August 2024
GLO Reservoir Assessment

Assessment of Reservoir-Impounded Sediment as a Sediment Source for Coastal Resiliency Projects

Prepared for the Texas General Land Office

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Prepared for
Texas General Land Office
1700 Congress Avenue
Austin, Texas 78701

Prepared by
Anchor QEA
901 South Mopac Expressway
Barton Oaks Plaza V, Suite 150
Austin, Texas 78746

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ABBREVIATIONS

BA	Biological Assessment
CFR	Code of Federal Regulations
CoCC	City of Corpus Christi
CWA of 1972	Clean Waters Act of 1972
cy	cubic yard
EA	Environmental Assessment
EIS	Environmental impact statement
EPA	U.S. Environmental Protection Agency
ERL	Effects Range Low
ERM	Effects Range Medium
FEMA	Federal Emergency Management Agency
GLDD	Great Lakes Dredge and Dock Company, LLC
GLO	Texas General Land Office
GP	General Permits
IP	Individual Permit
LNRA	Lavaca-Navidad River Authority
LRWPG	Lavaca Regional Water Planning Group
LNRWP	Lower Nueces River Watershed Partnership
M	million
NEPA	National Environmental Policy Act
NHPA of 1966	National Historic Preservation Act of 1966
NOAA	National Oceanic and Atmospheric Administration
NRA	Nueces River Authority
NWP	Nationwide Permit
OHWM	Ordinary High Water Mark
PCL	Protective Concentration Levels
PGP	Programmatic General Permit
POL	Port of Liberty
RGP	Regional General Permit
RHA 1899	Rivers and Harbors Act of 1899
RL	reporting level
SM	silty sand
SP	poorly graded sand
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
THC	Texas Historical commission

TPWD	Texas Parks and Wildlife Department
TRA	Trinity River Authority
TRRP	Texas Risk Reduction Program
TSS	total suspended solids
TWDB	Texas Water Development Board
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WPP	Watershed Protection Plan

1 Background

The Texas General Land Office (GLO) is Texas's lead agency for many coastal restoration and resiliency projects. These projects are critical to sustain natural ecosystems and protect human infrastructure and, as such, are critically important to the economy and future of Texas. A combination of factors, including relative sea level rise, trapping of sediment behind reservoirs, and hydraulic modifications of coastal rivers and streams, has contributed to a loss of coastal ecosystems, which may be ameliorated by the intentional addition of sediments to improve coastal resiliency. Possible sediment sources include off-shore dredging, dredging of ship channels, and dredging of reservoirs.

To better understand these issues, the GLO has undertaken the development of a Sediment Management Plan, which will, in part, identify sediment sources and sinks throughout the coast. This report documents an analysis performed by Anchor QEA for the GLO regarding the possibility of using reservoir-impounded sediment as a sediment source for coastal resiliency projects. The beneficial use of reservoir sediments for coastal resiliency projects will support the GLO's mission and the GLO's Texas Coastal Resiliency Master Plan. Such dredging will also provide benefits to reservoir owners, including increased water supply, improved recreation, reduced flood risks, or other management objectives.

Studies have been completed by Texas and federal agencies to identify sources of sediment for use in coastal resiliency projects (USACE and GLO 2021, Freese and Nichols 2016). While these previous studies have assessed various sources of sediment, they have not included feasibility analysis of reservoir-impounded sediment. This report is intended to focus on the use of reservoir-impounded sediment that would provide a benefit for both the reservoir as well as the coastal resiliency project.

This desktop study includes an assessment and quantification of accumulated sediments in three reservoirs and covers both technical and economic viability for use of dredged sediments in coastal resiliency projects.

To meet the objectives of this study, available information on sediment accumulation and material quality was compiled for each selected candidate reservoir, and generalized cost projections were prepared for each reservoir-coastal resiliency project pairing. The project-pairing cost projections were then compared to estimated costs for import of new material to the coastal resiliency projects to evaluate economic feasibility. An additional analysis was performed to assess the feasibility of using sediment removed from a shipping channel to the Port of Liberty for coastal resiliency purposes. This study includes pre-design level cost projections due to the lack of engineering design and resulting uncertainty of many project aspects. However, this study provides general recommendations for dredging project design, as well as alternatives for material transport between the dredging site and the coastal restoration site.

Overall, this document provides a summary of the analysis, as well as broader discussions of the feasibility of pairing reservoir dredging with coastal resiliency and restoration. The objectives of this study are to provide the GLO with a framework for further assessment of beneficial use opportunities, including substantial cost drivers and constructability factors.

1.1 Review of Comparable Dredging Projects

This section presents examples of reservoir and coastal dredging projects that incorporated beneficial use of the dredged material. These examples illustrate design factors that promote successful projects and, hence, may serve as guidance to future dredging and restoration project parings.

A frequently used resource for best practices and project examples for coastal resiliency projects is the U.S. Army Corps of Engineers (USACE) Engineering With Nature Initiative, and its Atlas Series publications. Additional examples of beneficial uses of dredged material for coastal resiliency are represented in all three volumes of the Atlas Series (Bridges et al 2018, Bridges et al 2021, and Tritinger et al 2024), which serve as a general reference for successful projects.

1.1.1 Pierce Marsh Wetland Restoration Project, Texas

The Pierce Marsh Wetland Restoration Project involved the use of sediment dredged from the Gulf Intracoastal Waterway to restore over 115 acres of wetlands. The Pierce Marsh project was conducted in two phases to improve marsh habitat to offset the effects of estuarine marsh contamination and habitat degradation from industrial activity near Texas City. By the completion of the second project phase in 2024, over 280,000 cubic yards (cy) of dredged sediment were placed over the Pierce Marsh site to increase elevations for revegetation with cordgrass (NOAA 2024). Dredged sediment was hydraulically pumped over 7 miles from the navigation channel to the Pierce Marsh site.

