by the addition of stone to the revetment increase the thickness of the structure.	USACE, Seattle District (2013)
Atlantic Harbor of Refuge Breakwater, NC	A 2000 ft. sand breakwater with a riprap head was constructed in 1972.	Significant erosion occurred along the southeastern face of the breakwater leading to a large escarpment of 3 ft and displacing the armor stone protection. The sand fill behind the stone eroded way undermining the rock and displacing it.	As of 1985, no rehabilitation or repairs have been made.	Sargent, USACE (1988)

Site Name/ Location	Site Details	Breach/Failure	Rehabilitation/Repairs	References
Two Mile Breakwater, Two Mile Florida	The two breakwaters were constructed in 1976 on either side of the entrance to Two Mile Channel and were designed to retain dredged material. The L-shaped dikes were built up using bottom material and were revetted with filter fabric and rubble stone.	The outer ends began eroding significantly by 1982.	Additional rubble stone was added to the ends of the breakwaters to protect against erosion.	Sargent, USACE (1988)
Siuslaw River Jetties, OR	Two entrance jetties to the Siuslaw River have been improved and altered since their original construction in 1917. The jetties were extended seaward in 1985 and spurs were added to the ocean side of each jetty. The jetty expansion and spurs were constructed of randomly placed rubble and armored with 12-19 ton stones.	Wave actions eroded the heads of each jetty where slopes were steep and armor stones were pulled down by wave action. Erosion also occurred along the jetty spurs and voids in the jetty were found.	No repairs detailed in survey; however, it is recommended that armor stones be placed in the voids and damaged areas to prevent further damage during a major storm event.	Bottin *et al.,* USACE (1999)
Yaquina Bay North Jetty, OR	Located in the Yaquina Bay on the Oregon coast, two parallel rubble mound breakwaters with the final extension of the south jetty being completed in 1972 and experiencing no major problems. The final extension of the north jetty was completed in 1966.	The north jetty routinely experiences severe wave conditions that damage the jetty. The seaward side is primarily affected with stone being removed and the jetty eroded.	The north jetty has been rehabilitated twice since the completion of the extension. In both instances, the repairs were made to the seaward side where rock had been removed below the water level. Survey recommends additional armor stones be placed to prevent future damage.	Bottin *et al.*, USACE (1999)

Site Name/ Location	Site Details	Breach/Failure	Rehabilitation/Repairs	References
Burns Harbor Breakwater, IN	The Burns Harbor located on the southern shore of Lake Michigan, includes two rubble mound breakwaters. The breakwaters were constructed with a multilayered design and random placement of armor stones consisting of rectangular-cut Indiana- Bedford limestone blocks.	Since completion of construction, extensive damage has occurred including the displacement of much of the armor stone. Inspections also noted that erosion had created large voids under the rock and that the breakwater was deteriorating. Navigation induced and wind and wave actions are the primary cause of damage to the breakwater.	In the first 19 years of operation alone, an average of 7,640 tons per year of stone were placed on the breakwater with both the lakeside and the harbor-side receiving equal distributions of stone. Construction of a submerged, offshore reef breakwater was designed to reduce wave heights along the north breakwater and decrease waves in the harbor.	Bottin *et al.*, USACE (1999)
Cattaraugus Creek Harbor, NY	Cattaraugus Creek Harbor is located on Lake Erie and consists of two breakwaters at the mouth of the creek. Both are rubble mount structures with a concrete cap on the south structure. The original armoring ranges in size from 2 - 13 tons.	Monitoring took place after construction and it was noted that damage occurred on the south breakwater primarily due to stone cracking. The loss of shattered stone resulted in adjacent stones collapsing into voids creating a steeper slope on the structure. The lakeside of the breakwater receives the bulk of the wave action and therefore carries the majority of the damage.	No repairs detailed in survey; however, it is recommended that armor stones be placed in the voids and damaged areas to prevent future damage.	Bottin *et al.*, USACE (1999)
Ocean City Inlet South Jetty, MD	The Ocean City Inlet consists of two jetties and three headland breakwaters to stabilize the pass. The south jetty was originally constructed in 1935 and an additional section was added in 1985. The new section was constructed with core stone, intermediate stone, capstone and precast concrete units to minimize sand transport.	While the added section of the south jetty has performed and help up well, the original portion of the south jetty has considerably deteriorated. The armoring stones had scattered and due to erosion, the crest of the jetty had been reduced unevenly.	No repairs detailed in survey.	Bottin *et al.*, USACE (1999)

Northwestern Area in 2015 may have resulted from ineffective filtering. Addition of more filter material or cohesive material along with more armor stone in the Northwestern Area will restrict migration of sediment through the armor cap.

Examination of the armor stability under very severe hydrodynamic and hydrologic events (100-yr hurricane) showed that the 3-inch recycled concrete placed in the Northwestern Area is insufficient to prevent erosion from the wave and current induced bottom shear stresses. The existing armor stone should be supplemented with six-inch armor stones to provide stability during the extreme storm events. In addition, some of the six-inch armor stones in Western and Eastern Cells were also insufficient. The six-inch armor stones should be supplemented with eight-inch armor stones to prevent their displacement.

Localized failures of the west berm of the Western Cell in areas of slopes steeper than 1V on 2H in 2012, which have been repaired with natural armor stone placed to flatten the slope to 1V on 3H. Alternative 3N proposes to flatten all slopes to no more than 1V on 3H. Additionally, Alternative 3N proposes to flatten the slopes of the eastern, central and western berms (the surf zones) to 1V on 5H. These slopes should be stable for armor stones of at least four inches in diameter. Enlarging the armor stone in the Northwestern Area will improve the factor of safety of its 1V:3H slope.

Task 11

Statement

Assess the potential amount or range of sediment resuspension and residuals under the various remedial alternatives and BMPs proposed in the Feasibility Study, which includes capping, solidification, and removal.

Resuspension and Residuals Estimates

After a review of the remedial actions proposed in the Feasibility Study Report, it was determined that Alternatives 4N, 5N, 5aN and 6N had some mechanisms creating a potential for resuspending contaminated sediments or for leaving residuals that may be exposed to the water column. In order to estimate and assess the potential for these releases or releases, the principal processes were identified as follows: sheet pile wall construction, sheet pile removal, removal of the TCRA armor cap materials in the wet and mechanical dredging in the wet. It was assumed that residuals would remain after mechanical dredging. The following sections detail the assumptions made, the equations used to estimate potential contaminated sediment releases and the results of the assessment.

Sheet Pile Construction and Removal

Alternatives 4N, 5aN and possibly 5N consider the use of a sheet pile wall as a means to control sediments during remedial actions. Based on the information provided in the Feasibility Study, it was determined that the sheet pile walls would need to be driven an average of 15 feet through the soft organic silt and clay layer into the sandy layer and in water depths of no greater than 10 feet. In soft sediments, sheet pile wall construction can lead to resuspension of the top soft sediment layer during wall construction if cap removal is needed to drive the sheet pile. During removal, fine-grained, cohesive sediments are subject to adhering to the walls of the sheet pile and washing off.

Assumptions

Many assumptions were made during this process. The assumptions used in estimating the potential disturbance from the use of sheet piles are given in Table 11-1. Based on the sediment characteristics listed in the Geotechnical Report, assumptions were made for the dry density of the loose top layer of sediment (top ¼”), the higher density soil underneath, as well as the relative “stickiness” of the soil as described in Hayes *et al.* (2007). Only the top 1/4” of sediment was considered for suspension during construction and all sediment resuspended was assumed lost. During removal, it was assumed that 50 percent of the soil adhering to the sheet pile wall would wash off and be lost. A Z-type section of sheet piling was selected due to its resistive forces and ability to better perform under loading conditions. The sheet pile wall specifications, as seen in Table 11-1, were taken from the specifications provided by Hammer & Steel. The heavy duty “Z” section has a single section width of 22 inches, depth of 9 inches and wall and flange thickness of 0.375 inches. The coating area, which is defined as the surface area required for protective coating, is 1.22 ft^2/ft^2 of wall. This area excludes the ball and the interior socket and only accounts for one side of the wall. It is described as an area to be coated per total area of wall.

Sediment characteristics were based off the initial saturated unit weight of 107 lb/ft^3, as provided in the Geotechnical Report. It was estimated, since no other sediment properties were provided, that the dry unit weight would be 60 lb/ft^3. The top ¼” of loose sediment would have a dry bulk soil density of 0.5 kg/L (500 kg/m^3) to be used in calculations, and from there, it was assumed that the underlying soil would be more dense, having a dry soil density of 950 kg/m^3. Sediment contaminant concentrations at the location of the sheet pile wall were assumed to be 1,000 ng/kg for Alternatives 4N and 5N, due to their proximity to the high concentration hot spots, and 200 ng/kg for Alternative 5aN since it is outside the 220 *ng/kg* $TEQ_{DF,M}$ contour.

It was also assumed that the sheet pile wall removal would act in a similar manner to a full bucket ascending through the water column, and using the equations found in Table 11-2, a volume of sediment per area of wall was calculated to adhere to the wall and a specified mass amount washed from the wall.

Equations

The methods used for determining the resuspended sediments can be found in Table 11-2 and are the recommended methods presented in *Resuspension Factor Approach for Estimating Dredging-related Sediment Resuspension* (Hayes *et al.* 2007) and referenced in *Technical*

Guidelines for Environmental Dredging of Contaminated Sediments (Palermo *et al.* 2008).

Table 11-1. Sheet Pile Assumptions

Property	Value	Property	Value
Dry Bulk Sediment Density (kg/L)	0.5	**Adjusted Adherence Thickness Δs (ft)**	0.0111
Top Layer Soil Density, ρ_t (kg/m^3)	500	**Sheet Pile Type**	PZ22 - Hammer Steel Heavy Duty
Dry Unit Weight (lb/ft^3)	60	**Sheet Pile Width (in)**	22
Underlying Dry Bulk Soil Density, ρ_b (kg/m^3)	950	**Sheet Pile Offset (in)**	9
Depth of Material Resuspended by Sheet Pile Construction, t (mm)	6	**Sheet Pile Thickness (in)**	0.375
Width of Material Disturbed by Sheet Pile Wall, w (Both Sides) (m)	1.8	**Surface Area (ft^2/ft of pile)**	6.47
Sediment Contaminant Concentration at Sheet Pile Wall, c (ng/kg)	1000 4N & 5N, 200 5aN	**Coating Area Wall Surface - One Side, Aw (ft^2/ft^2 of wall)**	1.22
Sediment Stickiness	Slightly -> Moderate	**Sediment Resuspended during Ascent through Water Column (%)**	50
Characteristic Adherence Thickness Δs_c (mm)	4.5	**Average Depth of Sheet Pile in Sediment, D_s (m)**	4.6

Results

Results of the sediment and contaminant mass disturbed as well as the rates of release can be found in Tables 11-3 and 11-4. Results are separated

Table 11-2. Equations Used for Resuspension Calculations during Sheet Pile Construction and Removal

Parameter	Equation
Mass Disturbed (kg)	$m = t * A * \rho_t$
Contaminant Release @ Assumed Sediment Conc. (ng)/(g)	$m_{cr} = m * c$
Volume of Sediment to Stick to Both Sides of Sheet Pile (ft^3 sediment / ft^2 wall)	$Vs = \Delta s * Aw * 2$
Mass of Sediment / ft^2 of Wall (kg/ft^2 wall)	$m_w = Vs * \rho_b$
Mass (kg)	$m_r = m_w * L_w * D_s$
Contaminant Release (ng)/(g)	$m_{cr} = m_r * c$

into the two groups of remedial alternatives, 4N or 5N, and 5aN; their respective proposed sheet pile wall lengths of 800 L.F. for Alternatives 4N or 5N and 1200 L.F. for Alternative 5aN. The total estimated sediment mass disturbed and resuspended for both construction and removal of the sheet pile walls is approximately 5700 kg for Alternatives 4N or 5N and approximately 8500 kg for Alternative 5aN. The alternatives had an approximate total loss rate of 142 kg/day over 40 days for the hot spot remediation Alternatives 4N or 5N and over 60 days for the more extensive removal Alternative 5aN. However, the contaminant mass loss is considerably lower for Alternative 5aN because the location of the sheet pile wall had a lower sediment contaminant concentration as given in Tables 11-3 and 11-4.

TCRA Cap Removal

Removing the TCRA Cap includes first removing the armor stone and then removing the geotextile underneath. While removing the rock rip rap will result in negligible amounts of sediment resuspension, the geotextile removal will result in considerable resuspension from sediment adhering to the geotextile and washing off as it is pulled through the water column. The amount of resuspended sediments was estimated incrementally for Alternatives 5N, 5aN, and 6N. It is assumed that in Alternative 4N the TCRA cap would be removed in the dry. Alternative 5N could also be performed in the dry; the results below (see Table 11-4) are for removal in the wet.

Table 11-3. Resuspended Sediments during Sheet Pile Construction

Parameter	Alternatives	
	4N or 5N	5aN
L.F. Wall	800	1200
Mass Disturbed (kg)	1310	1970
Solids Loss Rate (kg/day)	33	33
Contaminant Release @ assumed Sed. Conc. (μg)	1310	394
Rate of Contaminant Release (μg/day)	33	6.6

Table 11-4. Resuspended Sediments during Sheet Pile Removal

Parameter	Value
Volume of Sediment to Stick to Both Sides of Sheet Pile (ft^3 sediment/ft^2 wall)	0.027
Volume of Sediment to Stick to Both Sides of Sheet Pile (m^3 sediment/ft^2 wall)	0.00076
Mass of Sediment/ft^2 of Wall (kg/ft^2 wall)	0.727
Assume 50% Washes/Falls Off (kg/ft^2 wall)	0.363
Alternatives 4N or 5N (800 L.F. Sheet Pile Wall Removal)	
Mass (kg)	4360
Rate over 40 days (kg/day)	109
Contaminant Release (μg)	4360
Rate over 40 days (μg/day)	109
Alternative 5aN (1200 L.F. Sheet Pile Wall Removal)	
Mass (kg)	6540
Rate over 60 days (kg/day)	109
Contaminant Release (μg)	1310
Rate over 60 days (μg/day)	21.8

Assumptions

It was assumed that like the process of removing sheet pile wall from the sediment bed, the geotextile will act in a similar manner as a bucket dredge in that sediment will have stuck to the fabric during TCRA cap placement, which will wash off the fabric as the fabric is pulled through the water column during its removal. Assumptions used in the calculations can be found in Table 11-5. Based on information provided in the Feasibility Study, the surface area of the geotextile was estimated to be the same as that of the cap area, as stated in Section 1 of the Feasibility Study. The sediment was assumed to be slightly to moderately sticky with an adjusted sediment thickness of 3.375 mm as used in the sheet pile wall calculations. It was also assumed that only the top soft layer of soil would adhere to the geotextile, thus a density of 500 kg/m^3 was assumed. Average sediment concentrations used for this analysis were determined using the provided sample results in the Feasibility Study. During removal, it was estimated that 50% of the sediment would wash off and that all sediment that was washed off would be lost.

Table 11-5. TCRA Cap Removal Assumptions

Parameter	Value	Parameter	Value
4N/5N Area Disturbed (acres)	3.6	**Characteristic Sediment Thickness Δs_c (mm)**	4.5
5aN Area Disturbed (acres)	11.3	**Adjusted Sediment Thickness Δs (mm)**	3.38
6N Area Disturbed (acres)	15.7	**Sediment Resuspended during Ascent through Water Column (%)**	50
Sediment Stickiness	Slightly --> Moderate	**Surface Soil Density (kg/m^3)**	500

Equations

The methods used for determining the resuspended sediments can be found in Table 11-6 and are the recommended methods presented in *Resuspension Factor Approach for Estimating Dredging-related Sediment Resuspension* (Hayes *et al.* 2007) and referenced in *Technical Guidelines for Environmental Dredging of Contaminated Sediments*

(Palermo *et al.* 2008). These methods are the same as were used to determine resuspended sediments during sheet pile wall construction and removal.

Table 11-6. Equations Used to Estimate Sediment Resuspension during Geotextile Removal

Parameter	Equation
Mass Resuspended (kg)	$m_r = \Delta s*A*\rho*\%R$
Contaminant Release (ng)/(g)	$m_{cr} = m_r*C$

Results

Results for the incremental analysis of sediment resuspended during geotextile removal can be found in Table 11-7. Alternative 5N is the smallest alternative/increment for dredging and it was analyzed as a complete entity and formed the base for each additional increment of dredging. Increment 5aN – 5N is additional increment of dredging when added to Alternative 5N forms Alternative 5aN. Alternative 5aN is the sum of the first two increments. Increment 6N – 5aN is additional increment of dredging when added to Alternative 5aN forms Alternative 6N. Alternative 6N is the sum of all increments. The average surface sediment concentration was estimated using data provided in the Feasibility Study and was averaged across the footprint for each alternative. The potential amount of sediment resuspended increases significantly in Alternatives 5aN and 6N due to their larger footprint and also results in higher contaminant mass releases.

Dredging

The removal of sediments by dredging is an effective means to removing contaminated sediments, but can also lead to exposure, releases and lasting effects if proper planning is not completed and best management practices are not used. Alternatives 5N, 5aN, and 6N require removal of sediment by dredging, although Alternative 5N can largely be executed by excavation. The following sections detail the assumptions made, methods

Table 11-7. Incremental Analysis of Sediment Resuspended during Geotextile Removal

Parameter	Alternative/ Increment 5N	Increment 5aN-5N	Alternative 5aN	Increment 6N-5aN	Alternative 6N
Area Disturbed (m^2)	14,600	31,200	45,800	17,800	63,600
Average Surface Sediment Concentration (ng/kg)	19,400	2550	7930	365	5810
Sediment Mass Resuspended (kg)	12,300	26,300	38,600	15,000	53,600
Contaminant Mass Resuspended (mg)	239	67	306	5.5	311

used, and results of the estimated releases due to dredging.

Assumptions

After a review of the site conditions and project background, it was determined that for this assessment, a mechanical clamshell dredge would be the best method of material removal, although upland areas could be removed by excavator in a landside operation. Mechanical dredging was selected due to limited staging areas available for dewatering, minimum requirements for dewatering, better control of residuals for soft sediment, and the need to use mechanical methods to remove the existing armor cap. Dredging was recommended for Alternatives 5N and 6N in the wet with a silt curtain to control sediment releases, while Alternative 5aN was also recommended to be completed in the wet but with a sheet pile wall and berm. It was described in the Feasibility Study to perform upland portions of Alternative 5aN in dry conditions; however, to assess the worst-case scenario potential, the alternative was assessed as being performed in wet conditions. Predominantly, only the Western Cell could be excavated in the dry; this constitutes about 25% of the area encompassed in Alternative 5aN but contains about 30% of the volume and about 65% of the contaminant mass. Consequently, excavating the Western Cell in the dry can greatly reduce the contaminant releases and residuals from Alternative 5aN. Predictions of releases and residuals for each release BMP for each incremental area comprising the various alternatives so that the releases and residuals can be estimated from any combination of BMP and incremental areas.

The clamshell bucket was assumed to fit the description of the characteristic clamshell bucket as described in Hayes *et al.* (2007) and the resuspension factor method was used to determine the possible resuspension for the site conditions. Sediment was assumed to be slightly to moderately sticky, with an average thickness of 4.5 mm stuck to the bucket. A review of the Feasibility Study and Geotechnical Report indicated that the average dredge depth would be 10 feet plus 1 foot of over-dredging and water depths averaging 10 feet.

Descent and ascent speeds of the dredge were reduced from the characteristic value to account for the specific site conditions of dredging from a barge and the dredge rate as specified in the Feasibility Study. These assumptions as well as assumptions for the Resuspension Factor can be found in Table 11-8.

To best analyze the possible resuspended sediment releases due to mechanical dredging, an incremental analysis was performed to assess the partial footprints of increments of each alternative, 5N, 5aN – 5N, and 6N – 5aN. As shown in Table 11-9, the volume of resuspended sediment was calculated incrementally to add the resuspension from the incremental footprint to that of the previous alternative, which had already been calculated. For example, since Alternative 5aN encompasses the entire footprint of Alternative 5N, then the dredged area for 5N could be excluded for analysis of 5aN as it has been analyzed separately. The same methodology is applied to Alternative 6N.

An average sediment concentration was calculated based on the results of the grab samples and sediment cores as shown in the Feasibility Study Figure 2-4. The sediment concentrations for each component were averaged across each component footprint.

Equations

Methods used to determine the resuspension factor and consequently, the sediment mass lost and loss rates were completed using the methods as described in Hayes *et al.* (2007) for determination of a resuspension factor based on characteristic properties. The system of equations for variables and constants can be found in Table 11-10. Once the resuspension factor was determined, the mass rate of sediment release could be determined using the equations listed in Table 11-11.

Results

Table 11-12 describes the results of the Resuspension Factor method and the resulting resuspension factor, R_c of 0.777 percent. These parameters were determined by making assumptions on dredging characteristics as previously described in Table 11-10. Resuspension would be predicted to stay in suspension for hours, long enough to be transported from the dredging site if water is allowed to be exchanged to minimize differential pressure across the sheet pile wall or silt curtain.

Table 11-8. Dredging Resuspension Assumptions

Property	Value	Property	Value
Bucket Volume, Vb (m^3)	7.65	**Characteristic Descent Velocity, Ǔd (m/s)**	1.2
Equivalent Diameter (m)	2.45	**Descent Velocity, Ud (m/s)**	1
Equivalent Surface Area (m^2)	7.24	**Characteristic Pre-dredge Water Depth, hc (m)**	8.3
Average Dredge Depth (m)	3.1	**Pre-dredge Water Depth, h (m)**	1
Sediment Removal Thickness (m)	1.2	**Characteristic Ascent Velocity, Ǔa (m/s)**	1.6
Overdredging Depth (ft)	1	**Ascent Velocity, Ua (m/s)**	1.2
Average Water Depth (m)	3	**5N f_{74} (>13000 ng/kg) (%)**	100
Sediment Stickiness	Slightly --> Moderate	**5aN – 5N f_{74} (%)**	60
fsed	2	**5aN f_{74} (>220 ng/kg) (%)**	75
Characteristic Sediment Thickness Δs_c (mm)	4.5	**6N-5aN f_{74} (%)**	50
Adjusted Sediment Thickness Δs (mm)	3.375	**6N f_{74} (>220 ng/kg) (%)**	67
In Situ Solids Concentration, Cs (kg/m^3)	950	**Dredge Rate , Ṽs (m^3/hr)**	25.5

The results of the mechanical dredging resuspension can be found in the Tables 11-13. An incremental analysis was used to estimate the potential resuspension of fine sediments for the dredging activities of each of the alternatives respective footprints. The total mass of sediment removed was calculated assuming an average density throughout the sediment of 950 kg/m^3. As the method of determining mass rate of sediment release accounts for the rate only the fine sediments (f_{74}), as seen in Table 11-11, the bulk sediment concentration was adjusted to reflect the fine sediments that are resuspended during dredging activities. The bulk sediment concentration was estimated incrementally based on sediment cores provided in the Feasibility Study and was then adjusted based on the volume of fines in the sediment. This adjustment results in a higher contaminant concentration and therefore a higher mass of contaminants resuspended as shown in the table below.

Table 11-9. Dredging Incremental Analysis Assumptions

Parameter	Alternative/ Increment 5N	Increment 5aN - 5N	Alternative 5aN	Increment 6N - 5aN	Alternative 6N
Volume Dredged (c.y.)	52,000	85,600	138,000	62,500	200,000
Area Dredged (ft^2)	157,000	335,000	492,000	192,000	684,000
Sediment Dry Mass (metric tons)	36,300	59,800	96,100	43,700	140,000
Days Required	65	107	172	78	250
Average Contaminant Concentration (ng/kg)	13,000	1,450	5,800	168	4,030

Table 11-10. Dredging Resuspension Equations

Parameter	Equation	Parameter	Equation
Characteristic Resuspension Factor, Rc (%)	$Rc = r_1+r_2+r_3+r_4$	**Resuspension Factor, R'c (%)**	$R'c = r'_1+r'_2+r'_3+r'_4$
r'_1	$r'_1 = faa*fdv*ftd*fsed*r_1$	**r'_3**	$r'_3 = [(fla*wla+fbw*wbw+fea*web)*fta+fsw*wsw]*fsed*r_3$
faa	faa = 1.025*(π/Vb)^(1/3)	**Fbw**	fbw = 1.35*(π/Vb)^(1/3)
fdv	fdv = (Ud/Ǔd)^2	**fsw**	fsw = (Ua/Ǔa)^2
ftd	ftd = (h*Ǔd)/(hc*Ud)	**Fta**	fta = (h*Ǔa)/(hc*Ua)
r'_2	$r'_2 = fbv*fec*fsed*r_2$	**r'_4**	$r'_4 = fso*fsed*r_4$
fbv	fbv = (Ud/Ǔd)^2		

Table 11-11. Sediment Loss Equations

Parameter	Equation
Mass rate of sediment release, g, (g/s)	$g = Rc*(f_{74}/100)*((\tilde{V}s*Cs)/360)$
Mass of sediment released, m (kg)	m = g(kg/day) * days required

Residuals

Residuals can be divided into two categories, generated and undisturbed. Generated residuals are the result of sediment that is dislodged from its original location, but falls, sloughs, or settles forming a new sediment layer. Undisturbed residuals are the result of failing to dredge to the bottom of contamination. Factors affecting the amount of residuals include:

- Type, size and operation of dredging equipment.
- Amount of contaminated sediment resuspended by dredging operation.
- Dispersion controls (*e.g.*, sheet piling, silt curtains).
- Contaminant concentration in surrounding areas.
- Characteristics of dredged sediment as well as underlying sediment.
- Site conditions including depths and currents.
- Extent of debris, obstructions or confined operating areas.

As there is no commonly accepted method to accurately predict post-dredging generated residuals, it is recommended by Palermo *et al*. (2008) in the Technical Guidelines for Environmental Dredging of Contaminated Sediments to assume that the residual contaminant concentration be equal to the depth-averaged contaminant concentration of the sediment removed in the last pass, which would include residuals from the previous pass. This method is detailed in Palermo *et al*. (2008) and the assumptions made, methods used, and results for this assessment are described below.

Assumptions

All forms of dredging result in some amount of residuals typically averaging between 5 and 9% lost for strongly hydrophobic contaminants (Patmont 2006) with this percent varying based on type of equipment, sediment characteristics, and number of dredge lifts. Due to the relatively small dredge depth of 10 ft, 4 dredge lifts plus a 1 ft over dredge was selected and the worst-case scenario of 9% residuals was selected due to the soft materials and tendency for mechanical clamshell dredges to lose more sediment and therefore create more residuals. It was assumed that the residuals layer would be less dense than the underlying material and would subsequently have a density of 500 kg/m^3. These assumptions are found in Table 11-14.

The assumptions made concerning the dredge lifts, layer depths, densities, and concentrations can be found in Table 11-15. Four dredge cuts of 3 ft each for lifts 1 -3 and 1 ft plus 1 ft of overdredging for lift 4 were selected. The contaminant profiles were estimated based on the concentrations in the sediment cores presented in the Feasibility Study (Figure 2-4). The various sediment cores were averaged for each of the respective incremental footprints as shown in the table below. The top 0.2-foot of sediment was assumed to be generally soft having a density of 500 kg/m^3 while the densities of the underlying sediment would increase to 950 kg/m^3 and 1000 kg/m^3 for the overdredging.

Equations

The following method used to determine the residuals was presented in Palermo *et al*. (2008) and is broken down by each dredge layer as shown in Table 11-16. The resultant is the determination of the mass, contaminant concentration and thickness of residuals layer.