A unique aspect of this project was the number of private, state, and federal stakeholders involved from conceptualization to final completion. Industrial firms, environmental non-profit organizations, private consultants, and multiple federal agencies provided input on design, sequencing, funding, and permitting. The number of stakeholders involved indicate the complexity and logistical challenges coastal resiliency projects can face. This project illustrates that successful restoration projects may require the involvement of a diverse stakeholder group.

1.1.2 Lake Houston and the San Jacinto River, Texas

Hurricane Harvey made landfall on the Texas coast in August 2017, causing significant flooding and flood-related sediment deposition in the San Jacinto River and Lake Houston reservoir system. Accumulated sediment from Hurricane Harvey decreased the flow capacity of the San Jacinto River, increasing the likelihood of flooding and greatly reducing navigability (USACE 2019b).

The Texas Division of Emergency Management contacted the Federal Emergency Management Agency (FEMA) for federal assistance to improve the flood plain and restore navigability. FEMA assigned the USACE Galveston District to conduct dredging within the West Fork of the San Jacinto River. USACE created a dredging plan, permitted through the National Environmental Policy Act (NEPA), that encompassed the removal of 1.8 million cy of sand and debris from the river with the purpose of restoring the river and mouth of Lake Houston to pre-Hurricane Harvey conditions. Project objectives included dredging a channel approximately 400 feet wide by 2.7 miles long with a bottom depth of 6 to 8 feet deep (GLDD 2019).

Dredging operations began in September 2018 with USACE selecting Great Lakes Dredge LP as the prime contractor. Project operations were completed in January 2020 with a total of 1.8 million cy of sand and debris removed from the San Jacinto River and Lake Houston reservoir system. Dredging operations involved mechanical dredging for areas with large debris such as logs and concrete and hydraulic methods for removing finer sediment. Sediment was then pumped through booster pumps through 4.5 miles of 24-inch pipeline to a dewatering staging area (Despart 2018). This operation involved the mobilization of more than 200 truckloads of equipment and supplies. Removed sediment was repurposed for beneficial use in flood mitigation projects in the region (GLDD 2019). Publicly available cost information indicates that this project cost approximately $70 million, equating to approximately $40 per cy (Despart 2018).

This project illustrates the feasibility of utilizing reservoir-dredged sediment for beneficial use. The use of multiple forms of dredging, both mechanical for debris removal and hydraulic for fine sediment, indicate that sediment conditions drive equipment selection.

1.1.3 Buffalo Harbor—Unity Island North Pond Habitat Restoration, New York

This project involved dredging approximately 56,000 cubic yards of sediment from the Buffalo Harbor federal navigation channel for habitat restoration on Unity Island (Dredging Today 2018). The sediment was transported to an existing island, where it was used to restore approximately 10 acres of coastal wetland habitat. Construction was completed between 2018 and 2020, and successive habitat monitoring efforts have indicated a successful outcome including increasing vegetation. While not a reservoir dredging project, this example illustrates a successful implementation of a coastal habitat project, which was paired successfully with a dredging need (in this case, the sediment source from a dredging project to improve navigation on an inland river channel).

The project was funded through USACE’s Continuing Authorities Program 204 and a Habitat Enhancement and Restoration Fund grant awarded to the City of Buffalo from the New York Power Authority. The ability of this project to be funded by a group of diverse stakeholders indicates the ability to formulate successful project pairings if critical dredging needs are identified. In total, the project created over 35,000 square feet of new diverse vegetation that has been shown to be self-sustaining.

1.1.4 Hamilton Army Airfield Wetland Restoration, California

This project, located in coastal Marin County in California, was paired with the 50-foot Deepening Project that increased the permissible navigation draft in the Port of Oakland (USACE 2023a). This project was a joint venture between USACE and the California Coastal Conservancy, which was the local sponsoring agency. Approximately 3.5 million cubic yards from the Port of Oakland dredging project and an additional 2.3 million cubic yards from additional dredging projects were used to create 648 acres of restored wetland habitat in what was once the Hamilton Army Airfield. A beneficial aspect of this project is the ability for it to accept 16.8 million cubic yards of additional dredged material at different locations at the restoration site.

The cost of the project was somewhat subsidized by offsetting the transportation and disposal costs of the Port of Oakland dredging project. Without pairing with the restoration project, dredged sediment would require extensive transport and open-ocean disposal. By pairing with the coastal resiliency project, the dredging project was saved a portion of the transportation costs and the restoration project benefited from the use of the sediment. Due to the quantity of sediment required at the coastal resiliency project site, it is unlikely to have been a financially feasible project without the reuse of dredged material.

1.1.5 Lake Springfield Sediment Removal Project, Illinois

The Lake Springfield Sediment Removal Project occurred near Springfield, Illinois, in the late 1980s (Buckler et al 1988). This project involved dredging from a drinking water reservoir to recover water storage capacity and improve recreation. A total of 2.7 million cubic yards of material were targeted for hydraulic dredging from Lake Springfield. To improve the financial feasibility of the project and to beneficially reuse the material, the upland dewatering impoundment was reclaimed to farmland following project completion. The decision to reclaim the dredged material for farmland was based on a study that indicated success in corn production following the application of fine-grained silt from a dredging operation. A major benefit of farmland reclamation is the elimination of the need for additional transportation after dewatering operations were completed, which substantially reduced total project costs. The dredged sediment remained in place at the upland dewatering facility and the facility was converted to farmland.

Project costs were made available in a case study by Buckler et al (1988). Total project costs for Phase I of the project included dredging approximately 1.2 million cubic yards of sediment, at a cost of $3.01 per cy in 1988 (approximately equal to $8.31 per cy in 2024).

This project illustrates that the proximity of the dredging site to a terminal sediment location can be a driver for the feasibility of sediment beneficial use. Without the option for permanent upland placement, total project construction costs would have increased substantially. The proximity between the dredging project and beneficial use site is a project aspect that has major cost implications for economic feasibility.

1.2 Project Review Conclusions

Several conclusions can be drawn from the review of comparable projects, including the following:

- The scale of dredging may or may not match the need for material for beneficial use opportunities. In the Buffalo Harbor project, the total volume of sediment removed was much larger than the 56,000 cubic yards of material used for beneficial use. Alternatively, the Hamilton Army Airfield Wetland Restoration project was so large that it used dredged material from multiple dredging projects.
  - Volumetric analysis of dredging needs and coastal resiliency needs should be considered when assessing pairing feasibility. In many cases, the needs will not closely match, which will require either off-site disposal of excess sediment, or additional material sources for costal restoration construction. These steps will affect project costs and feasibility.
- Limited project examples exist where dredged material from reservoirs has been used for coastal resiliency projects.
  - The paucity of project examples implies that technical and financial challenges make such projects difficult to implement. While this is likely due to a variety of factors, coastal areas often do not make for the best reservoir sites. Hence, most reservoirs are inland, and transporting large volumes of sediment can be very expensive.
- Project examples illustrate a more common trend of using dredged sediment from navigation channels for coastal beneficial use.
  - The proximity of navigation channels to coastal areas improves the viability of beneficially using the dredge material. This does not mean that using dredged material from alternative locations is not feasible but increased transportation costs and logistical challenges can complicate pairing of projects that are distant from each other.

2 Site Selection

2.1 Reservoir Selection

Anchor QEA evaluated several major reservoirs within approximately 100 miles of the Texas coast and, with input from GLO, recommended further evaluating the following three reservoirs for this project: Lake Livingston, Lake Texana, and Lake Corpus Christi. Anchor QEA prepared a memorandum for the GLO that summarized the candidate reservoir selection process (Anchor QEA 2023). The three candidate reservoirs were selected for their proximity to the coast, quantity of impounded sediment, and simple single-party ownership or operation. The Texas Regional Water Plans can serve as an additional resource for identifying sediment-impacted reservoirs in different planning regions (Water Planning Group 2020).

2.1.1 Lake Livingston

Lake Livingston, shown in Figure 1, is located on the Trinity River approximately 60 miles inland from Galveston Bay and has a conservation storage capacity of 1,603,504 acre-feet. According to TWDB data, the water stored in the reservoir frequently exceeds the conservation pool. Lake Livingston is owned and operated by the Trinity River Authority and under contract with the City of Houston for municipal and industrial water supplies, irrigation, and recreation purposes (Anchor QEA 2023). Lake Livingston was constructed specifically for water supply for the City of Houston, as well as for irrigation to the rural communities, which make up a large portion of the lake's 16,583 square mile watershed (TWDB 2022a). With the water level at the top of the conservation pool, the surface area of Lake Livingston is approximately 78,000 acres.

2.1.2 Lake Texana

Lake Texana, shown in Figure 2, is on the Navidad River, a major tributary to the Lavaca River, in Jackson County, approximately 11 miles inland from Lavaca Bay. The lake has a conservation storage capacity of 159,975 acre-feet, and, according to TWDB data, water storage frequently meets or exceeds the capacity of the conservation pool. The lake and dam are managed by the Lavaca-Navidad River Authority for municipal and industrial water supply and recreational purposes (Anchor QEA 2023). Lake Texana was constructed primarily for industrial and municipal water supply within Jackson County, with recreation serving as another important use (TWDB 2022b). With water level at the top of conservation pool, the surface area of Lake Texana is approximately 10,000 acres.

2.1.3 Lake Corpus Christi

Lake Corpus Christi, shown in Figure 3, is located on the Nueces River approximately 25 miles northwest of Nueces Bay and has a conservation storage capacity of 256,062 acre-feet. The lake is owned and operated by the City of Corpus Christi (CoCC) and is primarily a water supply reservoir for the Coastal Bend. The water stored in the reservoir frequently exceeded the conservation pool in the 1960s through the 1980s but has rarely filled since the construction of Choke Canyon Reservoir in 1982 (Anchor QEA 2023). Lake Corpus Christi was constructed after state legislation created the Lower Nueces River Water Supply District to supply water to Corpus Christi, as well as Coastal Bend (TWDB 2012). The watershed of Lake Corpus Christi is 16,656 square miles and a surface area of approximately 20,000 acres when water levels are at the conservation pool elevation.

2.2 Coastal Resiliency Project Selection

Along with the candidate reservoirs discussed in Section 2.1, Anchor QEA recommended one candidate coastal resiliency project to pair with each reservoir. The rationale for selecting the restoration projects are discussed in detail in Anchor QEA (2023) and summarized in this section. Selection criteria included matching sediment requirements between the coastal resiliency site and the paired reservoir and the distance between the sites. These three projects have been proposed in conceptual formats and all are currently in a pre-design phase.