Table 11-12. Resuspension Factor for Clamshell Bucket

Parameter	Value
Characteristic Resuspension Factor, Rc (%)	Rc = r1+r2+r3+r4
Loss during descent ,	0.01
Loss during bucket	0.09
Loss during ascent ,	0.15
Loss during slewing ,	0.25
r'_1 (adjusted r_1)	r'_1 = faa*fdv*ftd*fsed*r_1
Faa	0.753
Fdv	0.694
Ftd	0.434
r'_1	0.0045
r'_2 (adjusted r_2)	r'_2 = fbv*fec*fsed*r_2
Fbv	0.694
Fec	1
r'_2	0.125
r'_3 (adjusted r_3)	r'_3 = [(fla*wla+fbw*wbw+fea*web)*fta+fsw*wsw]*fsed*r_3
wla	0.2
Fla	1
Wbw	0.05
Fbw	1.004
Web	0.65
fea (assume)	1
Wsw	0.1
fsw	0.563
Fta	0.482
r'_3	0.147
r'_4 (adjusted r_4)	r'_4 = fso*fsed*r_4
fso (assume)	1
r'_4	0.5
R'c (adjusted Rc)	0.777

Table 11-13. Incremental Analysis of Total Resuspended Sediments during Mechanical Dredging

Parameter	Alternative/ Increment 5N	Increment 5aN - 5N	Alternative 5aN	Increment 6N - 5aN	Alternative 6N
Volume Dredged (c.y.)	52,000	85,600	138,000	62,500	200,000
Total Dry Sediment Mass Dredged assuming 950 kg/m^3 (metric tons)	37,800	62,200	100,000	45,400	145,000
Dry Mass of Fine Sediments Dredged (metric tons)	37,800	37,300	75,100	22,700	97,800
Days Required	65	107	172	78	250
Average Bulk Sediment Concentration (ng/kg)	13,000	1,450	5,810	168	4,040
Fine Sediment Concentration (ng/kg)	13,000	2,420	7,730	336	6,010
Fine Sediment Release Rate (kg/day)	4,510	2,710	3,390	2,260	3,040
Dry Mass of Fine Sediments Resuspended (metric tons)	294	290	584	176	760
Contaminant Mass Resuspended (mg)	3,810	702	4,500	59	4,560
Contaminant Release Rate (mg/day)	59	6.6	26	0.8	18

Table 11-14. Assumptions Made for Residuals Estimate

Parameter	Value
Dredge Plan for Mechanical Clamshell Dredge	**4 Production Passes for 10 ft Sediment and 1 ft Overdredging**
Assessment	**Worst-Case Scenario for Potential Residuals**
Residuals Left (%)	9
Assumed Residuals Density, *ρ* (kg/m³)	500

Results

The results of the potential residuals as determined following the methods presented in the USACE Technical Guidelines for Environmental Dredging of Contaminated Sediments (2008) can be found in Tables 11-17, 11-18 and 11-19. Table 11-17 presents the step by step incremental analysis resulting in sediment mass and contaminant mass per surface area as well as a final residual concentration and residual layer thickness. From these results and the assumed alternative surfaces areas as found in Table 11-9, sediment and contaminated mass were calculated as seen in Table 11-18. The results of the incremental analysis show that potential residual from Alternative 5N, which removes sediments greater than 13,000 ng/kg, result in a very high contaminant concentration in the residuals, well above the required PCL.

Table 11-15. Assumed Dredge Lifts for Increments 5N, 5aN, and 6N

Dredge Lifts	Cut, D (ft)	Increment 5N (Surface > 13000 ng/kg)		Increment 5aN – 5N (13000 ng/kg>Surface>220 ng/kg)		Increment 6N – 5aN (Surface<220 ng/kg)	
		Density, ρ (kg/m³)	Concentration, C (ng/kg)	Density, ρ (kg/m³)	Concentration, C (ng/kg)	Density, ρ (kg/m³)	Concentration, C (ng/kg)
1	0.2	500	15,600	500	4,310	500	198
	2.8	950	15,600	950	4,310	950	198
2	3	950	15,500	950	908	950	349
3	3	950	11,400	950	169	950	60
4	1	950	9,050	950	111	950	34
	1 Over Dredge	1000	6,660	1000	53	1000	8

Table 11-19 presents the amount of the residuals lost with the use of a turbidity curtain. It is assumed, based on prior knowledge that roughly 20% of the fine-grained remaining residuals would be lost below the turbidity curtain due to currents.

Conclusions

This assessment examined the remediation alternatives as proposed in the Feasibility Study considering the BMP options given in the FS. The analyses showed that there is the potential for significant sediment releases depending on the methods used for remediation. Any remediation, solidification or dredging, that occurs should be completed in the dry to minimize the amount of resuspension releases and residuals that may be exposed to the water column, particularly in the area slated for removal in Alternative 5N. All activities completed in the dry, having a sheet pile wall barrier protecting the water from interacting with contaminated sediment will result in very small amounts of resuspension, and will have limited exposure to the water before the permanent cap is placed over the residual layers. Activities completed in the wet will result in much greater releases and potential long-term effects based on the residuals. The predicted residuals for Alternative 5N have a quite high contaminant concentration due to an insufficient depth of dredging, which does not include overdredging of sediment below the clean-up level.

A summary of incremental sediment releases can be found in Table 11-20. This table allows for comparison of the total mass of sediments and contaminants removed by dredging to the total mass of sediments and contaminant lost with either a sheet pile wall or a turbidity curtain as a best management practice. The mass of sediment removed by dredging was calculated by assuming an average sediment density of 950 kg/m^3 and by using the incremental sediment contaminant concentrations. Table 11-21 shows the releases for the various removal alternatives if a particular BMP where applied for all of the alternatives.

Table 11-16. Method of Residuals Estimation

1st Production Pass - Composite	
Mass, M_{1c} (kg-ft/m³)	$M_{1c} = (D_{1S} * \rho_{1S}) + (D_{1B} * \rho_{1B})$
Contaminant Mass, CM_1 (ng-ft/m³)	$CM_1 = C_1 * M_1$
1st Production Pass – Residuals Layer	
M_{1R} (kg-ft/m³)	$M_{1R} = \%R * M_1$
CM_{1R} (ng-ft/m³)	$CM_{1R} = \%R * CM_1$
Residual Contaminant Concentration,	$CC_{1R} = CM_{1R} / M_{1R}$
2nd Production Pass - Sediment	
M_2 (kg-ft/m³)	$M_2 = D_2 * \rho_2$
CM_2 (ng-ft/m³)	$CM_2 = C_2 * M_2$
2nd Production Pass - Composite	
M_{2c} (kg-ft/m³)	$M_{2c} = M_2 + M_{1R}$
CM_{2c} (ng-ft/m³)	$CM_{2c} = CM_2 + CM_{1R}$
2nd Production Pass -Residuals	
M_{2R} (kg-ft/m³)	$M_{2R} = \%R * M_{2c}$
CM_{2R} (ng-ft/m³)	$CM_{2R} = \%R * C_{2c}$
CC_{2R} (ng/kg)	$CC_{2R} = CM_{2R} / M_{2R}$
3rd Production Pass - Sediment	
M_3 (kg-ft/m³)	$M_3 = D_3 * \rho_3$
CM_3 (ng-ft/m³)	$CM_3 = C_3 * M_3$
3rd Production Pass - Composite	
M_{3c} (kg-ft/m³)	$M_{3c} = M_3 + M_{2R}$
CM_{3c} (ng-ft/m³)	$CM_{3c} = CM_3 + CM_{2R}$
3rd Production Pass -Residuals	
M_{3R} (kg-ft/m³)	$M_{3R} = \%R * M_{3c}$
CM_{3R} (ng-ft/m³)	$CM_{3R} = \%R * C_{3c}$
CC_{3R} (ng/kg)	$CC_{3R} = CM_{3R} / M_{3R}$
Final Production Pass - Sediment	
M_F (kg-ft/m³)	$M_F = D_F * P_F$
CM_F (ng-ft/m³)	$CM_F = C_F * M_F$
Final Production Pass - Overdredging	
M_{OD} (kg-ft/m³)	$M_{OD} = D_{OD} * \rho_{OD}$
CM_{OD} (ng-ft/m³)	$CM_{OD} = C_{OD} * M_{OD}$
Final Production Pass - Composite	
M_{Fc} (kg-ft/m³)	$M_{Fc} = M_{3R} + M_F + M_{OD}$
CM_{Fc} (ng-ft/m³)	$CM_{Fc} = CM_{3R} + CM_F + CM_{OD}$
Final Production Pass -Residuals	
M_{FR} (kg-ft/m³)	$M_{FR} = \%R * M_{Fc}$
CM_{FR} (ng-ft/m³)	$CM_{FR} = \%R * C_{Fc}$
CC_{FR} (ng/kg)	$CC_{FR} = CM_{FR} / M_{FR}$
Residual Thickness, T_R (ft)	$T_R = M_{FR} / \rho_R$

Table 11-17. Incremental Analysis of Potential Residuals

Parameter	Increment 5N	Increment 5aN -5N	Increment 6N -5aN
1st Production Pass - Composite			
M_{1C} (kg-ft/m³)	2,760	2,760	2,760
CM_{1C} (ng-ft/m³)	43,100,000	11,900,000	546,000
1st Production Pass - Residuals Layer			
M_{1R} (kg-ft/m³)	248	248	248
CM_{1R} (ng-ft/m³)	3,880,000	1,070,000	49,200
CC_{1R} (ng/kg)	15,600	4,310	198
2nd Production Pass - Sediment			
M_2 (kg-ft/m³)	2,850	2,850	2,850
CM_2 (ng-ft/m³)	44,200,000	2,590,000	995,000
2nd Production Pass - Composite			
M_{2c} (kg-ft/m³)	3,100	3,100	3,100
CM_{2c} (ng-ft/m³)	48,100,000	3,660,000	1,040,000
2nd Production Pass - Residuals			
M_{2R} (kg-ft/m³)	279	279	279
CM_{2R} (ng-ft/m³)	4,320,000	329,000	93,900
CC_{2R} (ng/kg)	15,500	1,180	337
3rd Production Pass - Sediment			
M_3 (kg-ft/m³)	2,850	2,850	2,850
CM_3 (ng-ft/m³)	32,500,000	482,000	171,000
3rd Production Pass - Composite			
M_{3c} (kg-ft/m³)	3,130	3,130	3,130
CM_{3c} (ng-ft/m³)	36,800,000	811,000	265,000
3rd Production Pass - Residuals			
M_{3R} (kg-ft/m³)	282	282	282
CM_{3R} (ng-ft/m³)	3,310,000	73,000	23,800
CC_{3R} (ng/kg)	11,800	259	85
4th (Final) Production Pass - Sediment			
M_4 (kg-ft/m³)	950	950	950
CM_4 (ng-ft/m³)	8,597,500	105,450	32,300
Final Production Pass - Overdredging			
M_{OD} (kg-ft/m³)	1,000	1,000	1,000
CM_{OD} (ng-ft/m³)	6,660,000	53,000	8,000
Final Production Pass - Composite			
M_{Fc} (kg-ft/m³)	2,230	2,230	2,230
CM_{Fc} (ng-ft/m³)	15,300,000	159,000	40,400
Final Production Pass - Residuals			
M_{FR} (kg-ft/m³)	201	201	201
CM_{FR} (ng-ft/m³)	1,370,000	14,300	3,640
CC_{FR} (ng/kg)	6,840	71	18.1
Residual Thickness, T_R (ft)	0.40	0.40	0.40

Table 11-18. Summary of Residuals Estimates

Parameter	Alternative/ Increment 5N	Increment 5aN - 5N	Alternative 5aN	Increment 6N - 5aN	Alternative 6N
Sediment Residual Mass (metric tons)	892	1,908	2,800	1,090	3,890
Contaminant Residual Mass (mg)	7,420	198	7,620	31	6,259
Contaminant Concentration (ng/kg)	8,320	104	2,720	29	1,970

Table 11-19. Potential Releases from Erosion of Residuals with a Silt Curtain Prior to Cover Placement

Parameter	Alternative/ Increment5N	Increment 5aN - 5N	Alternative 5aN	Increment 6N - 5aN	Alternative 6N
Sediment Residual Mass Erosion (metric tons)	897	1,150	2,050	550	2,600
Contaminant Residual Erosion Mass (mg)	11,700	2,840	14,600	188	14,700
Contaminant Concentration (ng/kg)	13,100	2,470	7,130	342	5,660

Table 11-20. Summary of Incremental Sediment and Contaminant Release Estimates*

Incremental Areas	BMP Options	Total mass of dry solids removed (metric tons)	Total mass of dry solids released (metric tons)	Percentage of sediment released (%)	Total mass of contaminant removed (g)	Total mass of contaminant released (g)	Percentage of contaminant released (%)
Alternative/ Increment 5N	Silt Curtain	37,800	1,200	3.18	491	15.8	3.21
	Sheet Pile Wall (Wet Removal)		312	0.83		3.82	0.78
	Sheet Pile Wall (Dry Removal)		5.7	0.015		0.0057	0.001
Increment 5aN - 5N	Silt Curtain	62,200	1,470	2.36	90.2	3.61	4.00
	Sheet Pile Wall (Wet Removal)		319	0.51		0.70	0.78
Increment 6N - 5aN	Silt Curtain	45,400	741	1.63	7.63	0.25	3.28
	Sheet Pile Wall (Wet Removal)		191	0.42		0.06	0.78

*As Alternative 4N will be performed in the dry, the only releases will be due to the sheet pile wall construction and removal and are the same as given above for Alternative 5N with a Sheet Pile Wall with Excavation in the Dry.

Table 11-21. Sediment and Contaminant Release Estimates as a Function of Selected BMP

Selected BMP	Solids Released (%)			Contaminant Released (%)		
	Alternatives			Alternatives		
	5N	5aN	6N	5N	5aN	6N
Sheet Pile Wall (Dry Removal)	0.015	NA	NA	0.001	NA	NA
Sheet Pile Wall (Wet Removal)	0.83	0.63	0.57	0.78	0.78	0.78
Silt Curtain	3.18	2.67	2.35	3.21	3.34	3.34

To determine the releases for any alternative using different BMPs for the various incremental areas, select the rows listing the selected BMP for each of the incremental areas contained in the alternative and then sum the incremental releases for the selected rows in Table 11-20. For example, for Alternative 6N using sheet pile walls and removal in the dry for Increment 5N, sheet pile walls and removal in the wet for Increment 5aN – 5N, and silt curtains for Increment 6N – 5aN, the dry solids release would be 1066 (5.7 + 319 + 741) metric tons and the contaminant release would be 0.956 (0.0057 + 0.70 + 0.25) grams. To obtain the percentages release, divide the releases by the masses removed. For this example, the solids release was 0.74% and the contaminant release was 0.16%.

This assessment presents the possible outcomes of remedial Alternatives 4N*, 5N, 5aN and 6N with very specific assumptions and site conditions. The actual sediment releases and residuals will vary depending on the actual circumstances of remedial activity. A new full removal Alternative 6N* is examined for potential releases in Task 12 with alternative BMPs.

Task 12

Statement

Identify and evaluate techniques, approaches, Best Management Practices (BMPs), temporary barriers, operational controls, and/or engineering controls (*i.e.*, silt curtains, sheet piles, berms, cofferdams constructed of earth filled caissons, etc.) to minimize the amount of sediment resuspension and sediment residuals concentrations during and after dredging/removal. Prepare a new full removal alternative that incorporates the relevant techniques identified as appropriate.

BMPs to Minimize Sediment Resuspension and Residuals during Dredging/Removal

Alternatives 4N, 5N, 5aN and 6N call for removal of a portion of the TCRA cap composed of armor stone and filter stone in the Northwestern Area, armor stone and geotextile in the Eastern Cell and armor material, geotextile and geomembrane in the Western Cell. Alternatives 5N, 5aN and 6N also call for partial or full removal of sediment. These removal operations will resuspend contaminated sediment and generate contaminated residuals which will increase the release of contaminants, requiring the implementation of Best Management Practices (BMPs) to control the release of contaminants.

Resuspension, Residuals, and Release

Sediment remediation techniques that disturb the sediment bed, such dredging, solidification, or treatment, have potential to expose contamination through resuspension, generation of residuals, or release of contaminants. Detailed information regarding these mechanisms with respect to dredging is provided by ERDC in the Technical Guidelines for Environmental Dredging of Contaminated Sediments (Palermo *et al.* 2008). Resuspension is the dislodgement and dispersal of sediment into the water column where finer particles and flocs are subject to transport by currents. Resuspension results in short-term release of contaminants by desorption and release of pore water. Residuals are contaminated sediments remaining in the dredging area after completion of the dredging operation and result from two main sources. Undisturbed residuals are contaminated sediments at the post-dredge surface that have been uncovered, but not removed. Generated residuals consist of sediment that

is dislodged, but not removed, and falls back into the dredging footprint where it contributes to contaminant release (Palermo *et al.* 2008).
A variety of control measures have been identified to minimize sediment resuspension, contaminant release and dredging residuals that may occur during sediment removal operations. These include both operational and engineered controls. Operational controls include actions that can be taken by the dredge operator, whereas engineered controls require a physical construction technology or modification of the dredge plant. It is pointed out in the Technical Guidelines (Palermo *et al.* 2008) that both, operational and engineered controls can reduce production rates and efficiency, can increase cost, and can even have negative impacts if used improperly, and therefore should only be applied when conditions clearly indicate their need.

Resuspension Controls

Operational Controls

Operational controls that may be considered to minimize resuspension during dredging include:

Mechanical Dredging:

- Reducing the dredging rate by slowing descent or hoist speed of wire-supported bucket
- Reducing bucket speed as it approaches sediment surface and after closing
- Prevent bucket over-penetration
- Eliminate barge overflow
- Employ aprons to catch spillage and a rinse tank to clean the bucket between cycles

Hydraulic Dredging:

- Modify cutterhead depth
- Modify rate of swing of the ladder
- Reduce speed of advance of the dredge

General:

- Adjust dredge operation according to changing site conditions
- Sequence the dredging moving upstream to down and to limit dredge traffic over exposed contaminated sediment
- Vary number of vertical cuts to increase sediment capture
- Use properly sized tugs and support equipment

- Limit barge, tender and tug traffic over exposed sediment and residuals
- Cover exposed residuals as soon as possible, minimizing the area of exposed residuals

Dredge operators are challenged to find an optimal rate to reduce resuspension and maximize production. For hydraulic dredging, resuspension is generally minimized at the same point that production is optimized.

Engineering Controls

Engineered control measures such as physical barriers can be used to reduce transport of resuspended contaminated sediment, and limit the areal extent of particle-bound contamination. However, containment of the resuspended sediment may increase residual concentrations inside the barrier. Types of physical barriers may include cofferdams, removable dams (*e.g*., Geotubes), sheet-pile enclosures, silt curtains, silt screens, and pneumatic (bubble) curtains. Cofferdams and removable dams are generally associated with dry excavation remedies.

Silt curtains and silt screens. Silt curtains and silt screens are flexible barriers that hang down from the water surface using a series of floats on the surface and a ballast chain or anchors along the bottom. Silt “curtains” are made of low permeability materials, and as such, redirect water flow around the enclosed area. Silt “screens” are made of permeable geotextile fabrics which allow a significant fraction of the water to flow through, but retain a large fraction of the suspended solids. The terms are frequently used interchangeably, and the term “curtain” is used here to apply to both types. Silt curtains either contain or redirect the transport of resuspended sediment. Partial depth deployment from the surface to a given depth prevents spreading in the upper water column, but allows transport beneath the curtain. Full depth deployment provides greater containment, although there are potential releases from ineffective seals along the bottom, tidal fluctuations, erosion by the curtain scraping the sediment bed, erosion outside the curtain from the flow being diverted around the site, and vessel movement through gaps. It is important to note that increased concentrations of TSS or dissolved contaminants contained within the curtain are generally released upon relocation or demobilization.

Guidance on the use of silt curtains, including descriptions, deployment, configurations, and “lessons learned” is provided by Francingues and Palermo (2005). Some of the key points include:

- Silt curtains are not very effective at current velocities > 1 ½ knots (2.5 ft/sec) and are best deployed in environments where the current speeds are less than 1 ft/sec. Application at higher velocities would require special designs.
- At depths greater than 10-12 ft, loads on the curtains and mooring systems become excessive and could result in failure.
- Silt curtains are highly specialized and should be tailored to the site-specific project. Planning elements should include construction specifications, performance criteria, plans for deployment, removal, decontamination and maintenance, and monitoring plans.
- Deployment is temporary, but should remain in place until all dredging is complete, allowing for traffic in and out, and for relocation as the dredge moves.

Hydrodynamic conditions that reduce effectiveness of the silt curtain include strong currents, high winds, fluctuating water levels, excessive wave height (including ship wakes), drifting ice and debris, and movement of equipment into or out of the area. Generally, silt curtains are most effective in relatively shallow, quiescent water without significant tidal fluctuations. Silt curtains can be used either to enclose the dredging area (keeping TSS inside), or to protect sensitive areas (keeping TSS out).

Structural barriers. Structural barriers should be considered if there is uncertainty that a silt curtain will be effective, or for containment of resuspended sediments that contain highly mobile, highly toxic, or bioaccumulative contaminants. Structural walls (*e.g*., sheet pile deflection walls) can also be used to partially shield silt curtains from high current velocities. Sheet-pile containment structures are generally more reliable than silt curtains, although the cost is significantly higher with different technological limitations. There is an increased potential for scour to occur around the outside of the containment area; however, the surrounding area could be armored to prevent scour at the base of the wall. If water levels are lowered on one side of the wall, the hydraulic loading effects may result in safety concerns; however, the wall can be designed to allow water exchange to accommodate changes is river stages or tides. Cofferdams composed of caissons anchored in a stiff, shear resistant stratum and filled with low permeability soils could be built instead of sheet pile walls to accommodate the differences in pressures resulting from dewatering the inside of the containment and allow greater excavation in the dry. The seepage through walls and the foundation pose large uncertainties in the implementability of excavation in the dry. The caissons would prevent exchange of water during removal in the wet and the associated resuspension releases but dredging residuals would still be created that would be required a residual cover. The residuals would still be a source of long-term releases and would be available to potentially erode under severe storm events. Another consideration is the resuspension and contaminant release that will occur during placement and removal. If the carrying capacity of a stream or river is changed significantly, it may make it more susceptible to flooding. Engineering design considerations include geotechnical characteristics of the sediment profile, proximity to bedrock, hydraulic head acting on the enclosure, and ice forces.

Release Controls

Controlling resuspension is the first step to controlling release of contaminants because the vast majority of dioxins and furans are associated with the sediment particles. However, additional controls may be necessary because the contaminants will partition to the water column when sediment particles are suspended in dispersions of low concentrations of total suspended solids.

For release of NAPL and floatable materials, oil booms may be used to contain contaminants. Oil booms may be supplemented with oil-absorbent materials. However, booms do not retain the soluble fraction of floatable materials that can volatilize. Monitoring for visible sheens or visibly soaked sorbent pads and changing out pads accordingly can improve effectiveness. NAPL and floatable materials are not a concern at the San Jacinto site.

Controlling release of particulate-bound contaminants is largely accomplished by controlling resuspension. However, increasing sedimentation rates will also decrease the spread of contaminants and bioavailability. Methods to improve sedimentation include: providing a zone for quiescent settling, addition of flocculants, or using containment enclosures designed as filters. Adsorbents integrated into permeable silt curtains essentially treat water as it passes through. Pilot studies may be needed to show effectiveness of these technologies.

Technology for controlling releases of dissolved contaminants is also largely limited to resuspension controls. However, dissolved contaminants may also be removed by dispersing adsorbents, such as activated carbon, inside containment enclosures. Upon settling, the adsorbents may further sequester the dissolved contaminant flux from the sediment bed and residuals. If the sediment bed or residuals were resuspended, the adsorbents would also be resuspended and then sequester the new releases. Filtering geotextiles with adsorbents used in conjunction with permeable silt curtains treat water passing through the site. Pilot studies are encouraged before application to large-scale projects.

Volatile emissions controls are limited and have not been adequately evaluated in the field. In addition to the controls mentioned above, controls for small hotspots may include: modifying the dredging schedule or sequence to dredge in winter or at night when temperatures are cooler; using hydraulic dredging to reduce concentrations at the water surface and in the air; applying surface volatilization barriers; and reducing the area of the dredge enclosure that is emitting volatiles. Other physical measures to control volatiles include covering the dredged material with physical barriers (*e.g.*, foam, mulch, plastic liner, or adsorbent mats). Dioxins and furans have both low solubility and low volatility; therefore, volatilization controls are not needed at the San Jacinto site.

Residual Controls

The nature and extent of residual contamination is difficult to estimate. Undisturbed residuals can be reduced by accurate and precise site characterization, proper establishment of the cut line, accurate and precise vertical and horizontal controls for positioning of dredge passes, accurate post-dredging bathymetric surveys, and an accurate cleanup pass. Generated residuals, however, are unavoidable, and it is accepted that a residuals layer will be present unless eroded away. The operational controls listed below may be effective for reducing residuals.

- If debris is present, a separate debris-removal operation can be considered either prior to dredging, in between passes, or prior to a cleanup pass. Little debris should be present in the contaminated sediment due to nature of the San Jacinto waste pits being a confined waste storage facility, its remoteness, and its lack of commercial or navigation activities at the site.

- Sequence dredging from upslope to downslope and upcurrent to downcurrent and to limit dredge traffic over exposed contaminated sediment.
- Limit traffic over the dredged area.
- Excavate in the dry where possible.
- Provide appropriate overdredging allowance for production cuts.
- Overdredge with a cleanup pass to reduce the residuals layer thickness and mix residuals from the underlying clean sediment with the contaminated residuals to reduce the concentration.
- Provide adequate overlap between bucket cuts with high resolution positioning controls to reduce residuals between bucket cuts.
- Terrace dredge cuts to limit sloughing.
- Eliminate bucket over-penetration and overfilling.
- Conduct rapid hydrographic surveys and sampling after dredging to provide feedback to the dredge operator.

Depending on the results of monitoring, several post-dredging control measures are available. The controls measures should be selected based on residuals' characteristics and site conditions.

A cleanup dredging pass or sweep pass may be conducted to remove the thin surficial layer of material containing residuals and minimal thickness of the underlying clean material. Performance requirements to achieve a very low residual contaminant concentration can be inefficient and costly. Limiting the number of passes and providing the option for placement of a residuals cap may bring more certainty into the cost estimating and bidding process. For thicker layers of residuals, especially undisturbed residuals, additional production dredging may be needed.

A thin layer of clean material may be placed over residuals to provide short-term isolation and long-term reduction in surficial contamination. The cover material does not need to be sand, and other materials with potential to reduce bioavailability may be preferable. Thin layer capping may be useful where residual layers are sufficiently thin with low contaminant concentrations, so that if the cover material mixes into the underlying residual, remediation action levels can still be achieved. Some mixing is likely to occur during placement, with additional mixing due to bioturbation and sediment transport processes. This would result in a lower contaminant concentration in the biologically active zone. Additional deposition of clean sediment may enhance physical and chemical isolation of the residuals.

An engineered isolation cap may be considered where substantial layers of residuals cannot be effectively removed. USEPA guidance for design of engineered caps is generally followed (USEPA 2005).

Best Management Practices for San Jacinto Proposed Alternatives

Alternatives currently being considered for San Jacinto are described in the Draft Final Interim Feasibility Study Report (Anchor QEA 2014). Within the management alternatives, a number of actions have been identified that have potential to generate resuspension, residuals, and contaminant release. The alternatives labeled as 1N (no further action) and 2N (monitored natural recovery (MNR) and institutional controls (ICs)) will leave the existing TCRA Armor Cap in place and does not include activities that would generate resuspension, residuals or release. Implementation of Alternative 3N would require enhancement of the Armored Cap including addition of armor rock to further flatten the slopes, and construction of a protective perimeter barrier to protect from vessel traffic. These activities would not expose the contaminated material and therefore would not have the potential to generate resuspension, residuals, and contaminant release. Alternative 4N calls for removal of 23% of the Armored Cap, and solidification/stabilization (S/S) of the underlying 52,000 cubic yards (cy) of contaminated material, followed by construction of a Permanent Cap. Alternative 5N also calls for partial removal of the Armored Cap and Permanent Cap construction, but also specifies excavation and off-site disposal of the 52,000 cy of contaminated material that exceed 13,000 *ng/kg* $TEQ_{DF,M}$ at any depth. More extensively, Alternative 5aN requires removal of the Armored Cap and all underlying material in high concentration areas greater than the PCL) with water depth of 10-feet or less, and materials that exceed 13,000 *ng/kg* $TEQ_{DF,M}$ at any depth. Removal for Alternative 5aN would involve 11.3 acres and 137,600 cy of contaminated material. Alternative 6N requires removal of the entire existing cap and 200,100 cy of contaminated material followed by covering with a layer of clean fill.

Activities that may generate resuspension, residuals, and contaminant release include:

- Removal of existing TCRA Armor Cap (under both submerged and upland conditions)(4N, 5N, 5aN, 6N)
- Resuspension and release from exposed, un-capped sediment (4N, 5N, 5aN, 6N)
- Solidification/Stabilization (4N)
- Sheet pile installation and removal (4N, 5aN, maybe 5N)
- Perimeter berm installation and removal (5aN)
- Removal of contaminated soil/sediment (5N, 5aN, 6N)
- Construction of Permanent Cap (4N, 5N, 5aN)
- Restoration of Armor Cap (in areas cap was removed to allow S/S (4N) or removal (5N) of material with TEQ > 13,000 *ng/kg* $TEQ_{DF,M}$)
- Addition of residuals cover/backfill (5N, 5aN, 6N)
- Installation/removal of silt curtain (5N, 6N)
- Site dewatering (4N, maybe 5N, possibly 5aN and 6N in Western Cell)
- Treatment/dewatering excavated sediment (5N, 5aN, 6N)

With dioxins as the primary COC, concerns are primarily associated with particulate-bound contaminants, rather than volatile emissions or dissolved contaminants.

<u>Removal of Existing Armor Cap</u>

Alternatives 4N, 5N, 5aN, and 6N involve removal of some or all of the existing TCRA Armor Cap. Armor cap would be removed from both submerged areas and areas that are not normally submerged though periodically flooded. The armor rock would be removed and stockpiled for reuse, if possible, or washed to remove adhering sediment and disposed in an upland facility. The geotextile and geomembrane would be removed and disposed as contaminated debris (Anchor QEA 2014). Removal equipment and methods were not specified. Alternatives 4N, 5aN, and potentially 5N include sheet pile enclosures, and Alternatives 5N and 6N suggest the use of silt curtain. However, the FS does not clearly specify whether the sheet pile or silt curtain would be installed before or after removal of the existing Armor Cap (Anchor QEA 2014). Dewatering is specified for submerged areas for Alternatives 4N and potentially 5N.

Resuspension is likely to occur as the sediment is disturbed upon removal of cap materials in contact with the contaminated sediment. A significant portion of the contaminated sediment may adhere to the armor rock, geotextile or geomembrane. In submerged areas, contaminated sediment that is resuspended into the water column has the potential for transport off site or for contamination of the clean cap. As part of the TCRA, solidification/stabilization (S/S) techniques were applied to the upper three feet in the Western Cell of the site prior to placement of the Armor Cap. The S/S efforts may have reduced the tendency of the contaminated sediments to adhere to the cap materials and to resuspend. In upland areas such as the Western Cell, contaminants could be transported off site via runoff or as dust.

Some contaminated material will adhere to the cap material (geotextile or armor rock) and be disposed with it. As discussed in the FS, hazardous materials (sediments, geotextile, used personal protective equipment and debris) would be packaged in accordance with Texas Department of Transportation shipping requirements and transported to a permitted landfill. Care should be taken to avoid re-use of cap material that has been contaminated with the sediment. It is difficult to understand how the armor cap material could be readily removed without snagging and disturbing the geotextile and sediment, particularly if performed underwater. The entire cap within the sheet pile enclosure should be removed prior to solidification, excavation or dredging to limit contamination of the TCRA armor cap material. The enclosed area could be sectioned with silt curtains to further limit the potential for contamination of the TCRA armor cap material. Additionally, a work plan should be in place to minimize equipment tracking between capped (or clean) and exposed contaminated areas. Periodic equipment cleaning could be employed to prevent contamination of otherwise clean, reusable cap materials.

In submerged areas, installation of sheet pile walls prior to cap removal would provide a barrier to contain resuspension from cap removal activities and reduce off site transport. If dewatering is possible, working in the dry would significantly reduce contaminant transport from resuspension and release. Though not as effective as sheet pile, silt curtains could also be used to reduce transport of resuspended contaminated sediments. Problems with silt curtains were noted during the TCRA cap construction, yet despite requiring a great deal of maintenance, the silt curtains appeared to be effective (Anchor QEA 2012). Resuspended sediment contained within the sheet pile or silt curtain enclosure may subsequently settle out within the contained area, which could contaminate remaining un-removed cap material. (See Sheet Pile and Silt Curtain Installation/Removal.)

Resuspension and Release from Exposed Uncapped Sediments

Removal of the existing cap (Alternatives 4N, 5N, 5aN) will also expose the contaminated sediments for a period of time until they are either stabilized, removed, or either covered or capped. There is potential for contaminants to be released into overlying water during exposure. Exposed upland soils can also be transported by rainfall runoff and dust. Also, resuspension of the contaminated material is possible during storm and flood events, which could allow transport to the surrounding area. The risk of flood occurrence depends on the season and duration of the construction. For alternatives 4N and 5aN, the area in which the cap will be removed will be enclosed within sheet pile. However, the FS suggests the likelihood of the sheet pile being overtopped and resulting in inundation of the construction footprint is approximately 38 percent for alternative 4N, and 40 percent for alternative 5aN. Alternatives 5N and 6N, using silt curtains, are also subject to inundation, with a likelihood of 30 percent and 36 percent, respectively (Anchor QEA 2014).

Potential practices that could minimize contaminant resuspension and release from exposed sediment include the use of silt curtains, or sheet piles. The FS report suggests limited effectiveness of the sheet pile due to gaps during construction, necessary openings to balance water pressures, and river-induced scour (Anchor QEA 2014). However, use of sheet piles in shallow water such as along the berms of the Western Cell may be able to operate in the dry. In deeper areas the remediation operations would need to proceed in the wet, use of sheet piles for controlling resuspension releases and contaminant releases would be much more effective than silt curtains even if water exchanges were allowed to balance water pressures. Exchanges would occur near the surface with sheet piles but near the bottom for silt curtains, resulting in about one third of the releases observed using silt curtains. Additionally, armoring around the outside of the sheet pile wall could control river-induced scour. For resuspended sediment that is contained within a sheet pile (4N, 5aN) or a turbidity curtain (5N, 6N), flocculants may be added to encourage settling of contaminated particles, but mixing and higher suspended solids concentrations would be needed to be particularly effective. Also, activated carbon may be added to sorb dissolved contaminants; however, activated carbon would need to be added regularly because the carbon will settle out of suspension, limiting its effectiveness. Neither application has been routinely performed and are not recommended due to the low suspended solids concentration and low dissolved contaminant concentration. As both silt curtains and sheet piles may leak, additional practices may be needed to manage contaminants released outside the contained area. Monitoring is recommended to determine the need for such controls.

For upland areas, water spraying should be employed as needed to control dust. Also, exposed sediment is subject to resuspension during rainfall runoff or tidal inundation. Silt fencing or hay bales may be used to minimize release of contaminated sediment-laden runoff. Also, during TCRA Armor Cap construction, a temporary water control berm was constructed to minimize potential for tidal water to inundate the Western Cell during stabilization activities. The berm was constructed with a crest elevation of approximately 2.5 feet NAVD 88, using CCRB and 6 mm thick polyethylene sheeting (Anchor QEA 2012, p. 39). Potentially, the surface area exposed at a given time could be reduced by staging the construction activities, working within subareas, and using sacrificial covers which would support fill, bedding or filter requirements for the final disposition.

Solidification/Stabilization

Alternative 4N proposes S/S performed using large-diameter augers or conventional excavators, similar to those used for S/S in the Western Cell during the TCRA. Submerged areas would be isolated from surface water with sheet pile and mostly dewatered prior to S/S. The FS assumes a sheet pile enclosure with a top elevation 2 feet above typical mean higher high water (mhhw). The sheet pile would be removed following completion of S/S; then, the Permanent Cap would be constructed over the S/S footprint. None of the other alternatives include S/S activities (Anchor QEA 2014). S/S activities will potentially result in resuspension, release, and residuals as the uncapped contaminated material is mixed with Portland cement. Mixing of the sediment will loosen it, making it temporarily more subject to resuspension and erosion. However, the S/S treatment will increase resistance to erosion as it cures over a period of about ten days. In upland areas, runoff controls should be in place to capture suspended sediment from rainfall. The FS suggests that the submerged areas be enclosed with sheet piles and dewatered. If not dewatered, sheet pile enclosures would also help retain resuspended solids, and released contaminants. The FS suggests ineffectiveness of sheet pile barriers due to gaps that occur during installation, openings to balance water pressures, and river-current-induced scour. If properly installed, shallow sheet pile barriers should be able for the most part to be installed without gaps, and any gaps could be sealed with fine-grained backfill. If water pressures are significant, a cofferdam may be needed. If S/S is performed in the wet, the degree to which resuspension occurs will depend on the equipment used to mix the sediment and cement.

S/S activities will involve transport across the site to maneuver mixing equipment and deliver Portland cement. To minimize contaminant spreading, decontamination of trucks and equipment (and workers) may be needed upon exiting the site. A water truck may be needed to suppress dust from both the contaminated sediment and Portland cement.
Post S/S monitoring will be needed to determine the extent to which S/S is effective for stabilizing contaminants. Residual contamination is addressed by the planned Permanent Cap, MNR, and ICs. Residuals may be further managed by addition of activated carbon prior to capping.

Sheet Pile Installation and Removal

For Alternatives 4N, 5aN, and potentially 5N and 6N, a sheet pile wall has been suggested as a means to dewater submerged areas and/or manage resuspended contaminated sediment. However, there are also risks associated with both installation and removal of the sheet pile itself. The FS suggests that sheet pile would be driven through the existing TCRA Cap. Although this approach allows coverage of the contaminated sediments during construction, it is not recommended because of the difficulties associated with driving sheet pile through the large armor rock, and achieving a tight seal between joints. Instead, it is recommended that a portion of the rock armor be removed from the sheet pile footprint, and the geotextile or geomembrane cut and peeled back to avoid damage or shifting during sheet pile installation. Activities associated with driving the sheet pile will disturb the exposed sediment causing some limited resuspension, considering that the sediment has been consolidated under the armor cap and geotextile. Additionally, the impact should be relatively small due to the small footprint required for the sheet pile.

Additional resuspension and release is likely to occur during removal of the sheet pile allowing recontamination of the cap or release of contaminants off site. The sheet pile will likely be driven through the entire depth of the contaminated sediment to achieve stability. Upon removal, sediment that adheres to the sheet pile will be subject to resuspension in the water column. Sheet pile should be removed carefully to minimize resuspension. The cap in the area from which the sheet pile was removed will need to be restored.

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

Silt Curtain Installation and Removal

The FS recommends a silt curtain be installed for Alternatives 5N and 6N. Installation of silt curtain should not cause significant resuspension of contaminated sediment. As with sheet pile, suspended contaminated sediment and dissolved contaminants that builds up behind the silt curtain is subject to release during curtain removal; however, this quantity would be expected to be quite small considering the exchange of water that will occur at the site. Silt curtains do very little to control releases at the bottom of the water column. Consequently, use of flocculants to promote settling and/or activated carbon to adsorb dissolved contaminants would not provide much benefit immediately prior to silt curtain removal. Silt curtains should be removed by pulling both the top and bottom lines, or by furling the curtain and removing with a boat.

As noted in the TCRA Final Removal Action Completion Report (Anchor QEA 2012), issues were experienced with the use of a turbidity curtain during the TCRA implementation. The turbidity curtain was subject to river currents and tidal fluctuations, and frequently shifted position. Repositioning and management of the curtain was needed on a regular basis. The strain resulted in detachment from the anchors, and tearing of the floating boom from the submerged skirt. It was noted that in some situations, the curtains can cause more resuspension than if the curtain were not there. Despite the problems, the silt curtain was considered effective. Sheet pile barriers such as proposed for Alternatives 4N and 5aN should also be considered.

The location of the proposed silt curtains was not specified. Some distance should be maintained between the silt curtain and the work area to allow for shifting of the curtain due to tidal fluctuation. Silt curtains may also increase turbidity and scour along the bottom due to movement along the bottom as well as increased current velocities underneath the curtain; however, this would not be a concern if the silt curtain were placed over the TCRA cap.

Site Dewatering

Site dewatering is suggested in the FS for Alternatives 4N, maybe 5N, and possibly in the Western Cell for 5aN and 6N. Site dewatering in submerged areas would require isolation with sheet pile (which has been addressed), berms, cofferdam, or removable dams (geotubes). Upland excavation that occurs below the groundwater table may also require dewatering. Dewatering effluent would need to be treated or shipped to a licensed facility.

Perimeter Berm Installation and Removal

To manage water quality during construction, Alternative 5aN includes an earthen berm in shallow water (depths up to approximately 3 feet), extending to an elevation at least 2 feet above mhhw, but limited to a total height of 4 to 5 feet above the existing mudline. In greater water depths, the berm would transition into a sheet pile barrier. It is assumed that the existing TCRA cap would be removed from the berm area prior to berm construction, thus exposing the geotextile or underlying contaminated soils/sediments. Conventional earth-moving equipment would likely be used to construct the berm. Berm construction activities could disturb the underlying sediments, resulting in resuspension. It appears sediments in the berm vicinity have concentrations less than the PCL, yielding limited potential for significant loss of contaminant mass.

Presumably, the containment berm will be removed after excavation and backfilling has been completed within the enclosed area. Care should be taken during removal minimized disturbance of the backfilled area. Alternatively, the berm could be left in place to protect the site from barge strikes under high water conditions.

Removal of Contaminated Soil/Sediment/Sludge

Alternatives 5N, 5aN and 6N involve removal of varying amounts of contaminated sediment. Alternative 5N would remove soil and sediment with concentrations exceeding 13,000 *ng/kg* $TEQ_{DF,M}$ (52,000 cy). Alternative 5aN would remove soil and sediment exceeding the PCL where the water depth is 10 feet or less, and soils exceeding 13,000 *ng/kg* $TEQ_{DF,M}$ at any depth (137,600 cy total). For Alternative 6N, all soil/sediment exceeding the PCL would be removed (200,100 cy). Water-side removal may occur via dredging, although the dredge type is not specified in the FS. The FS also refers to the possibility of dewatering the work area and using land-based earth-moving equipment, particularly in the Western Cell and perhaps shallow portions of the Eastern Cell. Upland excavation would be accomplished with conventional earthwork equipment (excavators, dozers, loaders, etc.). For upland excavation below the groundwater table, ditches, sumps, wellpoint systems or deep wells are discussed in the FS for water management. Dewatering effluent may need to be treated or shipped to a licensed facility (See Site Dewatering).

Land-based removal will involve disturbance of contaminated sediments with earthwork equipment. Risks include equipment tracking contamination off site, transport of disturbed sediment via dust or rainfall runoff, as well as residual contamination that is left in place. Water spraying may need to be employed to control dust, and silt fence or hay bales to prevent transport of runoff particulates. A work plan is needed to sequence excavation in order to minimize cross contamination of clean areas. Periodic equipment cleaning, such as prior to leaving the site may also be used to avoid spreading contamination.

Upon excavation, the material would likely be transported to an area where it is stockpiled prior to dewatering. Areas used to stockpile contaminated materials should also be managed to control dust and runoff, such as covering stockpiled materials, and the use of silt fence barriers. There are also risks associated with spills during transport to the disposal facility and releases from the landfill itself, which are not addressed here. Depending on the results of monitoring, a cleanup pass may be used to remove the top layer of soil with residual contamination.

For dredging activities, management strategies are needed to control resuspension, contaminant release, and residual contamination. Engineered barrier controls (sheet pile and earthen berm for Alternative 5aN, turbidity curtain for Alternatives 5N and 6N) are included in the FS, and would be appropriate for containment of resuspension. Although, the FS assumes a certain degree of leakage of these barriers, careful installment and management will optimize their efficiency.

Controls are needed for contaminated residuals that are left in place. For Alternatives 5N, 5aN and 6N, the FS calls for covering the excavated areas with backfill. Alternative 5N would be further covered with a permanent rock armor cap. Therefore, the dredge cut should be designed to leave a slope no greater than 1V:5H to permit placement of a stable cap or backfill. Monitoring post-dredging should be done to determine the need for controls to manage residuals left in place. A cleanup dredging pass may be useful to remove some of the residuals. A layer of carbon placed prior to backfilling, or blended with the backfill material would protect against contaminant releases from residuals (in both upland and submerged areas). Activated carbon has been shown to sequester dioxins and furans and reduce bioavailability (Chai *et al.* 2012, USEPA 2013). Carbon (or other amendments) may be delivered using engineered amendments such as AquaGate+™, which may both increase cohesion to prevent erosion, as well as adsorb contaminants. MNR is also planned, as natural deposition is predicted to occur. Institutional controls are also planned for long-term management of contaminants left on site.

Permanent Cap Construction

Alternatives 3N, 4N, 5N and 5aN include different variations of construction of a Permanent Cap. Each of the alternatives includes addition of armor rock and rubble mound protection to the existing Armor Cap to flatten the slopes and improve stability. A protective perimeter barrier consisting of a submerged rock berm would also be constructed to protect the cap from vessel traffic. Alternatives 3N and 5aN involve placement of armor rock over top of the existing cap and construction of the rock berm.

For Alternative 3N, there is little risk associated with resuspension of contaminated sediments during Permanent Cap construction, as the existing TCRA cap will be in place and intact. With Alternative 5aN, in the area adjacent to that planned for Permanent Cap construction, the existing cap will have been removed, and contaminated sediment excavated greater than the PCL), and backfilled with 6 inches clean sediment. Assuming the Permanent Cap will be constructed after placement of backfill, care should be taken to avoid disturbing the backfill. It is unclear whether the Permanent Cap area will be inside or outside the sheet pile and berm enclosure used to control resuspension during excavation, but presumably it would be constructed with the sheet pile wall and berm in place to control potential releases during cap placement.

In addition to the rock berm and placement of rock over the existing cap, Alternatives 4N and 5N also include construction of the permanent cap over areas of contaminated sediment where the existing TCRA cap was removed. Replacing cap that was removed is referred to as armored cap restoration and discussed below.

Restoration of Armor Cap

For Alternatives 4N and 5N the existing TCRA cap will be removed in areas to allow S/S (4N) or removal (5N) of material with TEQ > 13,000 *ng/kg*. After S/S or excavation, the Armored Cap will be replaced, which will include replacement of the armor rock layer, geomembrane and geotextile. Geomembrane or geotextile and armor rock should be placed carefully to minimize resuspension. It was noted in the TCRA Final Removal Action Completion Report (Anchor QEA 2012), that site monitoring of turbidity resulting from tugboat and barge movement around the TCRA Site during water-side placement activities showed no exceedances that would trigger additional BMPs. However, resuspension could be greater for Alternative 5N due to the presence of residuals and the loss of sediment strength from recent disturbance induced by the removal operation.

Plans for Alternative 4N include a sheet pile wall which will retain resuspended material. Presumably the sheet pile will remain in place until after the armor cap is restored. Alternative 5N may incorporate use of silt curtain rather than sheet pile walls for containment, which will provide some retention of resuspended solids. For Alternative 4N, the replacement will occur on top of stabilized soil/sediment which should improve cohesion and reduce resuspension. The Western Cell area is primarily upland, whereas the area in the Eastern Cell is submerged, although sheet pile containment is planned, with possible dewatering. Assuming the site is not dewatered, concentrations of resuspended contaminated sediment may have built up during S/S activities. Settlement of the resuspended solids should be allowed (either waiting a period of time, or enhancing settling by flocculant addition) prior to cap placement to avoid contaminating the clean cap. The cap placement should be sequenced so as to minimize equipment contact with the contaminated soils/sediments.

Addition of Residuals Cover/Backfill

Alternatives 5N, 5aN, and 6N would include backfilling the areas that are excavated with 6-inch thick cover. The backfilled areas in Alternative 5N would subsequently be covered with an armored cap. Natural deposition is further expected to cover the site; however, deposition rates are low in most areas, particularly shallow areas. For Alternative 5N, soils/ sediments exceeding 13,000 *ng/kg* $TEQ_{DF,M}$ would be removed prior to backfilling. For Alternatives 5aN and 6N, the soils/sediment exceeding the PCL would be removed, thus backfilling would occur over top relatively clean soil/sediment, with the exception of residuals. Backfill should be place in such a manner as to minimize disturbance of the residuals and underlying material. This includes sequencing the activity such as to minimize equipment tracking between backfilled and exposed areas.

Treatment/Dewatering Excavated Sediment

Landfills have been tentatively identified for disposal of materials from the site. Sediment dewatering by amendment prior to transporting for disposal is suggested for Alternatives 5N, 5aN and 6N in order to reduce potential mobility of contaminants during transportation and at the disposal facility. An off-site facility with water access has been suggested for processing dredged sediment prior to shipment. The facility would need the capacity to stockpile excavated material, treated material, and armor rock, as well as space for treatment. Institutional controls such as fencing and warning signs would also be needed at the off-site facility. Material stockpiles (both untreated and treated) would need to be managed to control runoff using covers for the stockpiles and silt fencing.

Dust controls may also be needed. Requirements for shipping hazardous materials would be followed, including packaging in appropriate containers and proper labeling. The FS notes that water generated from sediment dewatering would need to be treated on-site for discharge, or collected and transported off-site for disposal, depending on water quality.

Summary of BMPs

Several alternatives have been presented in the FS for remediation of the San Jacinto River Waste Pits Superfund Site. BMPs have been examined for the remediation activities planned for each of the alternatives.

1. Alternative 1N (no further action) and Alternative 2N (implementation of MNR and ICs) will not disturb the existing TCRA Armor and would not generate resuspension, residuals or release that would require BMPs outside the planned monitoring and maintenance.

2. Alternative 3N includes addition of armor stone to flatten slopes of the TCRA cap, as well as construction of a submerged perimeter berm to protect the Permanent Cap. As the TCRA cap will remain in place providing protection from the underlying sediments, generation of resuspension or releases is unlikely, and therefore does not require BMPs beyond the planned MNR and ICs.

3. Alternative 4N requires partial removal of the TCRA cap, S/S of the underlying sediments, restoration of the armored cap and implementation of MNR and ICs. The slopes of the remaining cap would be flattened and a perimeter berm installed to protect the Permanent Cap. A number of BMPs are recommended to manage resuspension from Alternative 4N activities. Installation of sheet pile walls is planned. As noted previously, better seals between joints may be achieved if the existing armor cap is removed from the sheet pile footprint prior to installation. The sheet pile should be in place to capture resuspension during removal of the existing TCRA cap, S/S, and restoration of the armored cap. If dewatering is conducted, the effluent may need to be treated or shipped to a licensed facility. Controls such as silt fence are needed to manage runoff from upland areas of the site. Application of water may be needed to control dust. The removed cap material should be handled to avoid spreading contamination or recontaminating the

site. Removed geotextile and geomembrane and contaminated armor stone should be disposed in appropriate containers for transport to landfill. As discussed in the FS, direct loading into trucks for transport to the disposal facility may eliminate the need for stockpiles. Periodic equipment cleaning and decontamination of trucks prior to leaving the site may reduce tracking contaminants off site. A plan to sequence cap removal, S/S and cap restoration activities is needed to minimize equipment tracking between clean and contaminated areas. This may include segmenting the site into subareas. Upon completion of S/S, monitoring should be conducted to determine residual contamination. Residual contamination is addressed to some extent by the planned Permanent Cap, MNR and ICs. Activated carbon may be dispersed in the water column or placed on the stabilized surface prior to capping as needed to further manage resuspension or releases in the water column or surface residuals. Flocculant may also be used to limit releases of resuspended solids during removal of the sheet pile.

4. Alternative 5N requires partial removal of the TCRA cap, and excavation of the underlying sediments, followed by restoration of the armored cap, enhancement of the remaining cap, perimeter berm installation, MNR and ICs. Rather than sheet pile walls, silt curtain is suggested in the FS to manage resuspended material from Alternative 5N activities. As experienced in the TCRA cap construction (Anchor QEA 2012), silt curtains can be problematic and will need to be managed throughout the duration of the construction activities. Sheet pile walls would provide much better control of contaminant releases, residuals and resuspension for these highly contaminated materials. As with Alternative 4N, flocculants or activated carbon may be needed to treat resuspended solids or dissolved contaminants trapped by the sheet pile wall prior to its removal, but would not provide much benefit if a silt curtain were used for resuspension control. For upland activities, runoff controls (silt fence and/or hay bales) and dust control are needed. As used in the TCRA activities, a temporary water control berm may be installed to reduce inundation of the upland area by tidal water. A work plan is needed to determine optimal sequence for working in different areas of the site to minimize cross contamination, as well as decontamination of equipment prior to

exiting the site. Staging the construction, may also reduce the surface area exposed at a given time, reducing the risk of contaminant releases during flood events. Residual contamination may be addressed by the use of a cleanup pass of either the dredge or land-based equipment. Prior to cap restoration, the area will be backfilled prior to removal of the resuspension BMP. If post-excavation monitoring indicates the need for additional residual management, activated carbon could be placed to provide sequestration of contaminants.

5. Alternative 5aN includes more extensive removal of the TCRA cap and excavation of underlying sediments which would be subsequently backfilled. Armor stone would be added to flatten the remaining existing cap slope, and the perimeter berm would be constructed along with MNR and ICs. Alternative 5aN includes the use of a perimeter berm in shallow areas which would transition to sheet pile walls in deeper water. The berm and sheet pile would serve to contain resuspended sediments during construction activities. As with Alternatives 4N and 5N, cross contamination should be minimized through work sequencing and decontamination of equipment. Removed cap material should be properly contained and shipped to a landfill, although clean armor rock may be reused. Other BMPs for upland areas include the use of silt fence to control runoff and water spraying for dust control. Water control berms could also be used to minimize tidal inundation of upland areas. Resuspended solids trapped behind the sheet pile/berm could be managed by allowing it to settle, or by addition of flocculant to promote settling. Similarly, dissolved contaminants could be treated by addition of activated carbon. Activated carbon may also be used to treat residual contamination left on the surface of the excavated area prior to backfill. A cleanup pass may also be useful to remove residual contamination from the surface. A residual cover/backfill should be placed carefully to avoid disturbing the underlying soil/sediment before removal of sheet pile walls or silt curtains. An off-site facility will likely be used to stockpile materials and treat excavated sediment prior to transportation to a landfill. The off-site location will also require dust and runoff controls as well as institutional controls. Water

from dewatering would need to be treated on-site for discharge or collected and transported off-site for disposal.

6. Alternative 6N involves complete removal of the TCRA cap and excavation of all soils and sediments exceeding the PCL, including the area near the Upland Sand Separation Area. The areas would be subsequently backfilled, and ICs and MNR implanted. A permanent cap is not included in this alternative. To manage resuspension, a silt curtain is planned, although sheet pile was mentioned as a possibility. Sheet pile would likely be more effective for controlling resuspension. Resuspended solids trapped behind the silt curtain should be allowed to settle prior to curtain removal. Residual contamination may also be managed by addition of activated carbon to the surface either before backfilling or as a component of the backfill material. The residual cover/backfill should be placed carefully to avoid disturbing the underlying soil/sediment before removal of sheet pile walls or silt curtains. Silt fence is recommended to manage upland runoff, and water spraying for dust control at both the upland portion of the SJRWP site, as well as at the off-site staging area.

Development of New Full Removal Alternative to Minimize Sediment Resuspension and Residuals during Dredging/Removal

Alternative 6N involves complete removal of the TCRA cap and excavation of all soils and sediments exceeding the PCL, including the area near the Upland Sand Separation Area. The areas would be subsequently backfilled, and ICs and MNR employed. A permanent cap is not included in this alternative. To manage resuspension, a silt curtain is planned, although sheet pile was mentioned as a possibility. Sheet pile would likely be more effective for controlling resuspension. Additionally, virtually all releases by resuspension and erosion of residuals could be eliminated by excavation in the dry. Evaluation of a new full removal Alternative 6N* incorporating these BMPs to the extent practicable is presented below and compared with Alternative 6N as proposed in the Feasibility Study.

Description and Implementation of New Full Removal Alternative

The proposed full removal alternative is an enhancement of Alternative 6N using enhanced BMPs to control contaminant releases during and following implementation. The alternative consists of full removal of materials exceeding the PCL. All material above the PCL located beneath the Armored Cap or at depth in an area to the west would be removed to the extent practicable. This would involve removal of approximately 200,000 cy of material as well as the existing Armored Cap within the footprint of the Eastern and Western Cells, inside the original berms, and in the northwestern area. The dredged area would then be covered with a layer of clean fill. Armored cap would be left in place where the sediment contaminant concentration is below the PCL. These areas include the area west of the western berm and north of the Eastern Cell, including a deeper area ranging in elevation from -4 to -10 ft NAV88.

Implementation of the alternative includes the following operations and components and could be performed in stages (one cell or area at a time):

Western and Eastern Cells:

1. Removal of armored cap from the footprint of the berms.

2. Construct or raise berms to desired elevation (e.g., the 10-yr flood stage) to enclose cell and prevent transport of resuspended contaminated sediment. Due to construction limitations, the eastern and northern berm of the Eastern Cell would be built where the surface sediment elevation is no lower than about -3 ft NAV88 and would connect from the northern end of the central berm to the eastern end of the southern berm. Enclosure of only shallow water areas (elevations above about -3 ft NAVD88) with a sheet pile wall and berm will reduce releases nearly as well as enclosing the entire TCRA cap area since the high sediment $TEQ_{DF,M}$ concentrations are nearly all in these shallow areas.

3. Install sheet pile wall within berm to strengthen and seal berm to aid dewatering; enhance berm as needed to accommodate design flood pressure loading on wall; use joint sealants to reduce potential leakage rates; and establish top elevation to provide protection from larger floods (e.g., 25-yr or 50-yr floods). The design elevation should balance the safe

design loading with the design flood stage and wave heights as well as the impacts of overtopping the wall.

4. Armor external side of berm with removed armor cap material to control erosion.

5. Dewater cell to the extent practicable and treat water as needed to control releases.

6. Remove armored cap and geotextile within cell in the dry to the extent practicable.

7. Remove contaminated sediment in the dry to the extent practicable. The removed material will be dewatered or solidified for disposal in an off-site facility. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. Some operations, such as water treatment, could be barge mounted.

8. Cover the dredged surface with two layers of clean fill to limit intermixing of residuals with fill.

9. Remove sheet pile walls. Flatten berm and cut slopes to promote stability.

Northwestern Area:

1. Install silt curtains in deeper waters above the armored cap outside the footprint of the area to be dredged, connecting to existing or newly constructed berms and enclosing the area.

2. Construct berms or install sheet pile wall in shallow water areas to limit the flow through the area and control contaminant releases.

3. Remove armored cap and geotextile in the wet.

4. Remove contaminated sediment in the wet to the target depth. Verify that the contaminated sediment inventory had been removed except for the generated residuals. Remove residuals in a cleanup if practicable. The removed material will be dewatered or solidified for disposal in an off-site facility.