It is important that the dredged sediment characteristics match the intended use at the coastal resiliency site. Accordingly, the coastal resiliency project selection process included a review of dredged sediment use feasibility. The design intent of each of the candidate coastal resiliency projects appears to be consistent with the sediment characteristics at each of the paired reservoir dredging sites. The likely dredged material appears to be predominantly silts, clays, and some minor fraction of sand, which can be used for wetland restoration projects. It is important that the dredge sediment characteristics match the intended use at the coastal resiliency site.

2.2.1 East Bay Living Shorelines and Wetland Restoration

This project, located near Smith Point in Galveston Bay and shown in Figure 1, would be paired with dredging Lake Livingston. The East Bay Living Shorelines and Wetland Restoration project would provide restoration efforts for estuarine wetland habitats in the area, which is aligned with the sediment characteristics within Lake Livingston. Living shorelines would be intended to create or enhance wetlands and oyster reefs that provide nesting sites for coastal birds.

2.2.2 Harbor of Refuge Protection and Restoration

This project, located near the City of Port Lavaca in the Matagorda Bay system and shown in Figure 2, would be paired with dredging Lake Texana. The Harbor of Refuge Protection and Restoration project would provide wetland restoration, construction of living shoreline breakwaters, and a shoreline revetment. The wetland restoration component of this project is aligned with the sediment characteristics within Lake Texana. Construction of breakwaters and shoreline revetment are unlikely to require a substantial quantity of reservoir-dredged sediment, as larger rock or coarse-grained material is more commonly used for those applications.

2.2.3 Nueces Delta Marsh Restoration

This project, located in the Nueces Delta near Corpus Christi Bay, is shown in Figure 3 and would be paired with dredging Lake Corpus Christi. This wetland restoration project is located along the northern extent of Nueces Bay and is an ideal candidate due to its location and the identified need for sediment in this area. Wetland restoration, proposed in the Nueces Delta Marsh Restoration project, appears to be an acceptable application for use of the sediment type within Lake Corpus Christi.

3 Coordination with Reservoir Owners

Reservoir sedimentation is a growing problem in the United States (NRSST 2019). Many reservoirs in Texas are more than 50 years old, with some more than 100 years old. As sediment accumulates, it can reduce capacity for water supply and flood control, inhibit recreation, interfere with water intakes, and contribute to worsening water quality. As a result, reservoir owners are often keenly interested in dredging. However, few reservoirs have been dredged, largely due to high costs and challenging permitting requirements.

For this project, the reservoir owners were contacted to solicit their interest in this project, including their interest in potential dredging of their reservoir. A summary is provided in the following subsections; additional details can be found in Anchor QEA (2024). All reservoir owners expressed support for this project, although it is recognized that because no project details are available, including no engineering designs or permitting documents, the reservoir owners reserve the right to withhold support at a later date if project details are not consistent with their management objectives.

3.1 Trinity River Authority

The owner of Lake Livingston is the Trinity River Authority (TRA). Dan Opdyke of Anchor QEA reached out to Glenn Clingenpeel, TRA's Executive Manager, Technical Services and Basin Planning, who indicated that TRA supports the project. Mr. Clingenpeel also indicated that there is interest in dredging the lower Trinity River from Liberty to Trinity Bay, and he would welcome options for beneficially using that material. Based on this information, Anchor QEA added an evaluation of the lower Trinity River to this project. TRA staff subsequently provided data to support this project, which is discussed in more detail in Section 5.3.

3.2 Lavaca-Navidad River Authority

The owner of Lake Texana is the Lavaca-Navidad River Authority (LNRA). Dan Opdyke reached out to Patrick Brzozowski, LNRA's General Manager, who indicated that LNRA supports the Project. LNRA has explored options for dredging Lake Texana in the past through the regional water planning process (Lavaca Regional Water Planning Group 2020), but has not done a detailed study and would be interested in participating in such a study. LNRA staff subsequently provided data to support this project.

3.3 City of Corpus Christi

The owner of Lake Corpus Christi is the CoCC. Mr. Opdyke reached out to CoCC's consultant, Kristi Shaw of HDR, who facilitated a conference call with Maria Corona and Esteban Ramos of CoCC.

Ms. Corona and Mr. Ramos indicated support for the Project, but cautioned that any dredging must not compromise the integrity of the dam.

Ms. Shaw then facilitated a conference call with John Byrum, Executive Director of the Nueces River Authority (NRA), and Travis Pruski, Chief Operating Officer of the NRA. During the call, Mr. Byrum and Mr. Pruski expressed strong support for the Project. Mr. Byrum offered to write a letter of support to GLO, if desired.

Both NRA and CoCC staff described notable areas of shoaling in Lake Corpus Christi, which is impacting recreation, homeowners use of the lake, and the City of Beeville water intake. In 2001, the Region N Regional Water Planning Group evaluated the potential for dredging Lake Corpus Christi (Coastal Bend Regional Water Planning Group 2020). Ms. Shaw and Mr. Byrum indicated that there was a discussion about revisiting this option at the most recent Region N meeting. NRA staff subsequently provided data to support this project, including grain size data that they collected expressly for this project.

The proposed coastal resiliency project associated with the potential dredging of Lake Corpus Christi is wetland restoration in the Nueces Delta. This restoration project is not a Tier 1 project in GLO's Coastal Resiliency Master Plan. Accordingly, Mr. Opdyke emailed the project objectives to the property owner, Kiersten Stanzel, the Executive Director of the Coastal Bend Bays & Estuaries Program. Ms. Stanzel responded, in part, that placement of sediment in the upper delta has been discussed with CoCC in the past and concluded with "Let us know how we can support your efforts moving forward."