5. Cover the dredged surface with multiple layers of clean fill to limit intermixing of residuals with fill.

6. Remove sheet pile walls. Flatten berm and cut slopes to promote stability. Remove silt curtains.

Resuspension and Residuals Estimates Cell/Area Wide

In order to develop a new full removal alternative, 6N*, the impoundment area was divided into sections developed during the TCRA cap installation. The area was divided into a Western Cell, Eastern Cell and a Northwestern Area with each having different site conditions including contaminant concentrations and permanent cap cover. The recommended approach to achieve complete removal would be by dredging and excavating incrementally and completing activities in such a way that releases are reduced by best management practices such as berm construction and utilizing sheet pile walls.

Western Cell

The Western Cell, which typically sits above the water surface and is temporarily submerged during storm events, is by all accounts a stable surface that has been protected by the installation of a geomembrane, geotextile and rock riprap. The Western Cell is also protected by berms along the east and west sides of the cell. This cell may be excavated in the dry by constructing a berm on the north side of the cell and installing a sheet pile wall through the berms to raise the effective height of the berms and provide protection from storm flows, tidal fluctuations, waves and up to 10-year flood events. Installing the sheet pile walls at the top of the berms would provide more support for the wall, facilitate sealing joints between the sheet piles above the berm, and reduce the potential leakage through the wall and berms since the wall would not be exposed to the water column except during very high flow conditions. Excavation and backfilling in the dry will eliminate potential resuspension and residuals releases.

Eastern Cell

The Eastern Cell is open on the north and east sides with a berm on the western and southern boundaries. This cell was repaired as a part of the original TCRA remediation and has an armored cap in place that consists of both recycled concrete and natural rock with geotextile. To minimize releases it is advised that the Eastern Cell be divided into two sections: shallow water with depths no greater than about 4 ft and deep water that encompasses the northwest section of the Eastern cell and has depths from 10-15 ft. By dividing the cell into two sections, releases can be minimized and incremental releases can be better estimated for the cell. It should also be noted that an area of roughly 2.5 acres of the Eastern cell is not included in this analysis as the sediment concentrations are well below the PCL as stated in the Feasibility Study.

Shallow Water. The shallow water portion of the Eastern Cell is the largest section to be removed, as shown in Table 12-1. The surface area is approximately 5.7 acres and 46,000 c.y. of sediment are to be dredged from the area assuming an average dredge depth of 5 feet. Since this area is located in shallow water, it can easily be confined with a sheet pile wall to reduce the releases from dredging to just the releases to the water column and not the residuals. Sheet pile should be installed along the north and east sides, tying in to the existing berms on the south and west sides of the area as well as the former berm on the east side. If the deep water section of the Eastern Cell were confined with its sheet pile wall prior to dredging the shallow water section of the Eastern Cell, a silt curtain could be substituted for the sheet pile wall along the northern boundary of this shallow water section due to potential construction issues from the soft fill conditions. With the installation of the sheet pile wall, the releases predicted in this section will be the result of the removal of the TCRA cap including geotextile and rock rip rap, suspended material during the installation and removal of the sheet pile wall, and an assumed loss of all material suspended during dredging operations.

Deep Water. The deep water portion of the Eastern Cell is a small section along the northern edge of the cell and connecting to the Northwestern Area. This section has a deeper channel running through it where the depths average 10 feet and are 15 feet in the deepest portion. Smaller than the shallow water area, this section can be dredged with either a turbidity curtain or a sheet pile wall to control the sediment releases while allowing interchange of water to reduce the net force on the controls. Due to its small size of 1.8 acres, the area will be easy to confine with either method.

Table 12-1. Cell and Area Parameters

Parameter	Western Cell	Northwestern Area	East Cell: Shallow Water	East Cell: Deep Water
Surface Area (acres)	4.1	1.7	5.7	1.8
Volume Dredged (cy)	66,700	19,496	46,074	14,222
Average Surface Sediment Concentration (ng/kg)	6471	7799	6048	5127
Weighted Average Contaminant Concentration (ng/kg)	15,806	3095	2394	2023

The existing TCRA permanent cap in this area consists of geotextile and natural stone armoring. Some releases will occur during the removal of the cap, but they will be minimal compared to potential releases from dredging and generated residuals. The sheet pile wall should be installed slightly outside the limits of the section and outside of the deep channel.

This will allow for more stable conditions with the sheet pile wall. The wall should also be designed that it does allow for tidal interchange. The wall should be installed in a U-shape with the deepest portion left open allowing flow into and out of the containment. In combination with the wall, a turbidity curtain should be used to help contain some of the suspended materials. For the purposes of this analysis, it was assumed that the wall completely enclosed the area but through the interchange a worst-case scenario of all resuspended material during dredging activities was lost. It was assumed that the dredging residuals would not be subject to erosion due to the control of bottom currents by the wall. It was further assumed that the any disturbed residual material would settle before the sheet pile wall was removed. Other releases include the minor loss of sediment during the construction and removal of the sheet pile wall.

If only a turbidity curtain were used to confine the area, then releases will be considerably greater due to potential erosion and transport of a portion of the dredging residuals. All resuspended material from TCRA removal and dredging activities will be lost below the turbidity curtain. It was also assumed that 20% of the generated residuals will lost below the turbidity curtain. Analyses of both control methods were completed to provide a comparison of the releases of both methods.

Northwestern Area

The Northwestern Area is a steeply sloped, deep water extension of the Western Cell, which was originally separated by a berm. The area is a relatively small section of 1.7 acres. The TCRA armored cap is composed of varying thicknesses of recycled concrete with a blended granular filter instead of a geotextile. The average depth in this section is 15 feet, which makes it somewhat impractical to confine with a sheet pile wall. To construct a wall or cofferdam that provides protection from flood flows, the sheet piles would have to be driven into the sediment as much as 40 feet. With a sheet pile wall, removal would need to be performed in the wet, but removal could be performed in the dry with a cofferdam. Building a cofferdam to enclose this area could require several years to construct and thousands of truckloads of materials and would be expected to cost about five times as much as a sheet pile wall. The most practical method of controlling resuspended material would be the use of a turbidity curtain. For this analysis, it was assumed that all resuspended material would be lost through the turbidity curtain including releases from the removal of the armoring, dredging activities and 20% of the generated residuals that would be lost through the bottom due to currents. If a sheet pile wall were used, much of the resuspended material would be expected to be released, while none of the generated residuals would be eroded and transported. If a cofferdam were used, only minor releases of sediment during the construction and removal of the cofferdam would occur if removal is performed in the dry.

Sheet Pile Wall

A sheet pile wall is recommended for both portions of the Eastern Cell as a means to control sediment releases during remedial actions; however, both sections of the Eastern Cell will be dredged in the wet and will both experience some releases due to the construction and removal of the sheet pile wall. Incorporation of a berm into sheet pile wall design would provide increased stability for the wall. The berm material could be used as fill or cover material for the site after dredging is completed.

Assumptions

The basic assumptions used in this analysis are the same as used in the resuspension calculations used in Task 11. These assumptions can be found in Table 12-2. It is assumed that the contaminant concentration of the surrounding sediment in the deep water portions will be 1,000 ng/kg while the average surficial concentration will be roughly 6,000 ng/kg in the shallow water sections based on information provided in the Feasibility Study. The sheet pile wall will be required to be driven through the soft clay layer and into the sand layer as suggested in Task 11. The sheet pile wall in both sections of the Eastern Cell will be constructed outside of the limits of the deep water and in water with an average depth of no more than 5 ft, allowing for a more stable wall. Tidal water exchange is also allowed to preserve stability. Sediment properties and sheet pile wall properties were assumed to be the same as those listed in Task 11 in Table 11-1.

Equations

The methods used for determining the resuspended sediments can be found in Table 12-2 and are the recommended methods presented in *Resuspension Factor Approach for Estimating Dredging-related Sediment Resuspension* (Hayes *et al.*, 2007) and referenced in the *Technical Guidelines for Environmental Dredging of Contaminated Sediments* (Palermo *et al.*, 2008).

Results

The results from the sheet pile wall releases analysis can be found in Table 12-3. The results present both a mass of suspended solids and contaminant lost as well as a daily loss rate. The releases for the shallow water are considerably more due to the larger amount of sheet pile being installed and removed as well as the fact that the sheet pile wall is running through the highest surface contaminant concentrations along the northern boundary of the shallow water area.

Table 12-2. Equations Used for Resuspension Calculations during Sheet Pile Construction and Removal

Parameter	Equation
Mass Disturbed (kg)	$m = t * A * \rho_t$
Contaminant Release @ Assumed Sediment Conc. (ng)	$m_{cr} = m * c$
Volume of Sediment to Stick to Both Sides of Sheet Pile (ft^3 sediment / ft^2 wall)	$Vs = \Delta s * Aw * 2$
Mass of Sediment / ft^2 of Wall (kg/ft^2 wall)	$m_w = Vs * \rho_b$
Mass (kg)	$m_r = m_w * L_w * D_s$
Contaminant Release (ng)	$m_{cr} = m_r * c$

TCRA Cap Removal

The process of removing the TCRA is completed by first removing the rock riprap and then removing the geotextile. This process results in some amount of material disturbed and material sticking to the surface of the geotextile and washed as it pulled through the water column. The amount of resuspended sediment was estimated for all three areas. The shallow water area could be removed in the dry once the sheet pile wall is installed, but for the purposes of this analysis was included as a worst case.

Assumptions

As previously stated in Task 11, the process of removing the geotextile from the surface will act similar to that of a bucket dredge with sediment stuck to the fabric that will wash off as it is pulled through the water column. Assumptions for the removal of the TCRA cap can be found in Table 12-4. The surface area of each section was estimated and the sediment characteristics were assumed to be the same as assumed during the sheet pile wall construction and removal. Sediment was assumed to be slightly to moderately sticky with an adjusted thickness of 3.375 mm adhering to the geotextile. An average surface concentration was estimated

Table 12-3. Resuspended Sediments During Sheet Pile Construction and Removal in Eastern Cell

Parameter	Construction		Removal	
	Shallow Water	Deep Water	Shallow Water	Deep Water
Mass Disturbed (kg)	2470	1810	5450	4000
Solids Loss Rate (kg/day)	33	33	73	73
Contaminant Release @ assumed Sed. Conc. (mg)	14.8	1.81	32.7	4.00
Rate of Contaminant Release (mg/day)	0.198	0.033	0.436	0.073

for each area incrementally based on information provided in the Feasibility Study. It was also assumed that during removal 50% of the sediment would wash from the geotextile and all sediment suspended would be lost.

Equations

The methods used for determining the resuspended sediments can be found in Table 12-5 and are the recommended methods presented in *Resuspension Factor Approach for Estimating Dredging-related Sediment Resuspension* (Hayes *et al.*, 2007) and referenced in *Technical Guidelines for Environmental Dredging of Contaminated Sediments* (Palermo *et al.*, 2008). These methods are the same as were used to determine resuspended sediments during sheet pile wall construction and removal.

Results

Results from the incremental analysis of sediment resuspended during the TCRA cap removal can be found in Table 12-6. The average surface sediment concentration was estimated using data provided in the Feasibility Study and was averaged across the footprint for each alternative. The largest quantity of sediment and contaminant to be lost comes from the shallow water portion of the Eastern Cell which also has the largest surface area to be disturbed. Combined, it is estimated that 31 metric tons of sediment will be resuspended during the removal process and only 0.2 grams of contaminant will be released during this process.

Table 12-4. TCRA Cap Removal Assumptions

Parameter	Value	Parameter	Value
NW Area (acres)	1.7	**Characteristic sediment thickness Δs_c (mm)**	4.5
East Cell: Shallow Water (acres)	5.7	**Adjusted sediment thickness Δs (mm)**	3.375
East Cell: Deep Water (acres)	1.8	**Sediment resuspended during ascent through water column (%)**	50
Sediment Stickiness	Slightly --> Moderate	**Surface Soil Density (kg/m^3)**	500

Table 12-5. Equations Used to Estimate Sediment Resuspension During Geotextile Removal

Geotextile Removal Equations	
Mass Resuspended (kg)	$m_r = \Delta s * A * \rho * \%R$
Contaminant Release (ng)	$m_{cr} = m_r * C$

Dredging

Dredging can be an effective way to remove large quantities of sediments, but this method can lead to exposure, releases and lasting effects if proper planning is not completed and best management practices are not used. Dredging is being considered for all areas, but releases should only be expected when removal is completed in the wet as in the Northwestern Area and the Eastern Cell. Excavation of the Western Cell will be performed in the dry and will have no releases during the removal process.

Table 12-6. Incremental Analysis of Sediment Resuspended During Geotextile Removal

Parameter	NW Area	Eastern Cell: Shallow Water	Eastern Cell: Deep Water
Area Disturbed (m^2)	6,880	23,067	7,284
Average Surface Sediment Concentration (ng/kg)	7,799	6,048	5,127
Sediment Mass Resuspended (metric tons)	6	19	6
Contaminant Mass Resuspended (g)	0.045	0.118	0.032

Assumptions

Many of the assumptions stated in Task 11 for dredging resuspension are applicable to the analysis of the Northwestern Area and Eastern Cell. A mechanical clamshell dredge is recommended as the best method of material removal for areas to be dredged in the wet, while an excavator is recommended to be used in a land side operation or shallow water. The Northwestern Area is assumed to utilize a turbidity curtain as a means of controlling releases while the deep water section of the Eastern Cell is analyzed with both the use of a turbidity curtain and a sheet pile wall to illustrate the effectiveness of the alternative BMPs and present the best method of removal.

For this analysis, the clamshell bucket was assumed to fit the description of the characteristic clamshell bucket as described in Hayes *et al.* (2007) and the resuspension factor method was used to determine the possible resuspension for the site conditions. Sediment was assumed to be slightly to moderately sticky with an average thickness of 4.5 mm stuck to the bucket. The assumption of an average dredge depth of 10 feet plus a 1 foot over-dredge is applied in this analysis; however, the average water depth is assumed to be 15 feet in both sections. All assumptions made in the determination of the Resuspension Factor can be found in Table 12-7.
A weighted average sediment concentration was calculated based on the results of the grab samples and sediment cores as presented in the Feasibility Study Figure 2-4. The sediment concentrations for each area

were averaged across the area specific footprint. Assumptions for the weighted average sediment concentration and dredge area can be found in Table 12-8.

Equations

Methods used to determine the resuspension factor and the resuspended sediment mass were completed using techniques described in Hayes *et al.* (2007) for the determination of the resuspension factor based on characteristic properties. The equations and constants used to determine the resuspension factor can be found in Table 12-9 and the equations used to determine the sediment and contaminant mass resuspended can be found in Table 12-10.

Results

The determination of the Resuspension Factor for each scenario can be found in Table 12-11. While it may be possible to excavate the shallow water section of the Eastern Cell in the dry if a berm were constructed, the estimated resuspension was calculated for dredging in the wet for comparison. The parameters used in this method were determined by making assumptions on dredging characteristics as described above. With each area having a different average water depth, they each have a slightly different Resuspension Factor. The Northwest Area has the greatest factor of 0.84 percent since it has the deepest water.

An estimation of the resuspension possible during mechanical dredging can be found in Table 12-12. An incremental analysis of each respective footprint was used to estimate the potential resuspension of fine sediments for the dredging activities of each of the areas. The total mass of sediment removed was calculated assuming an average density throughout the sediment of 950 kg/m^3. As the method of determining mass rate of sediment release accounts for only the fine sediments (f_{74}), as seen in Table 12-10, the bulk sediment concentration was adjusted to reflect the fine sediments that are resuspended during dredging activities. The bulk sediment concentration was estimated incrementally based on sediment core data provided in the Feasibility Study and was then adjusted based on the volume of fines in the sediment.

Table 12-7. Dredging Resuspension Assumptions

Property	Value	Property	Value
Bucket Volume, Vb (m^3)	7.65	**Characteristic Descent Velocity, Ǔd (m/s)**	1.2
Equivalent Diameter (m)	2.45	**Descent Velocity, Ud (m/s)**	1
Equivalent Surface Area (m^2)	7.24	**Characteristic Pre-dredge Water Depth, hc (m)**	8.3
Average Dredge Depth (ft)	NW Area: 6	**Pre-dredge Water Depth, h (m)**	NW Area: 4.5
	Eastern Cell: 4		Eastern Cell Deep: 3
Sediment Removal Thickness (m)	1.2		Eastern Cell Shallow: 1.5
Over dredging Depth (ft)	1	**Characteristic Ascent Velocity, Ǔa (m/s)**	1.6
fsed	2	**Ascent Velocity, Ua (m/s)**	1.2
Characteristic Sediment Thickness Δs_c (mm)	4.5	**f74 (%)**	NW Area: 60
Adjusted Sediment Thickness Δs (mm)	3.375		Eastern Cell: 75
In Situ Solids Concentration, Cs (kg/m^3)	950	**Dredge Rate , Ṽs (m^3/hr)**	25.5

Table 12-8. Mechanical Dredging Incremental Analysis Assumptions

Parameter	Northwestern Area	Eastern Cell: Deep Water	Eastern Cell: Shallow Water
Volume Dredged (c.y.)	19,496	14,222	46,074
Total Dry Sediment mass Dredged assuming 950 kg/m^3 (kg)	1.42E+07	1.03E+07	3.35E+07
Dry Mass of Fine Sediments (kg)	8.50E+06	7.75E+06	2.51E+07
Days Required	24	18	58
Average Bulk Sediment Concentration (ng/kg)	3,095	2,023	2,394

Table 12-9. Dredging Resuspension Equations

Parameter	Equation	Parameter	Equation
Characteristic Resuspension Factor, Rc (%)	$Rc = r_1+r_2+r_3+r_4$	**Resuspension Factor, R'c (%)**	$R'c = r'_1+r'_2+r'_3+r'_4$
r'_1	$r'_1 = faa*fdv*ftd*fsed*r_1$	**r'_3**	$r'_3 = [(fla*wla+fbw*wbw+fea*web)*fta+fsw*wsw]*fsed*r_3$
faa	faa = 1.025*(π/Vb)^(1/3)	**fbw**	fbw = 1.35*(π/Vb)^(1/3)
fdv	fdv = (Ud/Ǔd)^2	**fsw**	fsw = (Ua/Ǔa)^2
ftd	ftd = (h*Ǔd)/(hc*Ud)	**fta**	fta = (h*Ǔa)/(hc*Ua)
r'_2	$r'_2 = fbv*fec*fsed*r_2$	**r'_4**	$r'_4 = fso*fsed*r_4$
fbv	fbv = (Ud/Ǔd)^2		

Table 12-10. Sediment Loss Equations

Parameter	Equation
Mass rate of sediment release, g, (g/s)	**$g = Rc*(f_{74}/100)*((\tilde{V}s*Cs)/360)$**
Mass of sediment released, m (kg)	**m = g(kg/day) * days required**

Residuals

Residuals are the result of sediment that falls back or is dislodged, sloughed or left during dredging activities. Many different factors affect the amount of residuals and there is currently no commonly accepted method to accurately predict the post-dredging residuals. Palermo *et al*. (2008) recommends in the *Technical Guidelines for Environmental Dredging of Contaminated Sediments* to assume that the residual contaminant concentration be equal to the depth-averaged contaminant concentration of the sediment removed in the last pass, which would include residuals from the previous pass. This method is further detailed in Palermo *et al*. (2008) and was used in this analysis as was used in the residuals analysis in Task 11.

Assumptions

All forms of dredging result in some amount of residuals, typically averaging between 5 and 9% lost for strongly hydrophobic contaminants (Patmont, 2006) with this percent varying based on type of equipment, sediment characteristics, and number of dredge lifts. A worst-case scenario of 9% residuals was selected due to the soft materials and tendency for mechanical clamshell dredges to lose more sediment creating more residuals. The dredge plan was also assumed based on the weighted average contaminant concentration in the respective area. For the Northwestern Area the sediment profile was determined to only require an average dredge depth of 6 feet plus a 1 foot of overdredging, which would adequately remove sediments to the cleanup level. For the deep water section of the Eastern Cell, only an average dredge depth of 4 feet plus 1 foot of overdredging is needed. It was assumed that the residuals layer would be less dense than the underlying material and would have a density of 500 kg/m^3. All assumptions can be found in Table 12-13 and a suggested dredge plan found in Table 12-14.

Table 12-11. Resuspension Factor for Clamshell Bucket

Characteristic Resuspension Factor, R (%)	Northwestern Area	Deep Water Eastern Cell	Shallow Water Eastern Cell
Loss during descent , r1	0.01	0.01	0.01
Loss during bucket impact, r2	0.09	0.09	0.09
Loss during ascent , r3	0.15	0.15	0.15
Loss during slewing , r4	0.25	0.25	0.25
r'1 = faa*fdv*ftd*fsed*r1			
faa	0.753	0.753	0.753
fdv	0.694	0.694	0.694
ftd	0.661	0.441	0.220
r'1	0.007	0.005	0.002
r'2 = fbv*fec*fsed*r2			
fbv	0.694	0.694	0.694
fec	1	1	1
r'2	0.125	0.125	0.125
r'3 = [(fla*wla+fbw*wbw+fea*web)*fta+fsw*wsw]*fsed*r3			
wla	0.2	0.2	0.2
fla	1	1	1
wbw	0.05	0.05	0.05
fbw	1	1	1
web	0.65	0.65	0.65
fea (assume)	1	1	1
wsw	0.1	0.1	0.1
fsw	0.563	0.563	0.563
fta	0.734	0.490	0.245
r'3	0.215	0.149	0.083
r'4 = fso*fsed*r4			
fso (assume)	1	1	1
r'4	0.5	0.5	0.5
Rc	0.847	0.779	0.710

Table 12-12. Incremental Analysis of Total Resuspended Sediments during Mechanical Dredging

Parameter	Northwestern Area	Eastern Cell: Shallow Water	Eastern Cell: Deep Water
Volume Dredged (c.y.)	19,496	46,074	14,222
Total Dry Sediment Mass Dredged assuming 950 kg/m^3	14,160	33,465	10,330
Dry Mass of Fine Sediments Dredged (metric tons)	8,496	25,098	7,747
Days Required	24	58	18
Average Bulk Sediment Concentration (ng/kg)	3,095	2,394	2,023
Fine Sediment Concentration (ng/kg)	5,158	3,192	2,697
Fine Sediment Release Rate (kg/day)	2,953	3,095	3,394
Dry Mass of Fine Sediments Resuspended (metric tons)	72	178	60
Contaminant Mass Resuspended (mg)	371	569	163
Contaminant Release Rate (mg/day)	15	9.9	9.2

Table 12-13. Assumptions Made for Residuals Estimate

Parameter	Value
Assessment	Worst-case Scenario for Potential Residuals
Residuals Left (%)	9
Assumed Residuals Density, ρ (kg/m^3)	500

Equations

The following method used to determine the residuals was presented in Palermo *et al*. (2008) and is broken down by each dredge layer as shown in Table 12-15. The resultant is the determination of the mass, contaminant concentration and thickness of residuals layer.

Table 12-14. Recommended Dredge Plan for NW Area and Eastern Cell

Lift	Cut, D (ft.)	Density, ρ (kg/m³)	Average Concentration, C (ng/kg)
Northwestern Area			
1	0.2	500	7,799
	1.8	950	7,799
2	2	950	2,661
3	2	950	517
	1	950	159
Eastern Cell: Shallow Water			
1	0.2	500	6,049
	1.8	950	6,049
2	2	950	85
	1	950	51
Eastern Cell: Deep Water			
1	0.2	500	5127
	1.8	950	5127
2	2	950	34
	1	950	86

Results

The potential residuals were determined using methods presented in the USACE Technical Guidelines for *Environmental Dredging of Contaminated Sediments* (2008). The results of this analysis can be found in Tables 12-16, 12-17, and 12-18. Table 12-16 presents a step-by-step analysis of each area footprint resulting in sediment mass and contaminant mass per surface area as well as a final residual concentration and residual layer thickness. Using these results, as well as the estimated surface areas of each section, the sediment and contaminant mass could be determined as seen in Table 12-17. This table presents the total potential residuals that are generated during mechanical dredging for each section. Based on data provided in the Feasibility Study, dredging completed in the Eastern Cell would not be as deep as in the Northwestern Area and therefore would only require two dredging passes including the over dredging to ensure that all contaminated material was removed. The Northwestern Area, which is located with deep water and higher sediment concentration, will result in a higher residual concentration.

Table 12-15. Method of Residuals Estimation

1st Production Pass - Composite	
Mass, M_{1c} (kg-ft/m³)	$M_{1c} = (D_{1S} * \rho_{1S}) + (D_{1B}$ *
Contaminant Mass, CM_1 (ng-ft/m³)	$CM_1 = C_1 * M_1$
1st Production Pass – Residuals Layer	
M_{1R} (kg-ft/m³)	$M_{1R} = \%R * M_1$
CM_{1R} (ng-ft/m³)	$CM_{1R} = \%R * CM_1$
Residual Contaminant Concentration, CC_{1R} (ng/kg)	$CC_{1R} = CM_{1R}/M_{1R}$
2nd Production Pass - Sediment	
M_2 (kg-ft/m³)	$M_2 = D_2 * \rho_2$
CM_2 (ng-ft/m³)	$CM_2 = C_2 * M_2$
2nd Production Pass - Composite	
M_{2c} (kg-ft/m³)	$M_{2c} = M_2 + M_{1R}$
CM_{2c} (ng-ft/m³)	$CM_{2c} = CM_2 + CM_{1R}$
2nd Production Pass - Residuals	
M_{2R} (kg-ft/m³)	$M_{2R} = \%R * M_{2c}$
CM_{2R} (ng-ft/m³)	$CM_{2R} = \%R * C_{2c}$
CC_{2R} (ng/kg)	$CC_{2R} = CM_{2R}/M_{2R}$
Final Production Pass - Sediment	
M_F (kg-ft/m³)	$M_F = D_F * P_F$
CM_F (ng-ft/m³)	$CM_F = C_F * M_F$
Final Production Pass - Over Dredging	
M_{OD} (kg-ft/m³)	$M_{OD} = D_{OD} * \rho_{OD}$
CM_{OD} (ng-ft/m³)	$CM_{OD} = C_{OD} * M_{OD}$
Final Production Pass - Composite	
M_{Fc} (kg-ft/m³)	$M_{Fc} = M_{2R} + M_F + M_{OD}$
CM_{Fc} (ng-ft/m³)	$CM_{Fc} = CM_{2R} + CM_F$ +
Final Production Pass - Residuals	
M_{FR} (kg-ft/m³)	$M_{FR} = \%R * M_{Fc}$
CM_{FR} (ng-ft/m³)	$CM_{FR} = \%R * C_{Fc}$
CC_{FR} (ng/kg)	$CC_{FR} = CM_{FR}/M_{FR}$
Residual Thickness, T_R (ft)	$T_R = M_{FR}/\rho_R$

Table 12-16. Incremental Analysis of Potential Residuals

Parameter	Northwestern Area	Eastern Cell: Shallow Water	Eastern Cell: Deep Water
1st Production Pass -Top Layer			
Residual Mass, M_{1T} (kg-ft/m^3)	100	100	100
Residual Contaminant Mass, CM_{1T}	7.80E+05	6.05E+05	5.13E+05
1st Production Pass - Underlying Layer			
M_{1U} (kg-ft/m^3)	1,710	1,710	1,710
CM_{1U} (ng-ft/m^3)	1.33E+07	1.03E+07	8.77E+06
1st Production Pass - Composite			
M_{1C} (kg-ft/m^3)	1,810	1,810	1,810
CM_{1C} (ng-ft/m^3)	1.41E+07	1.09E+07	9.28E+06
1st Production Pass - Residuals Layer			
M_{1R} (kg-ft/m^3)	162	162	162
CM_{1R} (ng-ft/m^3)	1.27E+06	9.85E+05	8.35E+05
Residual Contaminant Concentration, CC_{1R}	7,799	6,049	5,127
2nd Production Pass - Sediment			
M_2 (kg-ft/m^3)	1,900		
CM_2 (ng-ft/m^3)	5.06E+06		
2nd Production Pass - Composite			
M_{2c} (kg-ft/m^3)	2,063		
CM_{2c} (ng-f./m^3)	6.33E+06		
2nd Production Pass -Residuals			
M_{2R} (kg-ft/m^3)	186		
CM_{2R} (ng-ft/m^3)	569,359		
CC_{2R} (ng/kg)	3,067		
Final Production Pass - Sediment			
M_F (kg-ft/m^3)	1,900	1,900	1,900
CM_F (ng-ft/m^3)	9.82E+05	1.61E+05	6.47E+04
Final Production Pass – Over Dredging			
M_{OD} (kg-ft/m^3)	950	950	950
CM_{OD} (ng-ft/m^3)	1.51E+05	4.87E+04	8.19E+04
Final Production Pass - Composite			
M_{Fc} (kg-ft/m^3)	3,036	3,013	3,013
CM_{Fc} (ng-ft/m^3)	1.70E+06	1.20E+06	1.52E+05
Final Production Pass -Residuals			
M_{FR} (kg-ft/m^3)	273	271	271
CM_{FR} (ng-ft/m^3)	1.53E+05	1.08E+05	1.37E+04
CC_{FR} (ng/kg)	561	397	50
Residual Thickness, T_R (ft)	0.546	0.542	0.542

Table 12-17. Incremental Analysis of Residuals

Parameter	Northwestern Area	Eastern Cell: Shallow Water	Eastern Cell: Deep Water
Sediment Residual Mass (metric tons)	573	1,907	602
Contaminant Residual Mass (mg)	321	756	30
Contaminant Concentration (ng/kg)	561	397	50

Table 12-18 presents the estimated amount of residuals lost with the use of a turbidity curtain. It was assumed that the Shallow Water section of the Eastern Cell would not have a loss of residuals due to the sheet pile wall, but is included in this analysis for a comparison of best management practices. It is assumed that based on prior knowledge that roughly 20% of the fine-grained remaining residuals would be lost below the turbidity curtain due to currents.

Table 12-18. Potential Incremental Releases from Erosion of Residuals with Silt Curtain during Dredging

Parameter	Northwestern Area	Eastern Cell: Shallow Water	Eastern Cell: Deep Water
Sediment Residual Mass (metric tons)	261	611	193
Contaminant Residual Mass (mg)	836	1,537	377
Contaminant Concentration (ng/kg)	3,205	2,518	1,956

Conclusions

This assessment on a sectional basis shows that there is sediment loss, but if completed using best management practices then releases can be considerably lessened. It is recommended that whenever possible, activities should be completed in the dry such as the shallow water portion of the Eastern Cell. By constructing a berm and sheet pile wall structure, the area can be completely dewatered and all activities can be completed in the dry. Releases in the deep water section of the Eastern Cell can be greatly minimized if a sheet pile wall is utilized and does not allow residual releases. There will also be limited exposure to the water before the permanent cap is placed over the residual layers if a sheet pile wall is used. If the conditions do not allow for the use of a sheet pile wall and only a turbidity curtain may be used, then releases are increased significantly as shown in the summary Table 12-19. These areas where a silt curtain is used will have greater releases and long term effects.

A summary of the sectional releases and the total releases can be found in Table 12-19. This table shows the comparison of the total mass of sediment and contaminants removed by dredging to the total mass of sediments and contaminants lost with the two methods of containment. The mass of sediment removed by dredging was calculated by assuming an average sediment density of 950 kg/m^3 and by using the averaged sediment contaminant concentrations.

This assessment presents the possible outcomes of the new full removal Alternative 6N* on a section and area basis with very specific assumptions and site conditions with the enhanced containment BMPs that could decreases the releases from about 3.3% of the contaminant mass based on dredging in the wet using silt curtains as the BMP in all areas to about 0.4% by a combination of excavation of shallow water areas in the dry, dredging deep water areas in the wet within a sheet pile and berm containment, or within a silt curtain enclosure. Nearly 89% of the contaminant mass is located in shallow water areas. If these shallow water areas are excavated in the dry as opposed to dredging in the wet as proposed in Alternative 6N, the predicted releases would be reduced by 88% as compared to Alternative 6N using silt curtains as the BMP or by 50% as compared to Alternative 6N using sheet pile walls as the BMP based on the predictions presented in Tables 11-21 and 12-19. The actual sediment releases and residuals will vary depending on the actual circumstances of remedial activity. Over 80% of the reduction in releases comes from excavating the Western Cell in the dry. Use of sheet pile walls that would be difficult to construct in deep water areas instead of silt curtains would provide only an additional 8% reduction of the overall releases predicted for Alternative 6N using silt curtains as the BMP as compared to an 88% reduction provided by excavation of shallow water areas in the dry.

Additionally, if sheet pile walls are used in the Northwestern Area while dredging in the wet and allowing water levels to equilibrate inside and outside the wall, then the predicted short-term contaminant releases are predicted to decrease by 0.14% of the contaminant removed. The minimum predicted short-term contaminant releases are 0.20% if shallow water areas are removed in the dry and deep water areas are enclosed in sheet pile walls while dredged in the wet. If sediments from the entire site are removed in the dry, the contaminants releases would be limited to releases from construction of the containment structures and fugitive dust losses which would amount to about 0.1% of the contaminants removed.

Table 12-19. Summary of Short-Term Sediment and Contaminant Release Estimates

Areas	BMP	Total mass of dry solids removed (metric tons)	Total mass of dry solids released (metric tons)	Sediment released (%)	Total mass of contaminant removed (g)	Total mass of contaminant released (g)	Percentage of contaminant released (%)
Northwestern Area[1, 2]	Silt Curtain	14,200	340	2.39	44	1.25	2.86
Western Cell	Sheet Pile Wall (Dry)	87,000	50	0.06	440	0.43	0.10
Eastern Cell: Shallow Water	Sheet Pile Wall (Dry)	33,500	19	0.06	80	0.12	0.15
Eastern Cell: Deep Water	Silt Curtain	10,300	260	2.51	21	0.57	2.73
	Sheet Pile Wall (Wet)		72	0.70		0.20	0.96
Total	Silt Curtains in Deep Water	145,000	670	0.46	590	2.37	0.40
	Sheet Pile Walls throughout Eastern Cell [3]		480	0.33		2.0	0.34[3]

1 If a sheet pile wall were able to be constructed and removal were performed in the wet, the releases would be reduced by about 65%.

2 If a cofferdam were able to be constructed and removal were performed in the dry, the releases would be reduced by about 95%.

3 If a sheet pile wall were used in all deep water areas and removal were performed in the wet, the total releases would be reduced by about 40% to an overall contaminant release rate of 0.2%.

Task 13

Statement

Assess the validity of statements made in the Feasibility Study that remedial alternative 4N with removal, solidification, and placing wastes again beneath the TCRA cap has great uncertainty as to implementation and that such management of the waste will result in significant releases.

Methodology

The feasibility of the solidification alternative will be reviewed for reliability, implementability, and constructability as well as short-term effectiveness.

Solidification

Western Cell

The Western Cell of the area north of I-10 has had action taken in it to deal with the contaminated soil in the short term. A portion of the Western Cell used solidification/stabilization in the top 3 feet of the soil. Once the S/S was complete a geomembrane and geotextiles were used to cover the area and armor rock was then placed on top.

The FS states that for the Western Cell, the maximum depth of S/S would be approximately 10-feet below the current base of the armored cap. Since a portion of the area to be solidified already has a 3-foot layer of solidified material with a geomembrane and geotextiles on top and covered with armor rock, the need for solidification to a depth of 10 feet below the armor cap in that area is questionable. If groundwater were migrating into the material below the solidified cap and moving material from underneath the cap, then solidification would be necessary; however, there is not a regional or local groundwater gradient to drive groundwater flow through the waste fill. Since dioxins have low water solubility and mainly bind to soil particles, there is no need to disturb the area for deeper mixing of S/S reagents.

The removal of the armor cap, geomembrane and geotextiles could cause problems with allowing contaminated material to be exposed to atmospheric variables that could cause the material to move. However,

this would be unlikely in the portion of the area that has already had the upper 3 feet solidified, which should be a stable mass of material.
The FS states that the geomembrane would be removed and disposed of as contaminated debris and the armor rock cap would be removed and washed for reuse or disposed in an upland facility. Once the materials are removed then either excavators or augers would be used for the S/S of the material. The use of augers in this situation would be a tedious task that would take a long time to accomplish. The use of excavators would be a more preferred method that would be quicker to accomplish the S/S of the material. The use of excavators would create problems by generating dust that could carry contaminants off the site. It is suggested that water be sprayed on the area during the process to reduce the generation of dust at the site.

Since the surficial material in the Western Cell is not submerged, there are many ways where S/S could be applied. The main problem is the presence of the geomembrane and the armor cap. It is a labor intensive effort to remove these materials so that S/S can be applied to the area for the treatment. It would probably prove best to remove smaller sections at a time rather than remove the entire armor cap and geomembrane at one time. With smaller sections removed, such as 0.25 acres, the material could be excavated to the desired depth and then placed back in lifts that are sufficient for mixing, 12 to 16 inches. Once the material is placed back, the recommended amount of Portland cement could be added to the material along with water; standard equipment such as tractors and discs could be used to mix the materials. After mixing the materials, the mixture would be compacted and the next layer would be added and the process repeated until the area has been refilled. Performing the cap removal and solidification in small sections would greatly reduce the sediment exposure and risk of releases from overtopping events.

The FS estimates that 0.85% of the solidified material will be lost during removal and treatment, although presumably only for the area to be excavated in the wet located in the Eastern Cell or Northwestern Area. This loss value is appropriate for solidification in the wet when water exchange is allowed to equalize the water level inside and outside the sheet pile wall. However, this value would be inappropriate for removal in the dry; very little loss should occur when solidifying in the dry. The releases for the Western Cell for excavation and solidification in the dry are unclear in the FS.

The FS expresses concern with the risks of storm and floods overtopping the Western Cell from as small as a 3-yr event. If this is the case, the sheet pile wall should be placed within the existing berm of the Western Cell, on the outer edge of the crest, which is generally dry. The joints could be sealed in the dry to below the TCRA cap, greatly reducing the potential for leakage. The top of the wall could also be placed several feet higher (at least 9 ft NAVD88) since the wall would be supported to an elevation of at least 4 ft NAVD88. This will greatly reduce the risk of overtopping in the Western Cell. Additionally, the removed armor stone could be used to support the wall. Consequently, the short-term effectiveness of Alternative 4N is significantly under predicted, unless releases are predicted only from solidification operations in the wet.

The FS also predicts an elevated contaminant concentration in the cap placed after solidification based on the perceived potential for mixing during cap placement (apparently in the wet). The FS assumes the contaminant concentration in the armor cap will equal 5% of the contaminated sediment concentration. The FS is not clear as to how this is applied in the F&T modeling. If cap placement is performed in the dry, there is little potential for mixing. This is particularly true for the existing cap design that calls for a geotextile, geomembrane, a second geotextile and armor stone. Examination of the existing TCRA cap did not find any mixing of the contaminated sediment with the armor cap. Therefore, the estimated surface cap contamination concentration is too high even in the wet. If residuals are present after solidification, a thin sand bedding layer could be placed prior to placing the armored cap and geosynthetics to secure the residuals from contaminating the armor cap. Consequently, the long-term effectiveness of Alternative 4N is significantly under predicted and should be comparable to Alternative 3N.

Eastern Cell

The Eastern Cell located north of I-10 is submerged and has water depths of up to 10 feet. The FS proposes to install a sheet pile wall around the Eastern Cell in order to isolate the area from adjacent water. In order for the sheet pile wall to be effective, the armored cap and geotextile would first have to be removed where the wall is to be constructed. This would be approximately a 10-foot-wide section of armored cap and geotextile. By doing this, the sheet pile wall could be constructed so that the area could be sealed off from adjacent waters. If the armored cap and geotextile are not removed, then there is no way to seal the sheet pile wall. Also, the sheet pile could not be driven through the armored cap and problems would arise with pushing the geotextile into the sediments.

Sheet pile walls are not structurally sound for 10 feet of pressure head. Reinforcements would have to be used to stabilize the wall so that the water pressure exerted on the outside of the wall would not cause failure of the wall. Another method that would work better would be the use of caissons but this would cause the cost to increase. The use of a wall to separate the treatment area from adjacent waters is a good thought but at these depths it is not feasible to do this in order to dewater the area. Even if dewatering could be done, the removal of the armored cap and geotextile would be a challenge and the mixing and setting of the material with Portland cement would be a long process.

For the *in situ* treatment of sediments other means could be applied in order to stabilize the sediments. Hollow stem augers have been demonstrated as one technique to stabilize contaminated sediments *in situ*. This system uses three augers, 3-foot in diameter, to drive into the sediment. The middle auger turns opposite of the other 2 augers to aid in the mixing of the sediment. Slurried Portland cement, or other pozzolanic reagents, is pumped into the augers both while they are going down in the sediments and while being withdrawn from the sediments to ensure complete mixing. The armored cap and geotextile would have to be removed in order for the augers to work and this would cause disturbance of the sediments beneath the geotextile. The sheet pile wall could still be installed in order to prevent loss of sediment resuspended during the removal of the cap and geotextile and during the mixing of the sediments with the Portland cement.

Any type of treatment for the stabilization of the sediments below the geotextile will disturb the sediment and will cause some resuspension of the material in the water column. A major factor that will suspend sediment will be the removal of the geotextile and the overlying armored cap, particularly if removed jointly. It is highly unlikely that the armored cap could be removed in a separate process without severely disturbing the sediment surface unless performed by divers, which would be very time-consuming and expensive.

Since the contaminants of concern are not extremely water soluble, the contaminants will be bound on the sediment. If the sediment is isolated and undisturbed, then the contaminants should not move in the system appreciably. The average current speed at the site is generally between 0.1 and 0.2 ft/sec for a tidal cycle; peak current speeds during a tidal cycle are generally less than 0.4 ft/sec. These currents would not erode the sediments if appropriate BMPs are used. Peak flooding event currents produce velocities in excess of 1 m/sec, which would be sufficient to erode sediment disturbed from cap/geotextile removal and solidification operations prior to amendment addition and compaction. Following solidification and armored capping, the solidified sediment should be sufficiently protected by the modified (flattened and thickened) cap to resist erosion during major storm events. Monitoring of the cap will have to be performed after these events to determine damage and what is needed to be repaired.

Removal

The FS provides numerous statements on the short- and long-term effectiveness of removal, particularly dredging in the wet rather than excavation in the dry. The statements are supported by past experiences; however, the formulation of the alternatives and the application of BMPs lack consistency. As an example, it appears that removal in the Western Cell is performed in the dry with landside operations in Alternatives 5N and 5aN, while its removal is performed in the wet in Alternative 6N. Similarly, removal in Alternative 5N is performed with a sheet pile wall to control releases while in Alternative 5aN removal within the footprint of Alternative 5N within the Eastern Cell is performed with a silt curtain, allowing greater releases from an area with very high contaminant concentrations. Ideally, removal in the Western Cell would be performed in the same manner in all of the alternatives so that one can understand the costs and benefits of expanding the footprint of remediation or removal. Consequently, the performance of the alternatives as predicted in the fate and transport modeling tends to distort the incremental impacts of expanding the comprehensiveness of the removal alternatives.

A comparison of short-term effectiveness of Alternative 4N and 5N illustrates differences in BMPs or fate and transport modeling assumptions. The FS states:

> *"The modeling presented in Appendix A demonstrates short-term water column impacts associated with Alternative 4N. Specifically, over the TCRA Site footprint, this alternative is estimated to increase the annual average water column concentration of TCDD by a factor of 10 in year 1 compared to existing conditions.*
>
> *The modeling presented in Appendix A demonstrates short-term water column impacts associated with Alternative 5N. Specifically, over the TCRA Site footprint, this alternative is estimated to increase the annual average water column concentration of TCDD by a factor of about 50 in year 1 compared to existing conditions."*

Since both alternatives are addressing the same area and mass of sediment and similarly disturbing the sediments, one would expect the similar releases and impacts on the water column. In both alternatives the sediment would or could be removed in the same manner, in 4N to add solidification reagents and in 5N for disposal. In fact, one would expect additional releases in 4N from placing the treated sediment back in place; yet, the impact of 4N on the water column is only 20% of the impact of 5N. The cause for these differences is not presented in the FS, but it appears that they reflect differences in the BMPs used, particularly in the Eastern Cell. The 50-fold increase is reflective of the use of silt curtains and removal in the wet. Existing conditions are reflective of Alternative 3N.

Containment Alternatives

BMPs

The FS states:

> *"Operational and engineering controls (rigid and flexible barriers) would be used to the extent practicable to mitigate these potential releases; however, case studies have shown that engineering controls used to control impacts from dredging such as sheetpiles may have limited effectiveness, are subject to leakage, accumulate*

resuspended sediments at the base of the walls which is impossible to completely capture, and have other technical limitations (USACE 2008b; Anchor Environmental 2005; Anchor QEA and Arcadis 2010). Further, use of rigid barriers can result in unintended consequences, such as concentration of dissolved-phase chemicals, localized scour adjacent to the barrier, and/or the spread of contaminants during structure removal (Ecology 1995; Konechne et al. 2010; Anchor QEA and Arcadis 2010).

Flexible barriers such as turbidity curtains will suffer from suspended sediment losses because these types of barriers are not truly water-tight (USACE 2008a; USACE 2008b; Francingues and Palermo 2006; Anchor Environmental 2005; Anchor QEA and Arcadis 2010). Proper design and installation of engineered barriers would be critical for minimizing the issues described above."

While sheet pile walls may have limited effectiveness, are subject to leakage, and accumulate resuspended sediments at the base of the walls, these walls are much more effective than silt curtains. Leakage through shallow walls can be controlled by covering the walls with plastic sheeting, adding sealants and incorporating the walls within shallow berms, which would allow excavation in the dry. Placing the walls in shallow areas would allow the walls to be taller, limiting their potential overtopping. In deeper waters, sheet pile walls limit flow through the site and can restrict flow to the surface, limiting erosion of residuals, while silt curtains direct flow along the bottom of the water column, promoting the transport of resuspended sediment and allowing erosion of residuals. Accumulated resuspended sediments at the base of the walls can be readily capped or covered in place, if not removed by a suction dredge.

The FS additionally provides the following statements regarding the use of sheet pile walls:

"The use of a sheetpile barrier does little to enhance the short-term effectiveness of this alternative because of documented effectiveness issues with engineered barriers discussed in Section 4.1, including:

> • *Incomplete isolation due to gaps in sheetpiles that may occur during installation*
>
> • *The need to provide openings in the sheetpile to balance water pressures on both sides of the pile*
>
> • *The potential for river-current-induced scour adjacent to the sheetpile"*

The three bullets listed above do not provide significant issues in shallow wall installations, such as a wall built at the crest of the outside face of the Western Cell berm, which is normally above the waterline. Gaps between sheet piles could be readily sealed, and there would not be a need to balance water pressures on both sides of the wall. Additionally, the base of the wall is already armored, which would limit the scour potential. For removal operations performed in the wet within sheet pile enclosures with openings to equalize water pressures on both sides of the wall, the sheet pile will virtually prevent erosion of the residuals, reducing releases by at least 70 percent and greatly increasing short-term effectiveness relative to silt curtains.

The FS further poses the following concerns for the use of sheet pile walls:

> *"In addition to these documented issues with sheetpile barriers, the use of sheetpiles increases the risk of recontamination and resuspension of soil/sediments during sheetpile installation and removal (Ecology 1995), and potential cross-contamination associated with driving sheetpiling through impacted materials into non-impacted material."*

The area and mass of contamination impacted by the sheet piles leading to potential recontamination and resuspension of contaminated sediment during installation and removal are equivalent to a very small fraction of the potential reduction in releases achieved by their use over that of other BMPs such as silt curtains. Cross-contamination associated with driving sheet piling through impacted materials into non-impacted material does not pose additional risk because there would not be any exposure to the underlying materials, besides being of limited mass.

Releases and Residuals

The FS assumes the following releases from removal:

> *"A 3-inch layer of dredge residuals was assumed to be generated above the deeper undredged sediments; 15 dioxin/furan concentrations in the residual layer were assumed to be equal to sediment concentrations in the deepest samples above the specified dredge depths, which were considered representative of the last dredge pass (Patmont and Palermo 2007; Bridges et al. 2010). In other words, because Alternatives 5aN and 6N include removal of sediments exceeding the PCL (220 ng/kg TEQ), the residual layer concentration was defined based on sampling data collected immediately above the 220 ng/kg TEQ depth horizon (which in many cases was greater than 220 ng/kg TEQ). As with the deep concentrations, the residual layer concentrations were defined as a single average concentration over the footprint of each dredge area.*
>
> *The top 6 inches of the simulated bed sediment in each dredge area was assumed to consist of a residual cover (e.g., sand); dioxin/furan concentrations in this cover material were assumed to be 5 percent of the dredge residual concentrations (due to mixing when the cover is placed). This value was specified based on experience from other dredging projects (e.g., Alcoa 2006; Anchor Environmental 2007)."*

If a 3-inch layer of dredge residuals having a concentration of the last dredge pass are presumed, then a clean-up pass should be included in the dredge plan to reduce the future exposure. Additionally, if mixing at a rate of 5 percent of the residuals concentration is expected in the 6-inch residual cover when residual concentrations may be quite high without over-dredging or a clean-up pass, then a 12-inch residuals cover should be placed in two 6-inch lifts so that the bioactive zone would be clean following remediation and would yield less diffusive flux than the existing TCRA cap without a geomembrane.

Task 14

Statement

Provide a model evaluation of the full removal Alternative 6N identified in the Feasibility Study as well any new alternative(s) developed under Task 12 (Identify and evaluate techniques …) above. Include modeling of sediment resuspension and residuals.

Methodology

Modeling was performed of the full removal Alternative 6N included representing the post-dredged elevations in the northern impoundments and a 1 cm layer of dredging sediment residuals on the surface of the newly exposed sediment bed in the Eastern Cell and Northwestern Area. The modeling did not simulate the relatively short period between dredging and cover placement.

Findings

The model was run for a one month period during which there were no releases of water from Lake Houston into the upper SJR in order to simulate the full range of tidal conditions over a lunar month. This simulated a low energy simulation in the SLR estuary, which was chosen to result in the minimum amount of area that would be exposed to the eroded and subsequently transported contaminated residuals (*i.e.*, the best case scenario).

The sediment bed below the residuals was assumed to be consolidated, and the critical shear stress for erosion was set at 1.0 Pa as found in the SedFlume study. No resuspension of that sediment occurred during the one month low-energy simulation. Using an estimated critical shear stress for erosion of 0.1 Pa for the residuals, approximately 25 percent of the total residual mass in the identified area was eroded and transported out of the Site. The eroded sediment residuals (represented as bed aggregates in the model) were transported in both the upstream direction during flood tides and downstream direction during ebb tides, though the majority of the eroded residuals were transported downstream. The area of the estuary in which the eroded sediment residuals were eventually deposited stretched halfway between Lynchburg and Morgan’s Point in the downstream direction. This was determined by representing the dredged residuals as a different sediment size class, which allowed percentages of that sediment class (above 1 percent) in the surface sediment bed layer to be the marker for locating where the residuals eventually deposited. In the upstream direction, the sediment residuals were present up to the area in proximity to the northern end of Grennel Slough.

Alternative 6N would set back the natural recovery of the site back to existing conditions by up to two decades considering the time required for design, construction and assimilation of the releases into the sediment bed below the bioactive zone. The setback for Alternative 6N if only silt curtains are used as the resuspension BMP may increase a measurable area of the sediment in the immediate vicinity of the cap area to a concentration exceeding the PCL. The new Alternative 6N* with enhanced BMPs, despite its much smaller short-term releases, would still set back the natural recovery of the site back to existing conditions by up to a decade considering the time required for design, construction and assimilation of the releases into the sediment bed below the bioactive zone. However, the setback for Alternative 6N* may not increase a sizeable area of the sediment outside the cap area to a concentration exceeding the PCL. These short-term releases that are incorporated into the surrounding sediment bed would subsequently be available for redistribution during erosion events from high flows or storm events.

In conclusion, the full remove alternative would result in a significant, albeit short-term increase in the exposures of the estuary to contamination due to the erosion and subsequent transport of the sediment residuals that would be present at the end of the dredging operations in the Northern Impoundments. The identified zone of this increased exposure, even during the simulated normal conditions is fairly far-reaching.

Task 15

Statement

Evaluate floodplain management and impact considerations of construction, considering Alternatives 3N, 5aN, 6N, and any new alternative(s) developed under Task 12, in the floodplain and floodwaters pathway and how that would impact flood control, water flow issues and obstructions in navigable waters. This includes impact on changes to potential flooding and any offsets that are needed due to displacement of water caused by construction in the floodway (height or overall footprint) including effects at the current temporary TCRA cap and any potential future remedial measures.

Findings

This task was accomplished using the calibrated LTFATE model described in Task 2. As described, the LTFATE model domain included the 100-year floodplain, so it was an appropriate tool to use to perform this evaluation. The strategy used with LTFATE was to block off the grid cells that represent the Northern Impoundments (even those representing the Western Cell). The LTFATE grid in proximity to the Site is shown in Figure 3-2. The grid with the blocked cells was used to evaluate the maximum impact that construction of any of the listed Alternatives would have on potential flooding in proximity to the Site. The one month normal weather period that was simulated in Task 14 was used as the simulation period for this task as well. Both the original (*i.e.*, base) model and the model with the blocked grid cells (subsequently referred to as the construction model) were run for this one month simulation. The blocked grid cells in the construction model did not cause any of the grid cells along the shoreline in the portion of the SJR estuary where the Site is located to flood (*i.e.*, become wet). The average difference between the base and construction models predicted water surface elevations in the 120 closest grid cells that surround the Site over the one month simulation was less than 1 cm. Considering the small ratio of the surface area of the Northern Impoundments to the surface area of the embayment where the impoundments are located, this result was not unexpected.

As stated above, the LTFATE model was used to perform the floodplain impacts evaluation. Often times the HEC-RAS model, which a onedimensional (1D) hydraulic model, is used to perform these evaluations. Since HEC-RAS is a 1D, it is severe limitations in representing complex water bodies such as the SJR estuary. In fact, at this time it would not be appropriate to use HEC-RAS to represent an estuary such as the SJR estuary, whereas it is appropriate to do using a multi-dimensional hydrodynamic model. The uncertainties associated with the use of HEC-RAS to perform the impact evaluation would be at a minimum one order of magnitude higher than those associated with the use of a 2D hydrodynamic model such as LTFATE.

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

Task 16

Statement

Project the long-term (500 years) effects of the capping alternative (3N) compared to the full removal alternative (6N) on water quality.

Predictions

To project and compare the long-term effects of the existing capping alternative (3N) versus the full removal alternative (6N), the contaminated sediment-water interaction model, the RECOVERY model was used to predict the contaminant flux and release into the overlying water and to analyze the interactions of a contaminant over 500 years in the sediment profile and bioactive zone. Using RECOVERY, a total flux of contaminant over time and a peak flux were determined to assess the performance of each of the alternatives. The mixed layer (bioactive zone) sediment concentrations were then used to estimate the total bioaccumulation potential of catfish, crabs and clams which were stated as the three species of concern in the RI.

RECOVERY Modeling

RECOVERY is a screening-level model used to assess the long-term impact of contaminated sediments on surface waters. The model couples contaminated interaction between the water column and the bottom sediment, as well as between the contaminated and clean bottom sediments. The analysis is intended primarily for organic contaminants with the assumption that the water column is well mixed. The processes that are incorporated in the model include sorption, decay, volatilization, burial, resuspension, settling, bioturbation, and pore-water diffusion. The solution couples contaminant mass balance in the water column and in the mixed sediment layer along with diffusion and bioturbation in the deep sediment layers.

As shown in Figure 16-1, the system is idealized as a well-mixed surface water layer underlain by a vertically stratified sediment column. The sediment is assumed to be well-mixed horizontally but segmented vertically into a well-mixed surface layer and deep sediment. The latter, in turn, is segmented into layers with varying thicknesses, porosities, and contaminant concentrations underlain by an uncontaminated region. This configuration is helpful for capping scenarios such as this where contamination occurred over a long time, therefore appearing layered. The mixed surface layer is needed because an unconsolidated layer is often observed at the surface of sediment due to a number of processes including bioturbation and mechanical mixing.

Figure 16-1 depicts a basic model simulation including a mixed surface layer, a clean cap underlain by contaminated sediments and a clean deep sediments layer. Figure 16-2 represents the conditions of cap mixed with dredge residuals or surface sediments during cap or backfill placement. Once the cap has been placed, the results are a mixed layer, a new clean cap followed by the contaminated cap, the underlying contaminated sediments, and finally the deep clean sediments.

<u>RECOVERY Scenarios</u>

To compare the full removal alternative (6N) to the current TCRA cap (3N) following remediation activities, the alternatives were broken down incrementally based on the conditions of the individual removal alternative footprints as described in Tasks 11 and 12. This resulted in multiple runs being completed for both alternatives 6N and 3N based on the conditions of the 5N, 5aN, and 6N footprints following remediation. These results were also compared to the background conditions outside of the TCRA cap area with a scenario of surrounding conditions without additional releases from removal activities.