4 Technical Feasibility

This section discusses several design considerations related to the feasibility of pairing reservoir dredging with coastal resiliency projects. This discussion includes both broad considerations that are relevant to any site pairings, as well as site-specific considerations for the three reservoir-restoration project pairings identified in this report.

4.1 Design Considerations

Successfully pairing reservoir dredging with coastal resiliency projects requires thorough consideration of several aspects of design, including sediment characteristics, availability of staging areas, dredging, sediment processing, and transportation methodologies, and permitting. This section provides a high-level overview of pertinent design considerations for successfully pairing projects.

4.1.1 Sediment Characteristics

4.1.1.1 Grain Size Distribution

Grain size distribution impacts many aspects of a dredging project, including dredging equipment selection, dewatering approach, transportation volumes (and hence cost), and the suitability of using the material for coastal resiliency purposes. The grain size distribution of sediment deposits is usually assessed during pre-design investigations, along with assessment of other geotechnical parameters, and requires the collection of sediment cores or grab samples.

The watershed upstream of any reservoir influences the type, size, and quantity of sediment that erodes and is transported. Watersheds containing a large proportion of agricultural land will typically produce a greater quantity of silts and clays than a watershed containing natural vegetation or hills, which may produce more coarse-grained material.

The type of coastal resiliency project will commonly determine what grain size distribution is suitable for us. Sediment containing a large portion of fine-grained material might not be appropriate for use as beach nourishment but may be well suited to thin layer placement for coastal marsh restoration. Reservoir dredging should target deposits of sediment that contain the grain size distribution desired for a specific application at a coastal resiliency site.

Fortunately, the grain size distribution of sediment within a reservoir is spatially variable, with coarser grained materials (gravel, coarse sand) depositing in the reservoir delta, near the location where rivers or streams discharge into the reservoir. When river or stream flow velocities decrease as water moves into the reservoir, coarser grained material will deposit in the reservoir relatively quickly, with finer grained sands, silts, and clays depositing successively further into the reservoir. This results in spatially variable and somewhat predictable grain size distributions within each reservoir, with coarser grained material located near the deltas and finer grained materials located near the outlet structure or dam. Coarse-grained materials can occasionally be deposited along the river's flow path through the reservoir, resulting in pockets of coarse material away from the delta.

The distribution of higher proportions of coarse- and fine-grained material can be used as an advantage in design, depending on the type of material that is most beneficial to a specific coastal resiliency project. If relatively coarse-grained sand is desired for beach nourishment or dune restoration, then deposits near reservoir deltas can be targeted for dredging. If fine-grained material is preferable for a specific restoration purpose, low energy areas near the reservoir outlet can be targeted for dredging. While these are general depositional trends, there is variability in the grain size distribution, especially for reservoirs susceptible to large floods, as most Texas reservoir are. Because all Texas rivers drain toward the coast, the reservoir deltas are always further from the coast—and coastal resiliency projects—than the dams; this has implications for transportation costs.

The Texas Water Development Board completed volumetric and sedimentation studies at each of the reservoirs investigated. These studies, which were conducted between 2016 and 2020, included sample collection and general material characterization. The results of these studies are summarized below by reservoir:

- Lake Livingston (TWDB 2022a):
  - Sediment cores collected at 20 locations throughout the reservoir.
  - Sediment types ranged from sands to silts.
  - The sampled areas indicate limited presence of coarse-grained material.
- Lake Texana (TWDB 2022b):
  - Sediment cores collected at 15 locations throughout the reservoir.
  - Sediment types ranged from medium sand to fine silt.
  - The sampled areas indicate limited presence of coarse-grained material.
- Lake Corpus Christi
  - TWDB (2017):
    - Sediment cores collected at 6 locations in the southern portion of the reservoir.
    - No sediment cores were collected near the delta area.
    - Collected samples indicate sediment is predominantly fine-grained material with some fine-grained sand.
  - Terracon (2024):
    - Sediment grab samples collected at 4 locations within the reservoir (referred to as sites 1, 3, 4, and 5)
    - Data indicate material at sites 1 and 3 are poorly graded sand (SP).
      - This material is 96% coarse grained with 4% fines and 0% gravel.

- Data indicate material at sites 4 and 5 are silty sand (SM).
  - This material is 80% coarse grained with 20% fines and 0% gravel.

Data at the three reservoirs indicate that the accumulated sediment is predominantly fine grained within the areas sampled, with the exception of the Terracon data from Lake Corpus Christi, which shows coarse-grained material in addition to fine. Coastal resiliency projects that can benefit from fine-grained material are therefore preferred based on these data. Due to the large size of these reservoirs and the relatively few number of samples, it is possible that additional targeted sampling, especially near deltas, would identify additional areas that contain predominantly sand.

4.1.1.2 Sediment Deposition

Sediment deposition within reservoirs is spatially variable and primarily influenced by water velocities, bathymetric features, and sediment grain size. Consequently, sediment thicknesses within a reservoir exhibit heterogeneity. This depositional pattern dictates the areas where dredging operations could be successful. The rationale for sediment removal in reservoirs stems from specific project requirements, such as augmenting water storage capacity, safeguarding existing infrastructure, or enhancing water quality. Targeting reservoir sediment for capacity improvement often prioritizes large deposits due to logistical advantages. Large deposits in a small area, require less equipment relocation during dredging operations. Conversely, the removal of thinner sediment layers poses increased challenges as it necessitates frequent equipment relocation.