Figure 16-1. Initial Clean Cap Scenario

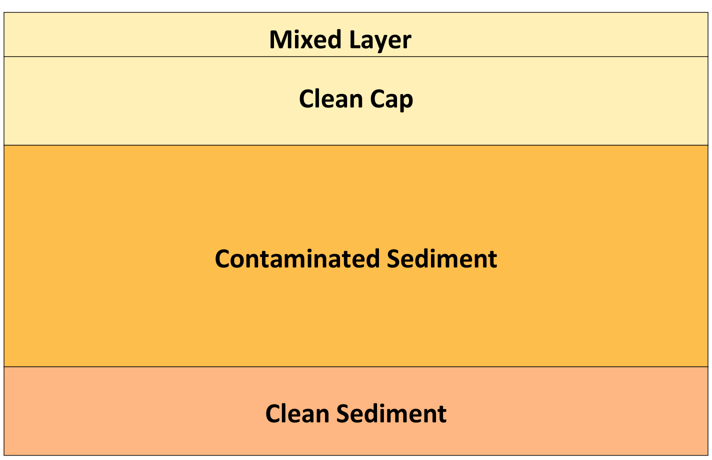
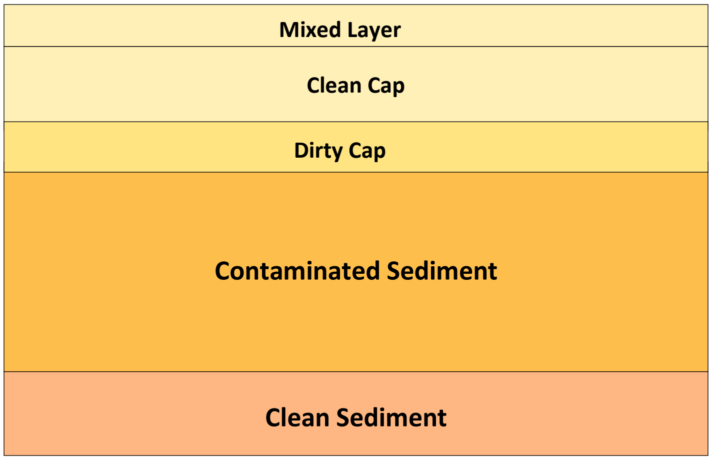


Figure 16-2. Remediated Cap Scenario



RECOVERY Assumptions

Assumptions what were made to complete the RECOVERY model runs are listed in Table 16-1. The contaminant selected for the model runs was 2,3,7,8-Tetrachlorodibenzodioxin (TCDD), which is present in the TCRA cap area and is noted in the Feasibility Study. The octanol-water partitioning coefficient was identified in the RECOVERY model as being 5.25E+06 and was adopted for use in this evaluation. The water suspended solids content and fraction organic carbon were assumed based on knowledge of the site and data from the Remedial Investigation and Feasibility Study. The residence time was estimated using velocity data provided in the Feasibility Study and was used in the calculation of the flow through the system. The surface area of both the water body and the sediment profile was estimated to be an arbitrary 1000 square meters, which would not affect the results of the model and could be scaled for any size surface area, with an assumed water depth of 1.5 m across all scenarios. The sediment profile depth was assumed to be 1 m for all scenarios and a constant specific gravity of 2.65 was used for all materials.

Based on information provided in the Feasibility Study, it was determined that the TCRA site is primarily a depositional site with very little erosion potential. As such, a low resuspension velocity was assumed along with a low burial velocity. These values were used to estimate the settling velocity as stated below, which is representative of clays and very fine silts.

Table 16-1. RECOVERY Model Assumptions

Parameter	**Assumption**
Contaminant	2,3,7,8 TCDD Dioxin
Partitioning Coefficient, K_{ow}	5.25E+06
Suspended Solids Concentration in Water	20
Fraction of Organic Carbon in Solids (%)	0.1
Residence Time (years)	0.0001
Calculated Flow Through (m^3/yr)	1.13E+07
Surface Area of Simulation (m^2)	1000
Water Depth (m)	1.5
Sediment Profile Depth (m)	1
Specific Gravity	2.65
Wind Speed (m/sec)	2
Resuspension Velocity (m/yr)	0.001
Burial Velocity (m/yr)	0.004
Calculated Settling Velocity (m/yr)	271

Surrounding Conditions

The details of the Surrounding Conditions scenario can be found in Table 16-2. This scenario was assumed to be outside of the TCRA region but within the Preliminary Site Perimeter and reflects the unremediated, impacted area (about 700 acres) that could be potentially affected by releases from the TCRA area or could affect the TCRA area in the future. The scenario was considered a simple two layer system having a 10-cm mixed layer that was slightly more organic than the underlying sediment. All sediment, including the mixed layer, was assumed to have an initial TCDD contaminant concentration of 10 ng/kg.

Table 16-2. Surrounding Conditions

Layer	Layer Depth (cm)	Porosity	TOC (%)	Concentration (ng/kg)
Mixed	10	0.7	4	10
Sediment	98	0.6	3	10

3N

Alternative 3N was divided into two TCRA cap regions, the Eastern Cell and Northwestern Area, as described in the Feasibility Study. The areas are very different in composition as the Eastern Cell has a geotextile and rock riprap protection while the Northwestern Area has only an aggregate filter and recycled concrete as a permanent cap. The 3N alternative was further divided based on the footprint of each of the removal alternatives, 5N, 5aN, and 6N, and an incremental analysis of the entire TCRA cap area. Porosities were assumed based on site conditions and the fraction of organic carbon (TOC %) was assumed based on data provided in the Feasibility Study. Sediment TCDD concentrations were assumed based on the average sediment concentrations determined in Task 11 for each footprint.

Table 16-3 describes the scenarios for the Eastern Cell of the TCRA cap. In this area, there is a geotextile along with a rock riprap permanent cap. For the purposes of this analysis, and due to restrictions in the RECOVERY model, the rock riprap layer could not be accurately modeled due to the absence of organic matter in the riprap and the potential rapid exchange of water within the interstices of the riprap with the water column. Therefore, the riprap was not included in any of the model runs. It was also assumed that for this area the geotextile, while not modeled, does keep the mixed layer clean and not exposed to the contaminated sediment. This resulted in a sediment profile with a 2-cm clean mixed layer and the remaining sediment having a constant contaminant concentration. TOC values varied for each removal footprints based on assumptions made in Task 11.

Table 16-4 represents the model runs completed for the Northwestern Area. The Northwestern Area is different from the Eastern Cell in that it does not have any form of geotextile to protect from sediment resuspension. Instead, there is a blended aggregate filter layer covered by recycled concrete as the permanent cap. For these model runs the concrete was not included as a layer and the aggregate was assumed to be very coarse sand with low organic content. The sediment profile was assumed to consist of a 2-cm mixed layer followed by a 12-cm aggregate layer, an 8-cm layer in which the aggregate was mixed with the contaminated sediment, and lastly the remaining 78 cm of completely contaminated sediment. The bottom contaminated sediment concentration was assumed based on calculations made in Task 11, and it was assumed that the mixed aggregate/sediment layer was approximately 15% of the contaminant concentration of the surficial sediment.

Table 16-3. Alternative 3N Eastern Cell Components

Layer	Thick-ness (cm)	Poro-sity	TOC (%)			Concentration (ng/kg)		
			5N Foot-print	5aN Incre-ment	6N Incre-ment	5N Foot-print	5aN Incre-ment	6N Incre-ment
Mixed	2	0.4	0.5	0.5	0.5	0	0	0
Sediment	98	0.6	12	6	5	13,000	5,800	4,030

Table 16-4. Alternative 3N Northwestern Area Components

Layer	Thick-ness (cm)	Poro-sity	TOC (%)			Concentration (ng/kg)		
			5N Foot-print	5aN Incre-ment	6N Incre-ment	5N Foot-print	5aN Incre-ment	6N Incre-ment
Mixed	2	0.4	0.5	0.5	0.5	0	0	0
Aggregate	12	0.2	0.5	0.5	0.5	1	1	1
Mixed Cap/ Sediment	8	0.4	3	3	3	1,950	870	605
Sediment	78	0.6	12	6	5	13,000	5,800	4,030

6N

The full removal alternative (6N) was divided into multiple scenarios; first, by the method of backfill placement and secondly by the footprint of each removal alternative. By specifying three methods of backfill placement, a comparison can be made between them and a best method of placement plan can be developed and utilized if the full removal alternative is selected. The three methods include a dump placement, raining of the material, and a recommended best practice method of placing the material in two layers.

The first method of placement is considered the least desirable. Dumping of the material from a barge or excavator leads to a great deal of suspension and mixing, and there is no acceptable way to ensure that the material is spread evenly over the surface and is the proper thickness. As such, the sediment profile is assumed to look similar to that in Table 16-5. Here the profile is divided into a 10-cm mixed layer, a small 5-cm sand layer, followed by the residual layer that remains following dredging, and lastly the deep sediment that has a concentration below the cleanup level. The residual thickness and concentration, as determined in Task 11, are considerably high, and when the backfill is dumped there is significant mixing that results in the sand and mixed layers having a concentration approximately 5% of the residuals concentration. The porosity and TOC were assumed based on data provided in the Feasibility Study. As previously stated, the rock riprap which would be used to reinforce the cap is not included in the model runs.

Table 16-6 represents the sediment profiles if the backfill material is placed by raining the material. This method is preferred to dumping since there is more control in the distribution of the material and layer thickness, as well as reduced mixing limited to a thin layer between the clean material and the residuals and less potential for resuspension. The top 10 cm of the mixed layer is left clean while the concentration that was previously mixed over 15 cm in the dump placement scenarios is now mixed with a smaller layer of 5 cm of sand. While this increases the concentration in the sand layer to 15% of the residuals contaminant concentration, there is now a clean barrier between the contaminant and the water column. Below the sand is the estimated 3 cm residuals layer followed by the remaining deep sediments that are below the cleanup level of contamination.

Lastly, a best practice method for placement is recommended as described in Table 16-7. This method involves carefully placing the sand material in two equal layers which considerably reduces mixing with the contaminated material and suspension. This results in the top 6 inches of material, including the mixed layer, remaining clean and increasing the barrier between the contaminated residuals and the water column. As seen in the profile, there is an assumed 10-cm mixed layer, with the next 5 cm below the mixed layer remaining clean, followed by 15 cm of sand having mixed with the residuals to yield a contaminant concentration of 5% of the residuals layer. Below the sand are the 3-cm residuals layer and the remaining deep sediments.

Table 16-5. 6N Scenario 1 - Dump Placement of Backfill

Layer	Layer Depth (cm)	Poro-sity	TOC (%)	Concentration (ng/kg)		
				5N Footprint	5aN Increment	6N Increment
Mixed	10	0.5	1	416	136	98.5
Sand	5	0.4	0.5	416	136	98.5
Residuals	3	0.6	3	8,320	2,720	1,970
Deep Sediment	82	0.6	3	200	200	200

Table 16-6. 6N Scenario 2 - Raining Placement of Backfill

Layer	Layer Depth (cm)	Poro-sity	TOC (%)	Concentration (ng/kg)		
				5N Footprint	5aN Increment	6N Increment
Mixed	10	0.5	1	0	0	0
Sand	5	0.4	0.5	1,248	408	295
Residuals	3	0.6	3	8,320	2,720	1,970
Deep Sediment	82	0.6	3	200	200	200

Table 16-7. 6N Scenario 3 - Best Practice Placement of Backfill in Two Layers

Layer	Layer Depth (cm)	Poro-sity	TOC (%)	Concentration (ng/kg)		
				5N Footprint	5aN Increment	6N Increment
Mixed	10	0.5	1	0	0	0
Sand	5	0.4	0.5	0	0	0
	15	0.4	0.5	416	136	98.5
Residuals	3	0.6	3	8,320	2,720	1,970
Deep Sediment	67	0.6	3	200	200	200

Results

Data from the multiple RECOVERY model runs were analyzed to determine the peak total flux of contaminant over the model period (500 years). These data are useful in determining how well the site is performing and how much contaminant is potentially lost into the water column over time.

Peak contaminant releases and dissolved contaminant concentrations driving the risks from contaminant exposures are shown in Tables 16-8 and 16-9. The peak contaminant flux given in Table 16-8 and the total contaminant releases during the simulation period given in Table 16-10 are low for all scenarios compared with the unremediated area within the Preliminary Site Perimeter. In a comparison between the two areas of the 3N alternative, there is more flux occurring in the Eastern Cell than in the Northwestern Area. This is due to the absence of a sand and gravel filter in the Eastern Cell and presence of a sand and gravel filter in the Northwestern Area. The blended filter restricts water exchange and decreases the contaminant concentration gradient that drives the diffusive contaminant flux. Comparing the three backfill placement methods of the 6N alternative, the best practice method of placing the material over two layers is far superior and has considerably less flux than the other two placement methods. The flux from this method is also significantly less than that experienced if the current cap remains in place. The dump backfill placement method with potential mixing throughout the fill yields contaminant fluxes greater than that occurring in the surrounding unremediated area.

Table 16-8. Peak Contaminant Flux Rate

Scenario	Time to Peak (years)	Peak Contaminant Flux ($\mu g/m^2$-yr)
Surrounding Conditions	0.047	8.34E-04
3N Eastern Cell 5N Footprint	3.45	6.09E-05
3N Eastern Cell 5aN – 5N Increment	3.46	5.43E-05
3N Eastern Cell 6N - 5aN Increment	3.46	4.53E-05
3N NW Area 3N - 5N Footprint	3.46	7.50E-09
3N NW Area 5aN – 5N Increment	3.46	7.50E-09
3N NW Area 6N – 5aN Increment	3.46	7.50E-09
6N Dump Placement - 5N Footprint	0.048	5.75E-02
6N Dump Placement - 5aN Increment	0.049	1.88E-02
6N Dump Placement - 6N Increment	0.048	1.36E-02
6N Rain Placement - 5N Footprint	6.31	1.76E-05
6N Rain Placement - 5aN Increment	6.33	5.75E-06
6N Rain Placement - 6N Increment	6.32	4.17E-06
6N Best Placement - 5N Footprint	22.3	4.24E-21
6N Best Placement - 5aN Increment	22.2	1.39E-21
6N Best Placement - 6N Increment	22.2	1.00E-21

Table 16-9. Peak Dissolved Contaminant Concentrations

Scenario	Cover Placement Method	BAZ ng/L	Water ng/L
Surroundings		3.20E-04	4E-08
3N		2.00E-05	7E-09
6N	Dump	4.40E-03	2E-06
6N	Rain	1.35E-06	5E-10
6N	Best	3.25E-22	1 E-25

Table 16-10. Total Contaminant Release over 500-yr Simulation Period

Scenario	Total Release over 500 years (mg)
Surrounding Conditions	28,900
Eastern Cell 3N - 5N Footprint	2.18
Eastern Cell 3N - 5aN Increment	8.11
Eastern Cell 3N - 6N Increment	0.0
NW Area 3N - 5N Footprint	0.0
NW Area 3N - 5aN Increment	2.54E-04
NW Area 3N - 6N Increment	2.54E-04
6N Dump Placement - 5N Footprint	10,200
6N Dump Placement - 5aN Increment	7,160
6N Dump Placement - 6N Increment	2,960
6N Rain Placement - 5N Footprint	4.06
6N Rain Placement - 5aN Increment	2.84
6N Rain Placement - 6N Increment	1.17
6N Best Practice Placement - 5N Footprint	1.22E-15
6N Best Practice Placement - 5aN Increment	8.49E-16
6N Best Practice Placement - 6N Increment	3.51E-16

Task 17

Statement

Assess the potential impacts to fish, shellfish, and crabs from sediment resuspension as a result of dredging in the near term and for the long term.

BSAF and Total Bioaccumulation Potential

Bioaccumulation is the uptake chemicals by an organism through routes of exposure including ingestion and inhalation. The amount of bioaccumulation depends on the bioavailability of a chemical contaminant as well sediment concentrations, and the specific organism. Other factors affecting the bioaccumulation include the total organic carbon (TOC) present in the sediment in which low TOC tends to result greater bioaccumulation while higher TOC contents result in lower bioaccumulation. Benthic organisms that dwell or ingest fine grained material, which itself is associated with higher contaminant concentrations, are more likely to be exposed to these higher concentrations of contaminants and resulting in a higher potential for bioaccumulation. Dredging and any other activities which disturb and resuspend sediments create conditions that allow for higher bioaccumulation potential and cause higher concentrations of contaminants in the water column creating a new pathway for organisms to ingest the contaminants.

In order to determine the concentration at which an organism exposed to contaminated sediments may become contaminated the biota-sediment accumulation factor (BSAF) in combination with the lipids content of an organism, the TOC and the sediment concentration of the specified area are used to estimate a Total Bioaccumulation Potential or TBP. The TBP is a useful tool in estimating the affect contaminated sediment may have on the food chain starting with the sediments that organisms such as blue crab, catfish and clams ingest. The following section estimates the TBP of the listed organisms in the TCRA cap area ingesting only organisms in equilibrium with the remediation areas.

Assumptions

Assumptions for the determination of the TBP can be found in Table 17-1. The lipid content for each species was assumed based on literature from the Texas Department of Health Services as well as from the report "Assessing Bioaccumulation in Aquatic Organisms Exposed to Contaminated Sediments" by Clarke and McFarland (1991). The BSAF value chosen for each species was assumed from data provided in Appendix B of the RI report. However, the analysis for these BSAF values did not follow standard practice which would define BSAF as the lipid normalized tissue concentration relative to an organic carbon normalized sediment concentration. As such, the BSAF values needed to be adjusted by the ratio of sediment TOC content to tissue lipid content. The mean surficial sediment TOC content is about 5% but may be as high as 12%. The BSAF values using normalized concentrations would be as much as 10 to 15 times higher than the reported values in Appendix B of the RI report. Baylor University computed BSAFs from measured tissue concentrations and sediment concentrations from San Jacinto River samples. The mean values for TCDD are reported in Table 17-1. The Baylor University values (TEHI BSAF Report 8/31/2012) are somewhat higher than the values reported in Appendix B of the RI but in the range of other reported values, some of which are about 4 times higher. Nevertheless, the values are suitable for comparing alternatives using TBP as a screening exercise. These values along with %TOC for the mixed layer and the peak and average mixed layer sediment concentrations for the 500 years simulated in Task 16 for each scenario were used in the calculation of the TBP.

Table 17-1. Assumptions for TBP Calculation

Parameter	Blue Crab	Catfish	Clam
Lipid Content (%)	0.8	6.2	2.2
BSAF	0.022	0.044	0.070

TBP

The total bioaccumulation potential is used to determine the contaminant concentration at which a specific species may become exposed to the contaminant through ingestion of sediment as its only source of contamination. The TBP presented here considers only the consumption of contaminated sediments and does not take into account the consumption of previously contaminated organisms.

For this analysis, the peak and average sediment concentrations for the mixed layer over the 500-yr simulation period were used in the calculation of the peak and an average TBP over time. This provides a worst-case scenario with the peak value and a more likely to occur average sediment concentration in which organisms may be exposed to the contaminant. Results from both analyses may be found below in Tables 17-2 and 17-

From the results, the catfish have the highest potential for bioaccumulation, which should be expected as it has the highest lipids content. Clarke *et al.* (1991) notes that in general, the higher the total lipids content of an organism, the greater its capacity for bioaccumulation. The clam and blue crab have lower potential for bioaccumulation, with the clam's being slightly higher. In a case-by-case comparison, the dump placement of backfill in the 6N alternative creates the highest potential for bioaccumulation due the likelihood of resuspending material and mixing of the backfill with the contaminated residuals. As expected, the best practice placement of backfill in the full removal alternative resulted in the lowest potential of bioaccumulation for all species. It is considerably lower than the potential for all other backfill methods, including the TBP of the current TCRA cap of the 3N alternative.

Conclusions

Both capping as performed in Alternative 3N and removal as performed in Alternative 6N are very effective; however, dredging is only particularly effective if backfill is placed without disturbing the residual. Backfilling must be performed by raining or placement in two layers. Post-remediation contaminant releases from the remediation area will be much smaller than the releases from the rest of the area within the Preliminary Site Perimeter.

Table 17-2. Peak Total Bioaccumulation Potential

RECOVERY Scenario		TOC (%)	Peak Mixed Layer TCDD Concentration (ng/kg)	Peak Blue Crab TBP (ppq)	Peak Catfish TBP (ppq)	Peak Clam TBP (ppq)
Surrounding Conditions		4	10.	44.0	682	385
3N Eastern Cell	5N Footprint	0.5	0.369	13.0	202	113
	5aN Increment	0.5	0.329	11.6	179	101
	6N Increment	0.5	0.275	9.6	150	84.5
3N Northwestern Area	5N Footprint	0.5	4.55E-05	1.60E-03	2.50E-02	1.40E-02
	5aN Increment	0.5	4.55E-05	1.60E-03	2.50E-02	1.40E-02
	6N Increment	0.5	4.55E-05	1.60E-03	2.50E-02	1.40E-02
6N Dump Placement	5N Footprint	1	416	7,319	114,000	64,200
	5aN Increment	1	136	2,390	37,100	21,000
	6N Increment	1	98.5	1,735	26,900	15,200
6N Raining Placement	5N Footprint	1	0.127	2.22	34.6	19.6
	5aN Increment	1	0.042	0.740	11.34	6.37
	6N Increment	1	0.030	0.529	8.20	4.63
6N Best Practice Placement	5N Footprint	1	3.06E-17	5.39E-16	8.34E-15	4.71E-15
	5aN Increment	1	1.00E-17	1.76E-16	2.73E-15	1.54E-15
	6N Increment	1	7.25E-17	1.28E-16	1.98E-15	1.12E-15

Table 17-3. Average Total Bioaccumulation Potential

RECOVERY Scenario		TOC (%)	Average Mixed Layer TCDD Conc. (ng/kg)	Average Blue Crab TBP (ppq)	Average Catfish TBP (ppq)	Average Clam TBP (ppq)
Surrounding Conditions		4	0.489	2.137	33.4	14.0
3N Eastern Cell	5N Footprint	0.5	7.44E-03	0.254	4.05	2.32
	5aN Increment	0.5	6.63E-03	0.233	3.61	2.03
	6N Increment	0.5	5.53E-03	0.190	3.02	1.69
3N Northwestern Area	5N Footprint	0.5	9.17E-07	3.24E-05	5.00E-04	2.82E-04
	5aN Increment	0.5	9.17E-07	3.24E-05	5.00E-04	2.82E-04
	6N Increment	0.5	9.17E-07	3.24E-05	5.00E-04	2.82E-04
6N Dump Placement	5N Footprint	1	20.3	358	5534	3128
	5aN Increment	1	6.65	117	1814	1023
	6N Increment	1	4.81	84.6	1312	739
6N Raining Placement	5N Footprint	1	8.09E-03	0.148	2.21	1.26
	5aN Increment	1	2.64E-03	0.042	0.721	0.386
	6N Increment	1	1.92E-03	0.042	0.525	0.290
6N Best Practice Placement	5N Footprint	1	2.40E-18	4.23E-17	6.55E-16	3.70E-16
	5aN Increment	1	7.87E-19	1.39E-17	2.15E-16	1.21E-16
	6N Increment	1	5.69E-19	1.00E-17	1.55E-16	8.79E-17

Task 18

Statement

Assess the potential for release of material from the waste pits caused by a storm occurring during a removal/dredging operation; identify and evaluate measures for mitigating/reducing any such releases.

Findings

The modeling performed in Task 14 clearly demonstrated that sediment residuals are predicted to be eroded from the areas that would be dredged in the Eastern Cell and Northwestern Area even during non-storm, *i.e.*, normal, conditions under routine high flow conditions. If a storm, *e.g.*, tropical storm or high flows under flood conditions in the SJR, occurred during the actual removal/dredging operation, the likelihood of extremely significant releases of contaminated sediment occurring is very high. There is the potential to erode exposed sediments as well as residuals without a resuspension BMP or if a silt curtain is used as the resuspension BMP. A silt curtain would not be able to withstand the forces of high flow or waves and therefore the bottom shear stresses would not be controlled. The mass of sediment residuals that would erode from the locations where removal and/or dredging operations had been performed would be significantly greater (at least several times greater depending on the magnitude of the hydrodynamic event) than that found from the modeling performed in Task 14 or predictions of releases presented in Tasks 11 and 12. Likewise, the portion of the estuary that would be exposed to the released contaminated sediments during a storm event would most likely be significantly larger than the zone of exposure identified in Task 14. It would probably even include significant portions of the floodplain since the latter would be inundated to some extent during any storm with a return period greater than approximately 2 years.

The only BMPs that would be capable of preventing most of the contaminated sediment releases would be a substantial containment structures to isolate the removal operations, residuals and exposed sediment. The containment structures could consist of berms and sheet pile walls or caissons to an elevation of about +9 NAVD88. If performing excavation of the sediments in the dry, the top of the berms would preferably be no lower than +4 NAVD88.

Without complete isolation by containment structures (*i.e.*, where water exchange is permitted to equilibrate the water surface elevation on both sides of the containment structure) or when the containment elevation is less than about +5 NAVD88, erosion of recently formed dredging residuals by the bottom shear stresses resulting from flow through the gaps and over the walls, depending on the magnitude of the flooding, would be expected; however, very limited erosion of exposed sediment would be expected. Recently formed residuals could contain up to about 1% of the contaminant mass. In these circumstances, it would be advisable to perform the removals in small sections at a time such that the armor stone and geotextile within the small section would be removed, and then the sediment removed and a thin layer of sacrificial fill placed before advancing to the next section and repeating the process. Under these removal operations, it would also be advisable to limit or restrict removal activities to a period when there is a lower probability of tropical storms and flooding conditions.

Task 19

Statement

Estimate the rate of natural attenuation in sediment concentrations / residuals and recommend a monitoring program to evaluate the progress. Discuss the uncertainty regarding the rate of natural attenuation.

Findings

Based on the modeling performed in Tasks 2, 3, 4, and 14, the estimated range of net sedimentation rates (NSR) at the site is 1.3 cm/yr ± 0.8 cm/yr. This NSR is the average value over the entire cap, and it is important to keep in mind that the NSR was calculated by averaging the instances of both erosion and deposition in each grid cell over the simulated time period. The latter included long periods of fair (*i.e.*, normal) weather, as well as high energy events including storms and floods. The positive value, i.e., 1.3 cm/yr, indicates that there was, averaged over the cap, more deposition than erosion, albeit a small net site-averaged quantity per year. Nevertheless, even this relatively low average NSR on the cap is predicted to maintain the cap's effectiveness, and will contribute to the rate of natural attenuation in the contaminated sediment concentrations found from the 500-year simulations performed using RECOVERY (as described in Task 16). The average NSR of 1.3 cm/yr is based on the modeling performed in previous tasks, as well as the analysis performed by AQ (Anchor QEA 2012). The uncertainty in the long-term NSR of ± 0.8 cm/yr is based on the sensitivity analysis performed in Task 4, and is in the same range as that given by AQ (Anchor QEA 2012).

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Appendix A

Description of LTFATE Modeling System

LTFATE is a multi-dimensional modeling system maintained by ERDC (Hayter *et al*. 2012). The hydrodynamic module in LTFATE is the Environmental Fluid Dynamics Code (EFDC) surface water modeling system (Hamrick 2007a; 2007b; and 2007c). EFDC is a public domain, three-dimensional finite difference model that contains dynamically linked hydrodynamic and sediment transport modules. Brief descriptions of these two modules are described below.

Hydrodynamic module in LTFATE

EFDC can simulate barotropic and baroclinic flow in a water body due to astronomical tides, wind, density gradients, and river inflow. It solves the three-dimensional (3D), vertically hydrostatic, free surface, turbulence averaged equations of motion. EFDC is extremely versatile, and can be used for 1D, 2D-laterally averaged (*2DV*), 2D-vertically averaged (2DH), or 3D simulations of rivers, lakes, reservoirs, estuaries, coastal seas, and wetlands.

For realistic representation of horizontal boundaries, the governing equations in EFDC are formulated such that the horizontal coordinates, x and y, are curvilinear. To provide uniform resolution in the vertical direction, the sigma (stretching) transformation is used. The equations of motion and transport solved in EFDC are turbulence-averaged, because prior to averaging, although they represent a closed set of instantaneous velocities and concentrations, they cannot be solved for turbulent flows. A statistical approach is applied, where the instantaneous values are decomposed into mean and fluctuating values to enable the solution. Additional terms that represent turbulence are introduced to the equations for the mean flow. Turbulent equations of motion are formulated to utilize the Boussinesq approximation for variable density. The Boussinesq approximation accounts for variations in density only in the gravity term. This assumption simplifies the governing equations significantly, but may introduce large errors when density gradients are large.

The resulting governing equations, presented in Appendix B, include parameterized, Reynolds-averaged stress and flux terms that account for the turbulent diffusion of momentum, heat and salt. The turbulence parameterization in EFDC is based on the Mellor and Yamada (1982) level 2.5 turbulence closure scheme, as modified by Galperin *et al.* (1988), that relates turbulent correlation terms to the mean state variables. The EFDC model also solves several transport and transformation equations for different dissolved and suspended constituents, including suspended sediments, toxic contaminants, and water quality state variables. Detailed descriptions of the model formulation and numerical solution technique used in EFDC are provided by Hamrick (2007b). Additional capabilities of EFDC include: 1) simulation of wetting and drying of flood plains, mud flats, and tidal marshes; 2) integrated, near-field mixing zone model; 3) simulation of hydraulic control structures such as dams and culverts; and 4) simulation of wave boundary layers and wave-induced mean currents. A more detailed description of EFDC is given in Appendix B.

Sediment transport module

The sediment transport model in LTFATE is a modified version of the SEDZLJ mixed sediment transport model (Jones and Lick 2001; James *et al.* 2010) that a) includes a three-dimensional representation of the sediment bed, and b) can simulate winnowing and armoring of the surficial layer of the sediment bed. SEDZLJ is dynamically linked to LTFATE in that the hydrodynamics and sediment transport modules are both run during each model time step. This enables simulated changes in morphology to be instantly fed-back to the hydrodynamic model. A more detailed description of SEDZLJ is given in Appendix C.