While specific dredging objectives for the three candidate reservoirs remain unspecified, enhancing storage capacity is recognized as a common benefit at most water storage reservoirs. Hence, to optimize construction costs, it is prudent to identify dredging locations within the reservoirs characterized by significant sediment accumulation.

Assessing sediment thickness in reservoirs entails comparing pre-impoundment surface data with recent bathymetric surveys. Typically, pre-construction survey records serve as foundational data for this assessment, complemented by project-specific bathymetric surveys for comparative analysis. Sedimentation studies conducted by the TWDB at each reservoir feature figures depicting sediment thickness derived from survey comparisons. Maps prepared by the TWDB at each of the reservoirs are included in Attachment A of this report (TWDB 2013, 2022a, and 2022b).

General patterns of sediment deposition at the candidate reservoirs are described below:

- Lake Livingston (TWDB 2022a)
  - As of 2019, TWDB estimated the reservoir contains 129,149 acre-feet (208 million [M] cy) of accumulated sediment, which reflects an average annual sedimentation rate of 2,583 acre-feet (4.2M cy) per year, below the conservation pool elevation. These sedimentation estimates, developed by the TWDB, were based on comparisons

between the bathymetric survey at the time of the TWDB study and the pre-impoundment surface.

  - Sediment deposition thicknesses are highly spatially variable, with thicker deposits located in the pre-impoundment thalweg of the Trinity River and along benches of shallow water depths.
  - Extensive deposits exist with thicknesses in the range of 2.0 to 4.5 feet, which are located along shorelines and in the upper reaches of the inlet delta. These deposits could be targeted for dredging for increasing storage capacity.
- Lake Texana (TWDB 2022b)
  - As of 2020, TWDB estimated that the reservoir contains a total of 11,523 acre-feet (18.6M cy) of accumulated sediment, which reflects an average annual sedimentation rate of 288 acre-feet (465,000 cy) per year, below the conservation pool elevation. These sedimentation estimates, developed by the TWDB, were based on comparisons between the bathymetric survey at the time of the TWDB study and the pre-impoundment surface. Sediment deposition thicknesses are variable in the upstream portion of the reservoir but become somewhat more uniform near the dam.
  - Extensive deposits exist near shorelines along the southern portion of the reservoir, with thicknesses ranging from approximately 1.5 to 3 feet thick. These deposits could be targeted for dredging for increasing storage capacity.
- Lake Corpus Christi (TWDB 2013, 2017)
  - As of 2016, estimates of reservoir capacity indicate approximately 36,400 acre-feet (58.7M cy) of water storage capacity has been lost since the impoundment was constructed. The capacity loss is attributed to sediment accumulation within the lake. Average annual sedimentation rates are estimated to be between 362 and 702 acre-feet (585,000 to 1.1M cy). These sedimentation estimates, developed by the TWDB, were based on comparisons between the bathymetric survey at the time of the TWDB study and the pre-impoundment surface.
  - Sedimentation figures were not prepared in the 2012 or 2016 TWDB reports due to field issues but the following description of sediment deposition was provided (TWDB 2013):
    - "In the area of the reservoir surveyed, the greatest sediment accumulation occurred downstream of the confluence of Penitas Creek with the Nueces River and upstream of the old La Fruta Dam. Another area of higher accumulation was west of the cities of Lakeside and Lake City."
  - The sedimentation rate and capacity loss, along with the description of depositional patterns, indicate suitable zones for dredging are likely present in the reservoir that contain greater than 5-foot thick deposits of sediment.

The TWDB volumetric and sedimentation studies provide sufficient information to confirm that substantial sedimentation has occurred, and several suitable locations exist within each candidate reservoir for dredging for capacity improvement.

It is important to note that the objectives of reservoir dredging projects are not limited to increasing reservoir capacity. Frequently, sediment accumulation near existing water intakes, dam infrastructure, or near shoreline features, such as marinas or docks, will require maintenance dredging to allow for continued operation. Maintenance dredging operations can generate large volumes of material removal, usually to reduce the frequency of sediment removal. These types of reservoir maintenance projects are very expensive for owners and represent excellent opportunities for pairing with a coastal resiliency project that would be interested in sharing project costs.

4.1.1.3 Sediment Analytical Data

The chemical composition of sediments may also impact their suitability for coastal resiliency projects. Sediments with chemicals that exceed certain screening levels in sufficiently high amounts may be unsuitable for placement at a restoration site or may require additional management to make them suitable (e.g., placement under a cap of clean material) or evaluation (e.g., a site-specific risk assessment). The availability of chemical data varies by reservoir and little, or no, data may exist if contaminants have not been perceived to be an issue.

Based on USACE sediment guidance (USACE 2019a), several screening benchmarks were compared against chemical concentration data from sediment samples provided by reservoir owners. These guidelines are the Effects Range Low (ERL), Effects Range Median (ERM; Buchman 2008), and the Texas Commission on Environmental Quality (TCEQ) Human Health Protective Concentration Levels (PCLs), which are part of the Texas Risk Reduction Program (TRRP; 30 Texas Administrative Code [TAC] Chapter 350) and set forth in USACE (2019a). ERLs and ERMs were established to represent concentrations above which adverse biological effects are probable. Dredged sediments destined for a dredge material placement area are often compared to the PCLs provided by the TCEQ as part of the TRRP. These guidelines were used to screen analytical sediment data provided by reservoir owners for each of the three selected reservoirs. The data reviewed for each reservoir included the following:

- Lake Livingston
  - The only data provided were grain size distribution and water quality; no analytical sediment data were provided, and, therefore, no data were screened.
- Lake Texana
  - Data from a U.S. Geological Survey (USGS) study were provided by LNRA and contain four sediment samples.
  - Data were tested for inorganic metals, nutrients, pesticides, and herbicides.
  - Data were collected between 1999 and 2012.

    - For several individual organophosphate pesticides and metals, the laboratory's reporting level (RL) exceeded either the ERL or PCL.
    - Exceedances of ERLs and PCLs for several individual metals and individual organophosphate pesticides were found from samples taken in 2003, 2004, 2005 and 2012; some of these exceedances were detected concentrations and some were not detected with an RL above the ERL or PCL.
- Lake Corpus Christi
    - The NRA report (NRA 2017) contains samples for metals from four locations in Lake Corpus Christi.
    - Data were collected between 1973 and 2017.
    - For mercury and silver, the laboratory's RL exceeded both the ERL and PCL.
    - Exceedances of ERLs and PCLs were found in samples from 1975, 1976, 2004, and 2017 for at least one of cadmium, mercury, or silver in each year; some of these exceedances were detected concentrations and some were not detected with a RL above the ERL or PCL.

Note that all data should be treated as preliminary as there are no records of validation. This data screening was simply a review of historical conditions and these results are not to preclude future use of sediments from these reservoirs.

4.1.2 Dredging Methodology

Dredging in reservoirs, as opposed to navigational or marine dredging, can be limited by equipment mobilization. Equipment will typically be mobilized overland on roads and highways and the types of equipment that can be mobilized are usually smaller than for marine dredging or modular in their assembly. Many large dredging vessels that are used for coastal dredging cannot be mobilized inland cost-effectively. The two most common types of dredging equipment used for reservoir dredging include mechanical clamshell dredging and hydraulic cutterhead dredging. These two technologies are described below.

4.1.2.1 Mechanical Dredging

This option involves mechanical dredging of sediment from within the reservoir and transport of dredged sediment to an on-land repository where it can be stockpiled and dewatered (see Photograph 1). An excavator or crane equipped with an open-digging or clamshell bucket would be used for mechanical dredging operations. When working over water, mechanical excavators are often mounted on a flat deck barge or flexi-floats and maneuvered by a boat to the required work areas, where sediment is removed and placed into an adjacent scow. In some portions of the reservoir, including areas along shorelines that are targeted for sediment removal, mechanical dredging can be conducted by excavators working on land and processed similar to as if the operations were on water.

Photograph 1
Representative Mechanical Dredging

As sediment-containing scows reach the shoreline offloading area, the dredged sediment is offloaded by an excavator and placed directly into land-based construction equipment (e.g., dump trucks, front-end loaders) for transport to the sediment stockpiling and dewatering area. If the duration of the dredging effort needs to be shortened, multiple scows and work boats can be used to accelerate the production schedule and removal efforts.

Once dredged sediment is placed into the sediment stockpiling area, the material is processed and conditioned (e.g., adding dewatering agents, as required) to meet the requirements for transport for beneficial use.

Mechanical dredging is typically employed at locations that contain large debris, such as logs, wood, or trash. Mechanical dredging has the benefit of removing sediment at nearly the in situ water content, which reduces the amount of water management that needs to occur prior to transport, as compared to hydraulic dredging.

4.1.2.2 Hydraulic Dredging

Hydraulic dredging involves the use of a "cutterhead" and pipelines to convey dredged sediment pumped in a slurry from the reservoir to a designated repository area, see Photograph 2. Booster pumps may be required if the pumping distance is greater than the main pump can handle. Pipelines would need to be installed from all dredges to an area for sediment management. The pipeline would be floating when in water and then would traverse land to reach the upland sediment management area.

Photograph 2
Representative Hydraulic Dredging

Credit: Bill Alden. Available at: https://search.creativecommons.org/photos/d3803161-1d18-42cc-a9f4-712e687bb134.

Hydraulic dredging can be used in a wide range of conditions but is well suited to relatively uniform sediments that contain little debris. Debris can cause clogs in the hydraulic pipeline and unanticipated changes in sediment density or grain sizes can lead to scour of the pipelines and pumps. Water management is an important consideration for hydraulic dredging, as the slurry that is produced may only contain a relatively small proportion of sediment, as low as 10%. The remaining volume is water, which must be separated from the sediment and managed according to relevant environmental regulations. Temporary water treatment systems may be required to reduce the turbidity of water that would be returned to the reservoir.

For projects with fine-grained material and limited debris, as well as short pumping distances, hydraulic dredging is frequently preferred due to reduced costs and higher rates of production. Hydraulic dredging is recommended as the planned dredging methodology for this assessment due to the material types identified in TWDB reports and no evidence of substantial volumes of large debris within the candidate reservoirs. The material types identified appear to be predominantly finer grained material (with the exception of coarser grained sand in an area of Lake Corpus Christi) with relatively limited spatial variability, but these generalizations must be confirmed with a site-specific sediment investigation.

4.1.3 Staging Availability

Large-scale reservoir dredging projects typically employ hydraulic dredges, in which sediment is mixed with water to form a slurry, which is then conveyed by pipeline to an on-land staging area. This staging area accommodates temporary storage of dredged sediments, sediment processing and/or dewatering, material transfer for off-site transportation, and equipment storage. Areas for staging are frequently identified during the pre-design phase of project development and require coordination with landowners.