One of the first steps in performing sediment transport modeling is to use grain size distribution data from sediment samples collected at different locations throughout the model domain to determine how many discrete sediment size classes are needed to adequately represent the full range of sediment sizes. Typically, three to eight size classes are used. For example, AQ used four sediment size classes in their sediment transport model of the SJR. One size class was used to represent sediment in the cohesive sediment size range, 5 μm, and three size classes were used to represent the noncohesive sediment size range, 140, 510 and 3,500 μm.

Appendix B

Description of LTFATE Hydrodynamic Module

EFDC is a public domain, 3D finite difference model that contains dynamically linked hydrodynamic and sediment transport modules. EFDC can simulate barotropic and baroclinic flow in a water body due to astronomical tides, wind, density gradients, and river inflow. It solves the 3D vertically hydrostatic, free surface, turbulence averaged equations of motion. EFDC can be used for 1D, 2D-laterally averaged (*2DV*), 2D-vertically averaged (2DH), or 3D simulations of rivers, lakes, reservoirs, estuaries, coastal seas, and wetlands.

EFDC solves the 3D Reynolds-averaged equations of continuity (Equation B-1), linear momentum (Equations B-2 and B-3), hydrostatic pressure (Equation B-4), equation of state (Equation B-5) and transport equations for salinity and temperature (Equations B-6 and B-7) written for curvilinear-orthogonal horizontal coordinates and a sigma (stretching) vertical coordinate. These are given by Hamrick (2007b) and repeated below:

$$\frac{\partial(m\varepsilon)}{\partial t}+\frac{\partial(m_y Hu)}{\partial x}+\frac{\partial(m_x Hv)}{\partial y}+\frac{\partial(mw)}{\partial z}=0 \qquad \text{(B-1)}$$

$$\frac{\partial(mHu)}{\partial t}+\frac{\partial(m_y Huu)}{\partial x}+\frac{\partial(m_x Hvu)}{\partial y}+\frac{\partial(mwu)}{\partial z}-$$

$$(mf+v\frac{\partial(m_y)}{\partial x}-u\frac{\partial m_x}{\partial y})Hv=m_y H\frac{\partial(g\varepsilon+p)}{\partial x}- \qquad \text{(B-2)}$$

$$m_y(\frac{\partial H}{\partial x}-z\frac{\partial H}{\partial x})\frac{\partial p}{\partial z}+\frac{\partial(mH^{-1}A_v\frac{\partial u}{\partial z})}{\partial z}+Q_u$$

$$\frac{\partial(mHv)}{\partial t}+\frac{\partial(m_y Huv)}{\partial x}+\frac{\partial(m_x Hvv)}{\partial y}+\frac{\partial(mwv)}{\partial z}+$$

$$(mf+v\frac{\partial(m_y)}{\partial x}+u\frac{\partial m_x}{\partial y})Hu=m_x H\frac{\partial(g\varepsilon+p)}{\partial y}- \tag{B-3}$$

$$m_x(\frac{\partial H}{\partial y}-z\frac{\partial H}{\partial y})\frac{\partial p}{\partial z}+\frac{\partial(mH^{-1}A_v\frac{\partial v}{\partial z})}{\partial z}+Q_v$$

$$\frac{\partial p}{\partial z}=\frac{gH(\rho-\rho_o)}{\rho_o}=gHb \tag{B-4}$$

$$\rho=\rho(\rho,S,T) \tag{B-5}$$

$$\frac{\partial(mHS)}{\partial t}+\frac{\partial(m_y HuS)}{\partial x}+\frac{\partial(m_x HvS)}{\partial y}+\frac{\partial(mwS)}{\partial z}=\frac{\partial(\frac{mA_b}{H}\frac{\partial S}{\partial z})}{\partial z}+Q_s \tag{B-6}$$

$$\frac{\partial(mHT)}{\partial t}+\frac{\partial(m_y HuT)}{\partial x}+\frac{\partial(m_x HvT)}{\partial y}+\frac{\partial(mwT)}{\partial z}=\frac{\partial(\frac{mA_b}{H}\frac{\partial T}{\partial z})}{\partial z}+Q_T \tag{B-7}$$

where u and v are the mean horizontal velocity components in (x,y) coordinates; m_x and m_y are the square roots of the diagonal components of the metric tensor, and $m= m_x\, m_y$ is the Jacobian or square root of the metric tensor determinant; p is the pressure in excess of the reference pressure, $\frac{\rho_o gH(1-z)}{\rho_o}$, where ρ_o is the reference density; f is the Coriolis parameter for latitudinal variation; A_v is the vertical turbulent viscosity; and A_b is the vertical turbulent diffusivity. The buoyancy b in Equation B-4 is the normalized deviation of density from the reference value. Equation B-5 is the equation of state that calculates water density, ρ, as functions of p, salinity, S, and temperature, T.

The sigma (stretching) transformation and mapping of the vertical coordinate is given as:

$$z=\frac{(z^*+h)}{(\xi+h)} \tag{B-8}$$

where z^* is the physical vertical coordinate, and h and ξ are the depth below and the displacement about the undisturbed physical vertical coordinate origin, $z^* = 0$, respectively, and $H=h+\xi$ is the total depth. The vertical velocity in z coordinates, w, is related to the physical vertical velocity w^* by:

$$w = w^* - z\left(\frac{\partial \xi}{\partial t} + \frac{u}{m_x}\frac{\partial \xi}{\partial x} + \frac{v}{m_y}\frac{\partial \xi}{\partial y}\right) + (1-z)\left(\frac{u}{m_x}\frac{\partial h}{\partial x} + \frac{v}{m_y}\frac{\partial h}{\partial y}\right) \qquad \text{(B-9)}$$

The solutions of Equations B-2, B-3, B-6 and B-7 require the values for the vertical turbulent viscosity and diffusivity and the source and sink terms. The vertical eddy viscosity and diffusivity, A_v and A_b, are parameterized according to the level 2.5 (second-order) turbulence closure model of Mellor and Yamada (1982), as modified by Galperin *et al*. (1988), in which the vertical eddy viscosities are calculated based on the turbulent kinetic energy and the turbulent macroscale equations. The Mellor and Yamada level 2.5 (MY2.5) turbulence closure model is derived by starting from the Reynolds stress and turbulent heat flux equations under the assumption of a nearly isotropic environment, where the Reynolds stress is generated due to the exchange of momentum in the turbulent mixing process. To make the turbulence equations closed, all empirical constants are obtained by assuming that turbulent heat production is primarily balanced by turbulent dissipation.

The vertical turbulent viscosity and diffusivity are related to the turbulent intensity, q^2, turbulent length scale, l and a Richardson number R_q as follows:

$$A_v = \Phi_v ql = 0.4(1+36R_q)^{-1}(1+6R_q)^{-1}(1+8R_q)ql \qquad \text{(B-10)}$$

$$A_b = \Phi_b ql = 0.5(1+36R_q)^{-1} ql \qquad \text{(B-11)}$$

where A_v and A_b are stability functions that account for reduced and enhanced vertical mixing or transport in stable and unstable vertical, density-stratified environments, respectively, and the local Richardson number is given as:

$$R_q = \frac{gH\frac{\partial b}{\partial z}}{q^2}\frac{l^2}{H^2} \qquad \text{(B-12)}$$

A critical Richardson number, $R_q = 0.20$, was found at which turbulence and mixing cease to exist (Mellor and Yamada 1982). Galperin *et al.* (1988) introduced a length scale limitation in the MY scheme by imposing an upper limit for the mixing length to account for the limitation of the vertical turbulent excursions in stably stratified flows. They also modified and introduced stability functions that account for reduced or enhanced vertical mixing for different stratification regimes.

The turbulence intensity (q^2) and the turbulence length scale (l) are computed using the following two transport equations:

$$\frac{\partial(mHq^2)}{\partial t}+\frac{\partial(m_yHuq^2)}{\partial x}+\frac{\partial(m_xHvq^2)}{\partial y}+\frac{\partial(mwq^2)}{\partial z}=\frac{\partial(\frac{mA_q\frac{\partial q^2}{\partial z}}{H})}{\partial z}+Q_q \qquad \text{(B-13)}$$
$$+2\frac{mA_v}{H}((\frac{\partial^2 u}{\partial z^2})+(\frac{\partial^2 v}{\partial z^2}))+2mgA_b\frac{\partial b}{\partial z}-2mH(\frac{q^3}{(B_1 l)})$$

$$\frac{\partial(mHq^2l)}{\partial t}+\frac{\partial(m_yHuq^2l)}{\partial x}+\frac{\partial(m_xHvq^2l)}{\partial y}+\frac{\partial(mwq^2l)}{\partial z}=$$
$$\frac{\partial(\frac{mA_q\frac{\partial q^2l}{\partial z}}{H})}{\partial z}+Q_l+2\frac{mE_1lA_v}{H}((\frac{\partial^2 u}{\partial z^2})+(\frac{\partial^2 v}{\partial z^2}))+mgE_1E_3lA_b\frac{\partial b}{\partial z} \qquad \text{(B-14)}$$
$$-H(\frac{q^3}{(B_1)})(1+E_2(\kappa L)^{-2}l^2)$$

The above two equations include a wall proximity function, $W = 1+E_2 l(\kappa L)^{-2}$, that assures a positive value of diffusion coefficient $L^{-1}=(H)^{-1}(z^{-1}+(1-z)^{-1})$). κ, B_1, E_1, E_2, and E_3 are empirical constants with values 0.4, 16.6, 1.8, 1.33, and 0.25, respectively. All terms with *Q's* (Q_u, Q_v, Q_q, Q_l, Q_s, Q_T) are sub-grid scale sink-source terms that are modeled as sub-grid scale horizontal diffusion. The vertical diffusivity, A_q, is in general taken to be equal to the vertical turbulent viscosity, A_v (Hamrick 2007b).

The vertical boundary conditions for the solutions of the momentum equations are based on the specification of the kinematic shear stresses. At the bottom, the bed shear stresses are computed using the near bed velocity components (u_1, v_1) as:

$$(\tau_{bx}, \tau_{by}) = c_b \sqrt{u_1^2 + v_1^2}(u_1, v_1) \qquad \text{(B-15)}$$

where the bottom drag coefficient $c_b = (\frac{\kappa}{\ln(\Delta_1 / 2z_o)})^2$, where κ is the von Karman constant, Δ_1 is the dimensionless thickness of the bottom layer, $z_o = z_o{*}/H$ is the dimensionless roughness height, and $z_o{*}$ is roughness height in meters. At the surface layer, the shear stresses are computed using the u, v components of the wind velocity (u_w, v_w) above the water surface (usually measured at 10 m above the surface) and are given as:

$$(\tau_{sx}, \tau_{sy}) = c_s \sqrt{u_w^2 + v_w^2}(u_w, v_w) \qquad \text{(B-16)}$$

where $c_s = 0.001 \frac{\rho_a}{\rho_w}(0.8 + 0.065\sqrt{u_w{}^2 + v_w^2})$ and ρ_a and ρ_w are the air and water densities, respectively. Zero flux vertical boundary conditions are used for the transport equations.

Numerically, EFDC is second-order accurate both in space and time. A staggered grid or C-grid provides the framework for the second-order accurate spatial finite differencing used to solve the equations of motion. Integration over time involves an internal-external mode splitting procedure separating the internal shear, or baroclinic mode, from the external free surface gravity wave, or barotropic mode. In the external mode, the model uses a semi-implicit scheme that allows the use of relatively large time steps. The internal equations are solved at the same time step as the external equations, and are implicit with respect to vertical diffusion. Details of the finite difference numerical schemes used in the EFDC model are given in Hamrick (2007b), and will not be presented in this report.

The generic transport equation solved in EFDC for a dissolved (*e.g.*, chemical contaminant) or suspended (*e.g.*, sediment) constituent having a mass per unit volume concentration C, is

$$\frac{\partial m_x m_y HC}{\partial t}+\frac{\partial m_y HuC}{\partial_x}+\frac{\partial m_x HvC}{\partial y}+\frac{\partial m_x m_y wC}{\partial z}-\frac{\partial m_x m_y w_{sc} C}{\partial z}= \\ \frac{\partial}{\partial_x}\left(\frac{m_y}{m_x}HK_H\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial_y}\left(\frac{m_x}{m_y}HK_H\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial_z}\left(m_x m_y\frac{K_v}{H}\frac{\partial C}{\partial z}\right)+Q_c \quad \text{(B-17)}$$

where K_V and K_H are the vertical and horizontal turbulent diffusion coefficients, respectively; w_{sc} is a positive settling velocity when C represents the mass concentration of suspended sediment; and Q_c represents external sources or sinks and reactive internal sources or sinks. For sediment, $C = S_i$, where S_i represents the concentration of the *ith* sediment class. So, Eq. B-17, which is the 3D advective-dispersive transport equation, is solved for each of the sediment size classes that the grain size distribution at the site is divided into. In this case, Q_{ci} = source/sink term for the *ith* sediment size class that accounts for erosion/deposition. The equation used to calculate Q_{ci} is the following:

$$S_i = E_{sus,i} - D_{sus,i} \quad \text{(B-18)}$$

where $E_{sus,i}$ = sediment erosion rate for the *ith* sediment size class that is eroded and entrained into suspension, and $D_{sus,i}$ = sediment deposition rate for the *ith* sediment size class. Expressions for $D_{sus,i}$ and $E_{sus,i}$ are given later in this chapter.

The solution procedure for Eq. B-17 is the same as that for the salinity and heat transport equations, which use a high-order upwind difference solution scheme for the advection terms (Hamrick 2007b). Although the advection scheme is designed to minimize numerical diffusion, a small amount of horizontal diffusion remains inherent in the numerical scheme. As such, the horizontal diffusion terms in Equation B-17 are omitted by setting K_H equal to zero.

Appendix C

Description of LTFATE Sediment Transport Module

The sediment transport model in LTFATE is a modified version of the SEDZLJ mixed sediment transport model (Jones and Lick 2001; James *et al.* 2010) that includes a 3D representation of the sediment bed, and can simulate winnowing and armoring of the surficial layer of the sediment bed. SEDZLJ is dynamically linked to LTFATE in that the hydrodynamic and sediment transport modules are both run during each model time step.

Suspended Load Transport of Sediment

LTFATE solves Equation B-17 for the transport of each of the sediment classes to determine the suspension concentration for each size class in every water column layer in each grid cell. Included in this equation is the settling velocity, $w_{sc,}$ for each sediment size class. The settling velocities for noncohesive sediments are calculated in SEDZLJ using the following equation (Cheng 1997):

$$W_s = \frac{\mu}{d}\left(\sqrt{25+1.2d_*^2}-5\right)^{\frac{3}{2}} \tag{C-1}$$

where μ = dynamic viscosity of water; d = sediment diameter; and d_* = non-dimensional particle diameter given by:

$$d_* = d\left[\left(\rho_s/\rho_w - 1\right)g/\nu^2\right]^{1/3} \tag{C-2}$$

where ρ_w = water density, ρ_s = sediment particle density, g = acceleration due to gravity, and ν = kinematic fluid viscosity. Cheng's formula is based on measured settling speeds of real sediments. As a result it produces slower settling speeds than those given by Stokes' Law because real sediments have irregular shapes and thus a greater hydrodynamic resistance than perfect spheres as assumed in Stokes' law.

For the cohesive sediment size classes, the settling velocities are set equal to the mean settling velocities of flocs and eroded bed aggregates determined from an empirical formulation that is a function of the concentration of suspended sediment.

The erosion and deposition of each of the sediment size classes, *i.e.*, the source/sink term in the 3D transport equation (Equation C-17), and the subsequent change in the composition and thickness of the sediment bed in each grid cell are calculated by SEDZLJ at each time step.

Description of SEDZLJ

The sediment bed model in LTFATE is the SEDZLJ sediment transport model (Jones and Lick 2001). SEDZLJ is dynamically linked to EFDC in LTFATE. SEDZLJ is an advanced sediment bed model that represents the dynamic processes of erosion, bedload transport, bed sorting, armoring, consolidation of fine-grain sediment dominated sediment beds, settling of flocculated cohesive sediment, settling of individual noncohesive sediment particles, and deposition. An active layer formulation is used to describe sediment bed interactions during simultaneous erosion and deposition. The active layer facilitates coarsening during the bed armoring process.

Figure C-1 shows the simulated sediment transport processes in SEDZLJ. In this figure, U = near bed flow velocity, δ_{bl} = thickness of layer in which bedload occurs, U_{bl} = average bedload transport velocity, D_{bl} = sediment deposition rate for the sediment being transported as bedload E_{bl} = sediment erosion rate for the sediment being transported as bedload, E_{sus} = sediment erosion rate for the sediment that is eroded and entrained into suspension, and D_{sus} = sediment deposition rate for suspended sediment. Specific capabilities of SEDZLJ are listed below.

- Whereas a hydrodynamic model is calibrated to account for the total bed shear stress, which is the sum of the form drag due to bed forms and other large-scale physical features and the skin friction (also called the surface friction), the correct component of the bed shear stress to

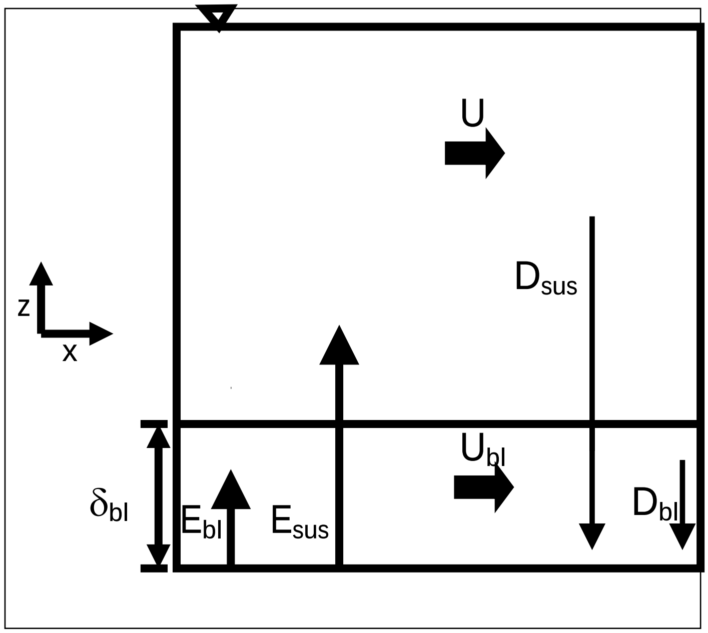

Figure C-1. Sediment transport processes simulated in SEDZLJ.

use in predicting sediment resuspension and deposition is the skin friction. The skin friction is calculated in SEDZLJ as a function of the near-bed current velocity and the effective bed roughness. The latter is specified in SEDZLJ as a linear function of the mean particle diameter in the active layer.

Multiple size classes of both fine-grain (*i.e.*, cohesive) and noncohesive sediments can be represented in the sediment bed. As stated previously, this capability is necessary to simulate coarsening and subsequent armoring of the surficial sediment bed surface during high flow events.

- To correctly represent the processes of erosion and deposition, the sediment bed in SEDZLJ can be divided into multiple layers, some of which are used to represent the existing sediment bed and others that are used to represent new bed layers that form due to deposition during model simulations. Figure C-2 shows a schematic diagram of this multiple bed layer structure. The graph on the right hand side of this figure shows the variation in the measured gross erosion rate (in units of cm/s) with depth into the sediment bed as a function of the applied skin friction. A SEDFLUME study is normally used to measure these erosion rates.

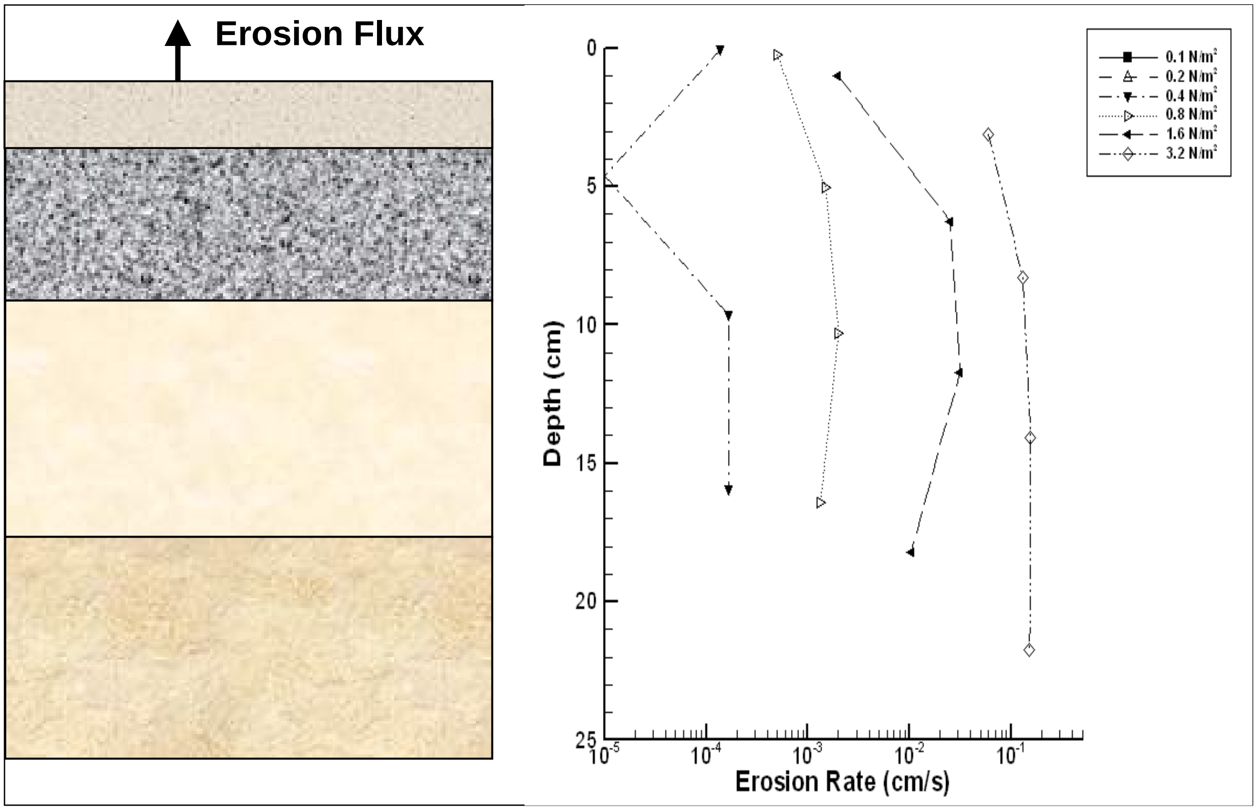

Figure C-2. Multi-bed layer model used in SEDZLJ.

- Erosion from both cohesive and non-cohesive beds is affected by bed armoring, which is a process that limits the amount of bed erosion that occurs during a high-flow event. Bed armoring occurs in a bed that contains a range of particle sizes (*e.g.*, clay, silt, sand). During a high-flow event when erosion is occurring, finer particles (*i.e.*, clay and silt, and fine sand) tend to be eroded at a faster rate than coarser particles (*i.e.*, medium to coarse sand). The differences in erosion rates of the various sediment particle sizes creates a thin layer at the surface of the sediment bed, referred to as the active layer, that is depleted of finer particles and enriched with coarser particles. This depletion-enrichment process can lead to bed armoring, where the active layer is primarily composed of coarse particles that have limited mobility. The multiple bed model in SEDZLJ accounts for the exchange of sediment through and the change in composition of this active layer. The thickness of the active layer is normally calculated as a time varying function of the mean sediment particle diameter in the active layer, the critical shear stress for resuspension corresponding to the mean particle diameter, and the bed shear stress. Figure C-3 shows a schematic of the active layer at the top of the multi-bed layer model used in SEDZLJ.

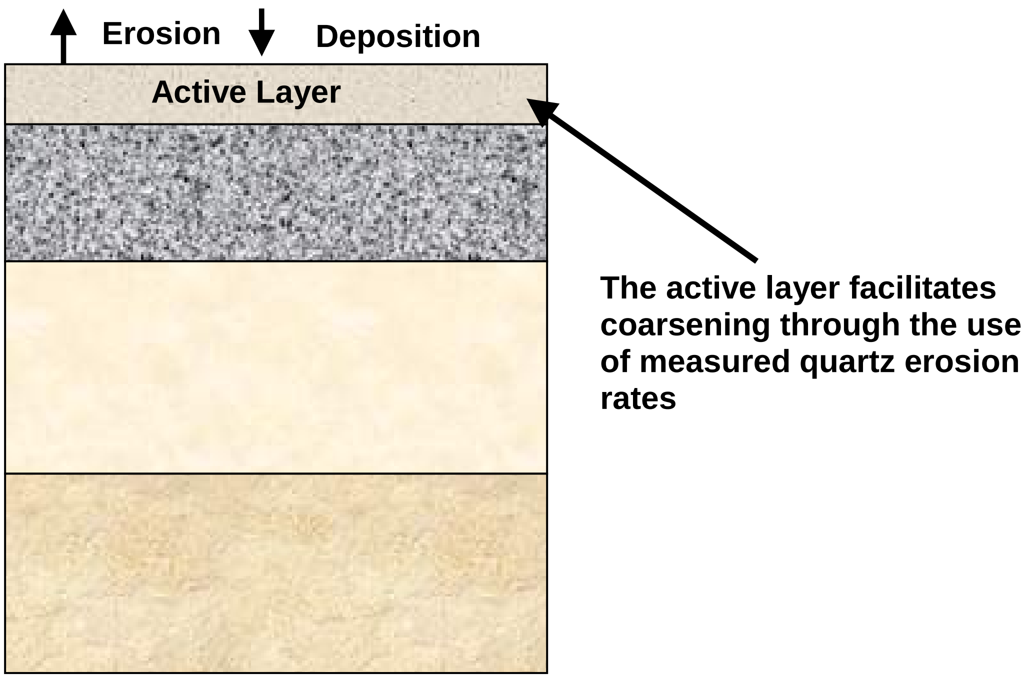

Figure C-3. Schematic of Active Layer used in SEDZLJ.

- SEDZLJ was designed to use the results obtained with SEDFLUME, which is a straight, closed conduit rectangular cross-section flume in which detailed measurements of critical shear stress of erosion and erosion rate as a function of sediment depth are made using sediment cores dominated by cohesive sediment collected at the site to be modeled (McNeil *et al*. 1996). However, when SEDFLUME results are not available, it is possible to use a combination of values for these parameters available from literature and/or the results of SEDFLUME tests performed at other similar sites. In this case, a detailed sensitivity analysis should be performed to assist in quantifying the uncertainty that results from the use of these non-site specific erosion parameters.

- SEDZLJ can simulate overburden-induced consolidation of cohesive sediments. An algorithm that simulates the process of primary consolidation, which is caused by the expulsion of pore water from the sediment, of a fine-grained, *i.e.*, cohesive, dominated sediment bed is included in SEDZLJ. The consolidation algorithm in SEDZLJ accounts for the following changes in two important bed parameters: 1) increase in bed bulk density with time due to the expulsion of pore water, and 2) increase in the bed shear strength (also referred to as the critical shear stress for resuspension) with time. The latter parameter is the minimum value of the bed shear stress at which measurable resuspension of cohesive sediment occurs. As such, the process of consolidation typically results in reduced erosion for a given excess bed shear stress (defined as the difference between the bed shear stress and the critical shear stress for erosion) due to the increase in the bed shear strength. In addition, the increase in bulk density needs to be represented to accurately account for the mass of sediment (per unit bed area) that resuspends when the bed surface is subjected to a flow-induced excess bed shear stress.

Models that represent primary consolidation range from empirical equations that approximate the increases in bed bulk density and critical shear stress for resuspension due to porewater expulsion (Sanford 2008) to finite difference models that solve the non-linear finite strain consolidation equation that governs primary consolidation in saturated porous media (*e.g.*, Arega and Hayter 2008). An empirical-based consolidation algorithm is included in SEDZLJ.

- SEDZLJ contains a morphologic algorithm that, when enabled by the model user, will adjust the bed elevation to account for erosion and deposition of sediment.

Bedload Transport of Noncohesive Sediment

The approach used by Van Rijn (1984) to simulate bedload transport is used in SEDZLJ. The 2D mass balance equation for the concentration of sediment moving as bedload is given by:

$$\frac{\partial\left(\delta_{bl}C_b\right)}{\partial t}=\frac{\partial q_{b,x}}{\partial x}+\frac{\partial q_{b,y}}{\partial y}+Q_b \qquad \text{(C-3)}$$

where δ_{bl} = bedload thickness; C_b = bedload concentration; $q_{b,x}$ and $q_{b,y}$ = x- and y-components of the bedload sediment flux, respectively; and Q_b =

sediment flux from the bed. Van Rijn (1984) gives the following equation for the thickness of the layer in which bedload is occurring:

$$\delta_{bl} = 0.3 d d_*^{0.7} (\Delta\tau)^{0.5} \tag{C-4}$$

where $\Delta\tau = \tau_b - \tau_{ce}$; τ_b = bed shear stress, and τ_{ce} = critical shear stress for erosion.

The bedload fluxes in the x- and y-directions are given by:

$$q_{b,x} = \delta_{bl}\, u_{b,x} C_b$$

$$q_{b,y} = \delta_{bl}\, u_{b,y} C_b$$

where $u_{b,x}$ and $u_{b,y}$ = x- and y-components of the bedload velocity, u_b, which van Rijn (1984) gave as

$$u_b = 1.5\tau_*^{0.6}\left[\left(\frac{\rho_s}{\rho_w} - 1\right) g d\right]^{0.5} \tag{C-5}$$

with the dimensionless parameter τ_* given as

$$\tau_* = \frac{\tau_b - \tau_{ce}}{\tau_{ce}} \tag{C-6}$$

The x- and y-components of u_b are calculated as the vector projections of the LTFATE Cartesian velocity components u and v.

The sediment flux from the bed due to bedload, Q_{bl}, is equal to

$$Q_b = E_{bl} - D_{bl} \tag{C-7}$$

Deposition of Sediment

In contrast to previous conceptual models, deposition of suspended noncohesive sediment and cohesive flocs is now believed to occur continually, and not just when the bed shear stress is less than a so-called critical shear stress of deposition (Mehta 2014). The rate of deposition of the *ith* sediment size class, $D_{sus,i}$ is given by:

$$D_{sus,i} = -\frac{W_{s,i} C_i}{d} \tag{C-8}$$

where $W_{s,i}$ is given by Eq. C-1 for noncohesive sediment and by the empirical formulation used for the settling velocities of suspended flocs and bed aggregates, and d = thickness of the bottom water column layer in a three-dimensional model. Because of their high settling velocities, noncohesive sediments deposit relatively quickly (in comparison to the deposition of cohesive sediments) under all flows. Due to the settling velocities of flocs being a lot slower than those of noncohesive sediment, the deposition rate of flocs are usually several orders of magnitude smaller.

Deposited cohesive sediments usually form a thin surface layer that is often called a fluff or benthic nepheloid layer that is often less than 1 cm in thickness. The fluff layer typically forms in estuaries and coastal waters via deposition of suspended flocs during the decelerating phase of tidal flows, in particular immediately before slack water (Krone 1972; and Hayter and Mehta 1986). The fluff layer is usually easily resuspended by the accelerating currents following slack water in tidal bodies of water.

The rate of deposition of the *ith* noncohesive sediment class moving as bedload is given by (James *et al.* 2010):

$$D_{bl,i} = -P_{bl,i} W_{s,i} C_{bl,i} \tag{C-9}$$

where $C_{bl,i}$ = mass concentration of the *ith* noncohesive sediment class being transported as bedload, and $P_{bl,i}$ = probability of deposition from bedload transport. The latter parameter is given by:

$$P_{bl,i} = \frac{E_{bl,i}}{W_{s,i} C_{bl,i}^{eq}} \tag{C-10}$$

where

$$C_{bl,i}^{eq} = \frac{0.18 C_o \tau_b}{d_*} \tag{C-11}$$

which is the steady-state sediment concentration in bedload that results from a dynamic equilibrium between erosion and deposition, d_* is given by Eq. C-2, and C_o = 0.65.

Erosion of Sediment

Erosion of a cohesive sediment bed occurs whenever the current and wave-induced bed shear stress is great enough to break the electrochemical interparticle bonds (Partheniades 1965; Paaswell 1973). When this happens, erosion takes place by the removal of individual sediment particles or bed aggregates. This type of erosion is time dependent and is defined as surface erosion or resuspension. In contrast, another type of erosion occurs more or less instantaneously by the removal of relatively large pieces of the bed. This process is referred to as mass erosion, and occurs when the bed shear stress exceeds the bed bulk strength along some deep-seated plane that is typically much greater than the bed shear strength of the surficial sediment.

The erosion rate of cohesive sediments, E, is given experimentally by:

$$\begin{aligned} E &= 0; && (\tau < \tau_{cr}) \\ E &= A\tau^n; && (\tau_{cr} < \tau < \tau_m) \\ E &= A\tau_m^n; && (\tau > \tau_m) \end{aligned} \tag{C-12}$$

where the exponent, coefficient, critical shear stress for erosion, and maximum shear stress (above which E is not a function of τ) n, A, and τ_{cr}, respectively, are determined from a SEDFLUME study. The erosion rates of the noncohesive sediment size classes were determined as a function of the difference between the bed shear stress and the critical shear stress for erosion using the results obtained by Roberts *et al.* (1998) who measured the erosion rates of quartz particles in a SEDFLUME.

The erosion rate of the *ith* noncohesive sediment size class that is transported as bedload, $E_{bl,i}$, is calculated by the following equation in which it is assumed there is dynamic equilibrium between erosion and deposition:

$$E_{bl,i} = P_{bl,i} W_{s,i} C_{bl,i} \tag{C-13}$$

Appendix D

Description of LTFATE Propwash Module

The propwash module added to LTFATE simulates the near-bed flow field behind a moving vessel, specifically the velocity within the ship's propeller jet, and calculates the resulting bed shear stresses. The latter are vectorially added to the current and wave induced bed shear stresses and used to calculate the rates of sediment erosion. This module is described in this Appendix.

Data Requirements

The data needed to fully utilize the propwash module consists of the history of vessel movements in the SJR, especially near the Site, the types (e.g., tugboats, tankers, container ships), sizes, and drafts of the vessels; the diameter, applied horsepower, depths of the propeller shafts, and number of propellers on each of the vessels; the vessel speeds and paths, and the times when the vessels pass close to the Site. This would be an enormous database, but it was not available to EPA. A greatly simplified and idealized representation of such a database was constructed for use with the propwash module. Following the description of the propwash module in the next section, the methodology of incorporating it into the sediment transport simulations performed with LTFATE is described.

Description of Propwash Module

The approach described by Lam *et al*. (2011) was used to predict the time-averaged axial, rotational and radial components of the velocity field within a vessel's propeller jet. The axial component of the propeller's velocity jet contributes the most to the near bed velocity that induces the shear stress that acts on the surface of the sediment bed. The following equations given by Lam *et al*. are used to calculate the efflux velocity. Equation D-1 gives the basic equation for calculating the efflux velocity (V_e), which is the maximum velocity at the propeller's face.

$$V_e = E_o n D (C_t)^{\frac{1}{2}} \qquad \text{(D-1)}$$

where E_o = efflux coefficient, n = rotation speed of the propeller (rps), D = propeller diameter (m), and C_t = propeller thrust coefficient. The latter is calculated using the area $A = \pi D^2/4$. The efflux coefficient is given by

$$E_o = \left(\frac{D}{D_h}\right)^{-0.403} C_t^{-1.79} BAR^{0.744} \qquad \text{(D-2)}$$

where BAR = ratio of projected area of all propeller blades to the propeller disc area.

Another parameter that is needed is the distance, R_{mo}, from the rotation axis to the location where the axial velocity is maximum, at which the maximum thrust occurs. Hamill *et al*. (2004) found the following expression for this distance.

$$R_{mo} = 0.7(R - R_h) \qquad \text{(D-3)}$$

where R = propeller radius, and R_h = radius of the propeller hub.

Using the values of R_{mo} and V_e, the maximum velocity and its location at different longitudinal distances can be predicted as follows for the zone of established flow. The following equation by Hashmi (1993) can be used to calculate the decay of the maximum velocity for a submerged jet, given by the ratio V_{max}/V_e, at a distance x from the initial efflux plane.

$$\frac{V_{max}}{V_e} = 0.638 e^{(-0.097(x/D))} \qquad \text{(D-4)}$$

Using the value of V_{max} at a given longitudinal distance x, the lateral velocity distribution ($V_{x,r}$) in the zone for established flow can be determined using the following equation.

$$\frac{V_{x,r}}{V_{max}} = e^{(-22.2(r/x)^2)} \qquad \text{(D-5)}$$

where r = the lateral distance from the longitudinal axis.

Application of the Propwash Module

Equation D-5 was used to calculate $V_{x,r}$ for a tugboat at the position just above the bed surface using estimates for the parameters defined above. The tugboat used in the model simulations was assumed to have the same physical characteristics as that given by Ziegler *et al.* (2014), these being D = 1.8 m, depth of propeller shaft = 2.7 m, number of propellers = 2, maximum horsepower = 6,000, and the power applied was 50 percent.

The assumed path of a tugboat, that being parallel to the eastern side of the cap and approximately 30 m from the eastern cap edge, defined the direction of $V_{x,r}$, and this velocity was vectorially added to the current- and wave-induced near bottom flow velocity in the specified grid cells. The grid cells were defined to be those along the path of the tugboat and that fell within the distance $8D$ from the instantaneous location of the tugboat. It was assumed that the tugboat did not cross the cap due to the relatively shallow water over the inundated portion of the cap.

The total near bottom flow velocity was used to calculate the bed shear stress in the SEDZLJ sediment bed model, and subsequently used to calculate the erosion rate of the surficial sediment bed layer. During the month-long model simulation in which the propwash module was activated, it was assumed that a single tugboat moved along the specified path, alternating in directions six times over the duration of a tidal cycle. A few centimeters of scour occurred during each passage of the tugboat, with the depth of scour decreasing throughout the model simulation due to increasing bed shear strength with depth into the sediment bed. This resulted in a net scour of more than 70 cm in most of the grid cells along the chosen path.

Appendix E

Wave Modeling during Hurricane Ike

Purpose

The purpose of the numerical wave modeling is to estimate storm waves during Hurricane Ike at the northern Galveston Bay and Port of Houston.

Wave Model

Wave modeling was conducted using CMS-Wave, a steady-state two-dimensional spectral wave model (Lin *et al.* 2008; Lin *et al.* 2011a, 2011b) capable of simulating wind waves in the open coast or in a bay or estuarine system. CMS-Wave is part of an integrated Coastal Modeling System (Demirbilek and Rosati 2011) developed at CHL to assist in coastal region project applications.

CMS-Wave can be used either in half-plane or full-plane mode for wind wave generation and transformation. It is based on the wave-action balance equation that includes wave propagation, refraction, shoaling, diffraction, reflection, breaking, and dissipation. The half-plane mode is the default and CMS-Wave can run more efficiently in this mode as waves are transformed primarily from the seaward boundary toward shore.

In the present study, CMS-Wave full-plane mode was used to simulate storm wave conditions during Hurricane Ike at the northern Galveston Bay and Port of Houston. The CMS-Wave uses the Surface-water Modeling System, SMS (Demirbilek *et al.* 2007; Zundel 2006) interface for grid generation, model setup, and post-processing.

Model Domain, Bathymetry, and Forcing

Bathymetry Data

Bay bathymetry data available for the wave modeling included LiDAR (http://shoals.sam.usace.army.mil) and periodic channel surveys conducted by the USACE Galveston District. The offshore bathymetry data were obtained from the US Coastal Relief Model by National Geophysical Data Center, NGDC (http://www.ngdc.noaa.gov/mgg/coastal/crm.html). The upland topography was downloaded from NOAA Gridded Global Topography Database (http://www.ngdc.noaa.gov/mgg/topo/topo.html). The digital coastlines are available from GEOphysical DAta System GEODAS (https://www.ngdc.noaa.gov/mgg/geodas/geodas.html).

Model Grid

The CMS model domain covers the Galveston Bay system with navigation channels connecting GIWW, Port of Houston, and Gulf of Mexico. It includes the Houston-Galveston Ship Channel, Galveston Entrance Channel between the east end of Galveston Island and the west end of Bolivar Peninsula, San Luis Pass between the west end of Galveston Island and the east end of Follets Island, and Rollover Pass, a small man-made cut located at the lower east end of East Bay. Figure E-1 shows the Galveston Bay system included in the present wave modeling area.

The CMS model grid extends approximately 60 mi (95 km) alongshore and 54 mi (86 km) cross-shore with the southern offshore boundary reaching to the 60-ft (18-m) isobaths, referenced to Mean Sea Level (MSL). Figure E-2 shows the model domain consisting of 1166 × 1406 cells with variable cell spacing of 130 ft (40 m) along the Houston-Galveston Ship Channel and 660 ft (200 m) at the corners of offshore boundary.

Forcing Conditions

Wind and water level data used to force the wave model are available from three NOAA coastal stations (http://tidesandcurrents.noaa.gov): Sta 8771013 at Eagle Point (29° 28' 54” N, 94° 55' 0” W), Sta 8770613 at Morgans Point (29° 40' 54” N, 94° 59' 6” W), and Sta 8771341 at Galveston Bay entrance north jetty (29° 21' 24” N, 94° 43' 30” W). Directional wave spectra measured from NDBC Buoy 42035 (29° 13' 54” N, 94° 24' 46” W)

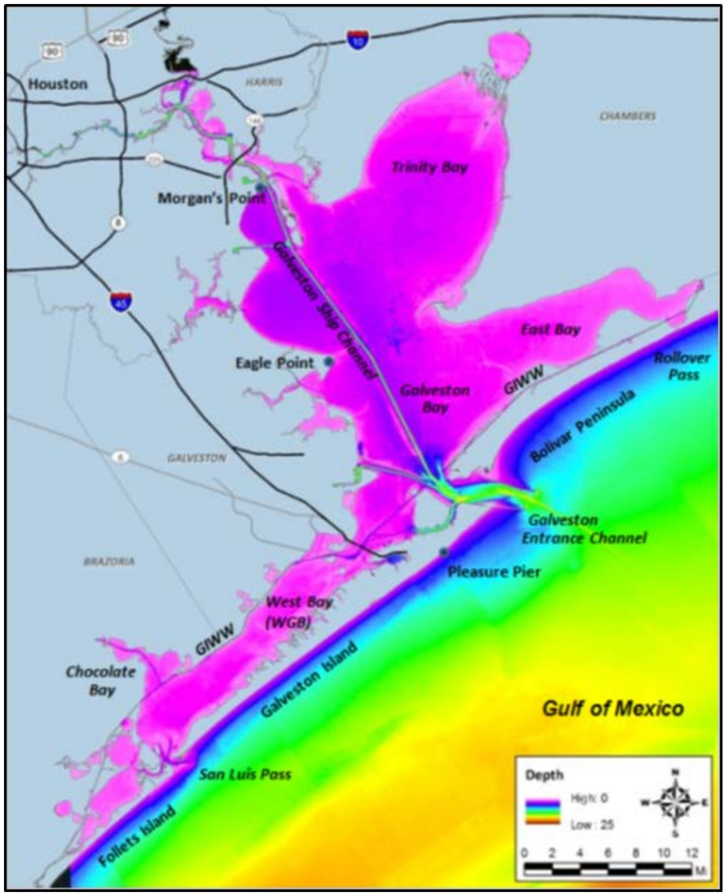

Figure E-1. Location map of Galveston Bay system

offshore Galveston Bay Entrance (Figure E-2) are use as incident waves along the wave model Gulf boundary. Buoy 42035 also collects surface wind data. Figures E-3 shows the hourly wind and wave data measured from NOAA Stations 8771013, 8770613, 8771341, and NDBC Buoy 42035 in September 2008. Strong winds with large waves observed around 13th September are corresponding to Hurricane Ike during landfall near the Galveston Bay entrance.

Figure E-4 shows the water level data collected at three NOAA coastal stations in September 2008. High water levels occurred on the 13th September corresponding to the storm surge during Hurricane Ike.

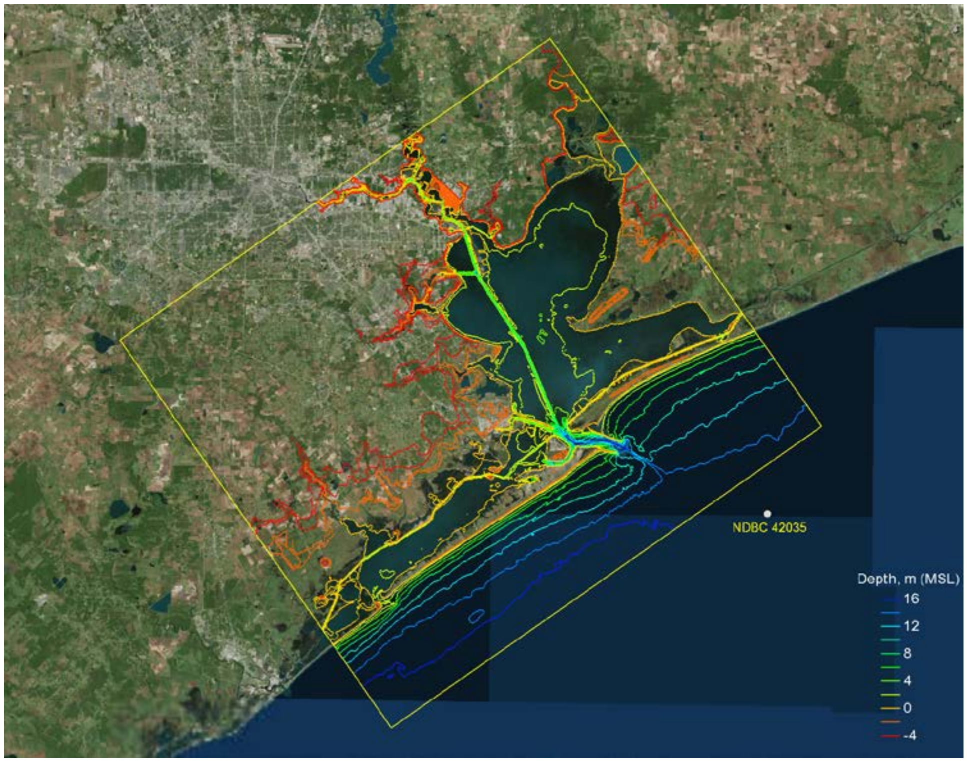

Figure E-2. CMS-Wave model domain and depth contours

Model Simulation

Wave simulation was conducted for Hurricane Ike for period of 15 August to 30 September 2008 with the wind, water level, and incident wave input in 1-hr interval. The wind and incident wave input was based on Buoy 42035 data. The water level input was based on NOAA Sta 8771013 at Eagle Point. Wave runup and wave setup calculations were included in the model simulation. Figure E-5, as an example, shows the model wave field under pre-Ike condition (incident wave height = 0.60 m, mean period = 6.2 sec, water level = 0 m, MSL, and wind speed = 6.7 m/sec from SSE) at 0100 GMT, 15th August 2008. Maximum wave height along the north perimeter of Galveston Bay is 0.28 m (mean period = 2.3 sec). Figure E-6 shows the storm wave field under high water level during Ike inside Galveston Bay (incident wave height = 5.3 m, mean period = 14.3 sec, water level = 2.5 m, MSL, and wind speed = 30.0 m/sec from SE) at 0400 GMT, 13th September 2008. Maximum wave height inside the bay is 1.4 m (mean period = 4.0 sec). Model results clearly show larger waves under strong wind and over high water level during Ike along the northern perimeter of Galveston Bay and around the Port of Houston area.

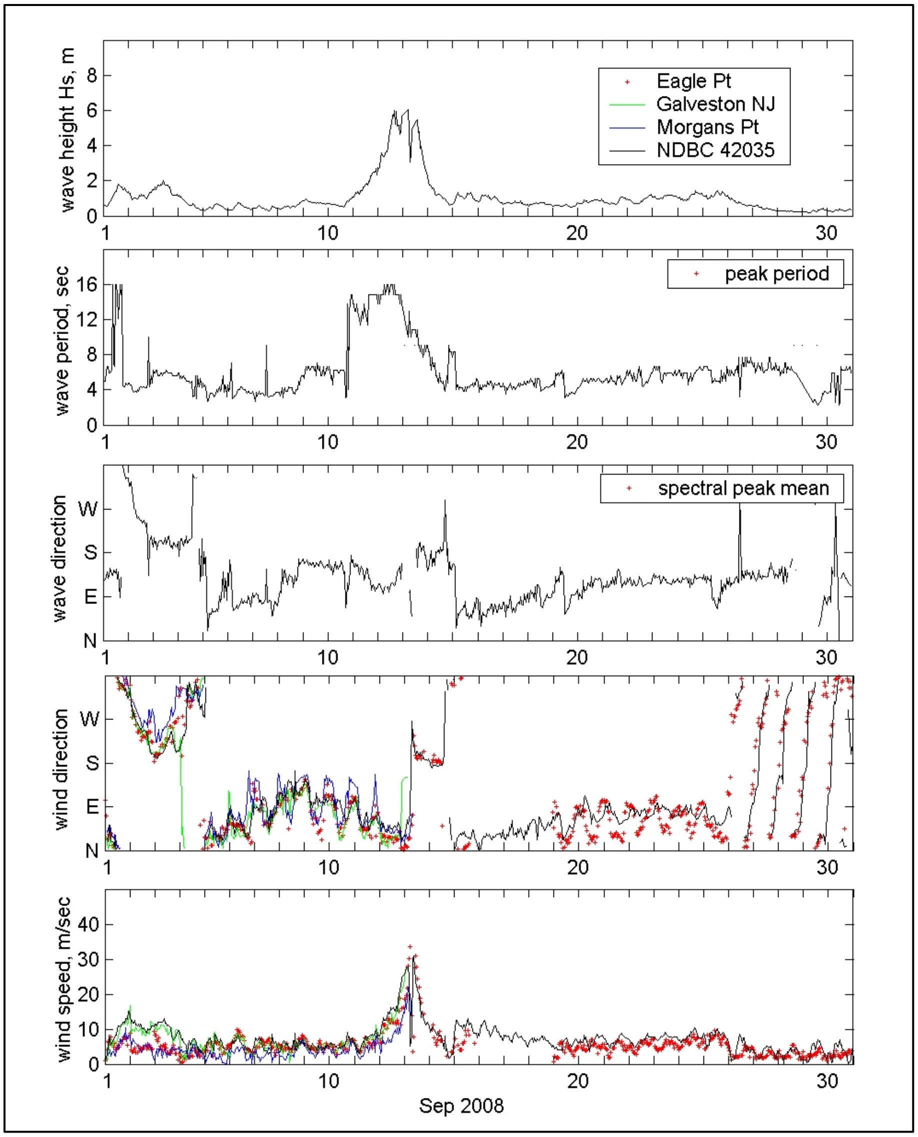

Figure E-3. Available wind and wave data in September 2008

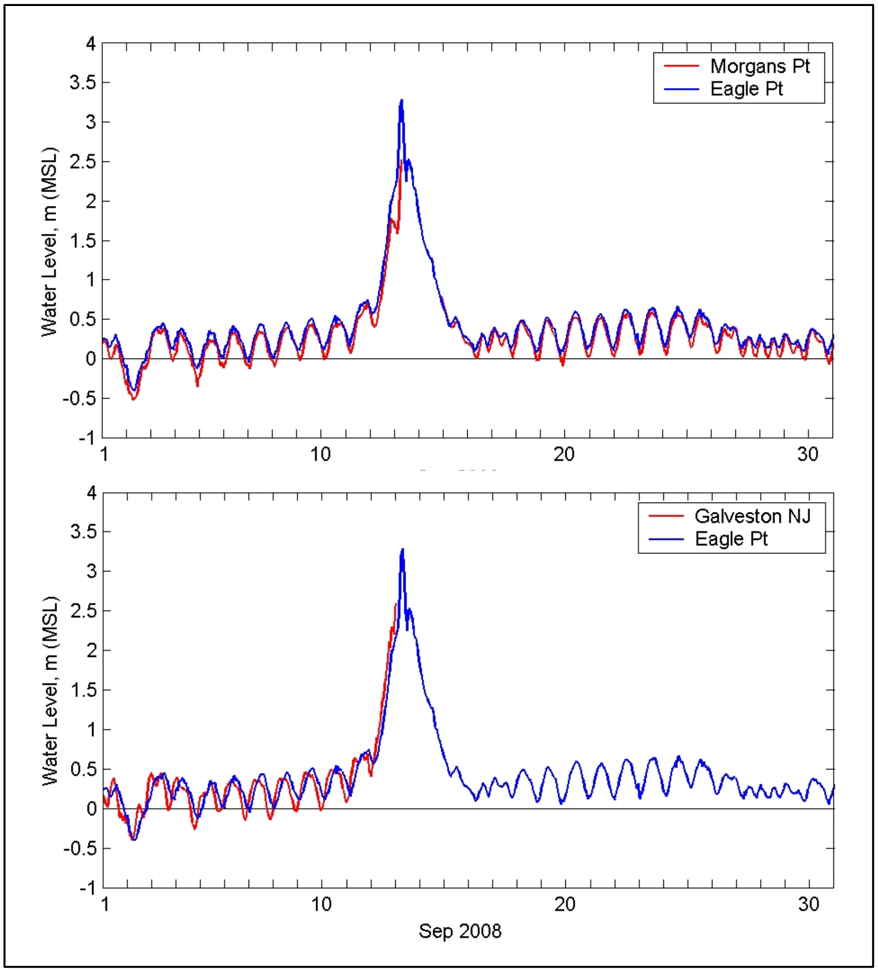

Figure E-4. Water level measurements in September 2008

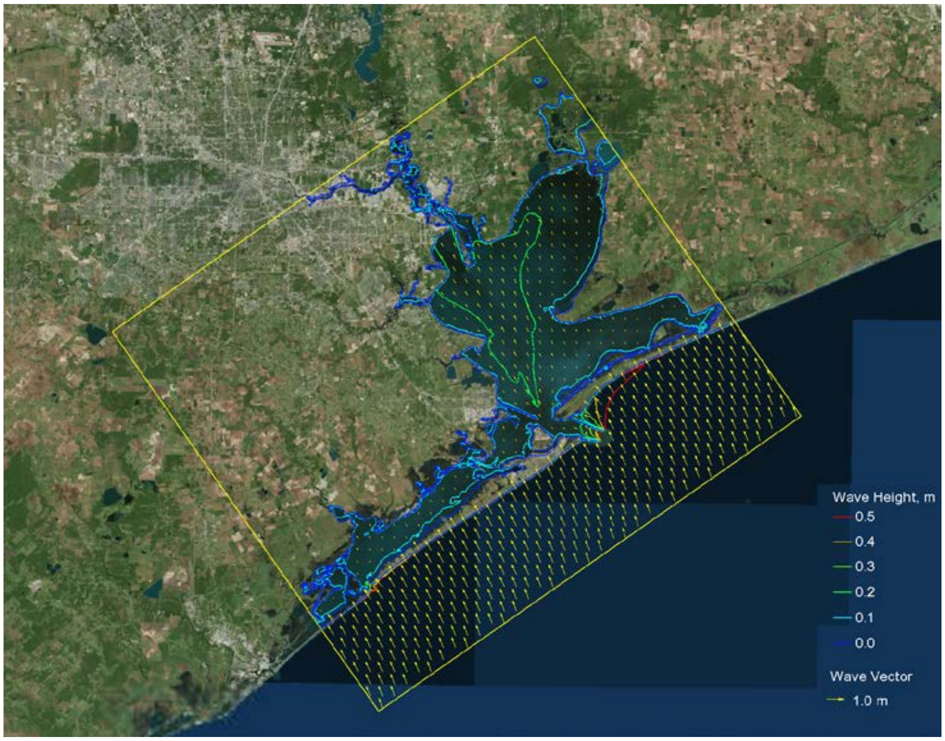

Figure E-5. Model calculated wave field at 0100 GMT, 15th August, 2008

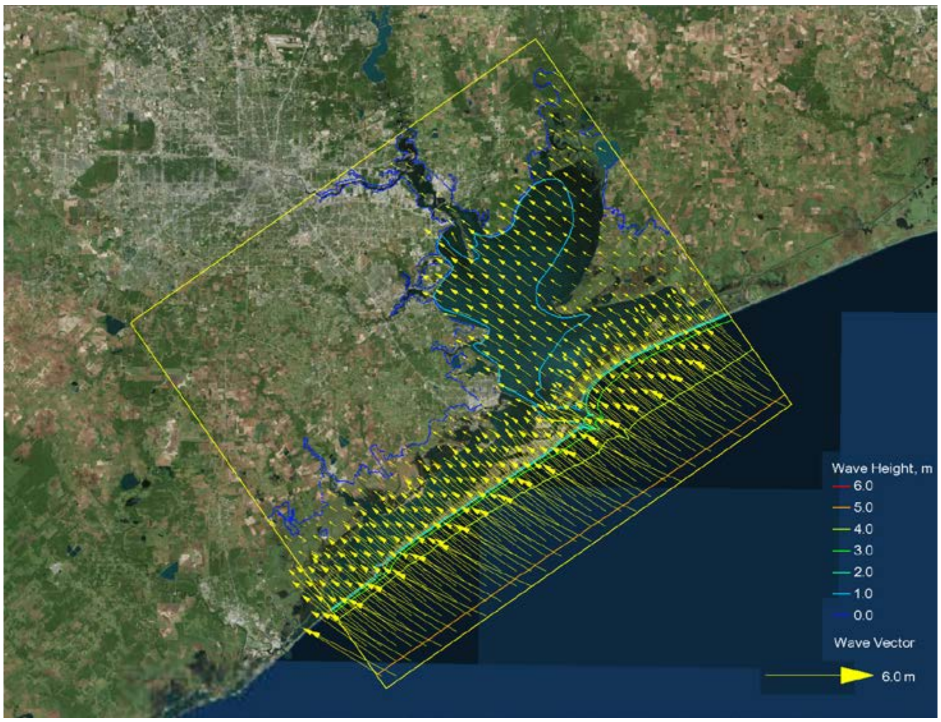

Figure E-6. Model calculated wave field at 0400 GMT, 13th September, 2008