Staging areas for reservoir dredging may be located on either public or private land. In many circumstances, the reservoir owner may own parcels of land along shorelines that could be used. State or federal land located along the shorelines may also make excellent candidates for staging areas, depending on the active use of the land and whether a lease agreement can be negotiated. A similar process can be followed for staging on private lands. The project owner, or contractor performing the dredging, can enter into a lease agreement with the private landowner to occupy the land for construction purposes. Leasing land for staging areas usually requires specific conditions to be followed, including site restoration at the end of construction.

It is beneficial for project costs to use land along or near reservoir shorelines to reduce hydraulic slurry pipeline lengths and to improve efficiency of equipment. If sufficient land immediately along shorelines is not available, areas further inland can be used if they can be accessed by hydraulic slurry pipelines as well as by truck. In general, locating staging areas near the dredging area should be prioritized.

The amount of area required for sediment stockpiling and dewatering is strongly dependent on the selected method of dewatering. The area required for sediment processing, including dewatering, is discussed in the Sediment Processing section. Staging requirements are typically identified during the pre-design phase of the project and the decision is contingent upon construction sequencing, sediment processing, and off-site transportation.

Parcels of land have been identified that are owned by the river authorities of each of the three reservoirs assessed in this evaluation. Their sizes and current use vary. For example, on Lake Texana, near the west side of the State Highway 111 bridge, which crosses the central portion of the reservoir, is a track of land that is owned by LNRA. This location is currently used as a day use and picnic area but could be used for staging and sediment processing during construction without the need for a lease agreement with a private landowner. Examples at other reservoirs include undeveloped land near the shoreline close to the dam on Lake Corpus Christi and parcels owned by the TRA, one of which is located on the east side of the U.S. Highway 190 bridge across the central portion of the reservoir.

4.1.4 Sediment Processing

Sediment processing for reservoir dredging relates to removing water from the dredged sediments to allow for off-site transport. Transportation is expensive, so the goal is to transport as little water as possible. Furthermore, if transporting by truck, sediment must be sufficiently devoid of free water, in order to reduce or eliminate material loss during transport. A paint filter test, which assesses the presence of free liquids present in waste or sediment, is required for disposal at landfills and serves as a benchmark that sediment has been sufficiently dewatered or processed. Several options are available for sediment dewatering of hydraulically dredged materials, several of which are discussed below.

4.1.4.1 Geotextile Bags/Geotubes

Geotextile bags, also referred to as geotubes or geotextile filter bags, can be used for dewatering hydraulically dredged sediment. Geotubes have been extensively used with high success at numerous dredging projects where fine-grained material was targeted for dewatering.

Dredged slurry is pumped into the geotubes, and water flows out of the pore spaces in the geotextile, while most sediments remain in the geotubes. To reduce total suspended solids (TSS) in the water discharged by the geotubes, environmentally compatible polymers are typically added to the dredged slurry prior to filling the geotubes to facilitate coagulation and binding of sediment particles. Once full capacity is reached, the geotubes are left to drain until the sediment reaches the desired water content. As with other dewatering options, the remaining water needs to be discharged back to the reservoir, subject to permitting considerations and possible monitoring.

The design and selection of geotube products is influenced by information collected during pre-design investigations. Bench-scale testing, polymer dosing, hanging bag test, slurry feed rate, and geotextile mesh sizes can all be optimized for specific projects, and odor issues can be mitigated with additional additives. Geotubes can be stacked vertically to allow a larger volume of material to dewater over a smaller footprint, if sufficient space is unavailable at the processing area. The volume and size of geotubes can be modified to suit a specific project.

The geotubes can be left in place for extended periods of time. Once the desired water content is achieved, they can be cut open to access the dewatered sediment, which would then be removed with an excavator, loaded into trucks, and transported to the beneficial use site. Transporting geotubes full of sediment is not practical due to their size, shape, and potential for rupture if moved around or lifted. Geotextile bags are typically disposed of at an appropriate disposal facility after the sediment is removed.

While efficient and cost-effective for use at many hydraulic dredging projects, geotubes are an engineered system that can clog and require attention while they are being filled. Dewatering areas that use geotubes still need to manage the water that discharges from the tubes, which could involve additional water treatment. Gravel is typically used to line the base of the geotubes to promote infiltration and dewatering. For larger projects, it is not uncommon for a considerable volume of gravel to be required for this purpose. The gravel may have to be removed upon project completion, which further increases cost.

4.1.4.2 Impoundment

In this approach, prior to any dredging operations, an upland bermed impoundment would be constructed, into which the dredge slurry can be pumped directly. This option is similar in construction to an upland confined disposal area, which are frequently used for coastal hydraulic dredging projects. The sediment-water slurry would be pumped through a pipeline into the impoundment, and then weir boxes would allow for relatively clear water to exit the impoundment via gravity as the sediment settles.

The impoundment would need to be sized to hold the in situ dredging volume, plus a percentage increase to accommodate temporary sediment bulking (up to 50%). The impoundment also needs to provide a sufficient amount of freeboard space (2 or more feet is customarily used in design) to contain water generated by the hydraulic dredging process, as well as additional water from large storm events. Sizing the impoundment properly is important because it lessens or avoids the need to pause dredging should the impoundment fill up. Weirs, spillways, and piping systems are an important design element to allow for water management in sediment impoundments. The specific location of the dredge slurry discharge would be moved as filling proceeds, facilitating the ability of free water to discharge through the weir boxes during dredging while limiting the release of suspended sediment.

If sufficient land is available and inexpensive, the use of impoundments for dewatering is often less expensive than geotubes, because impoundments are passive systems that require limited maintenance and limited additional materials to construct. Impoundments can also be reused multiple times if the material is removed after each use and the land it occupies remains available for this purpose.

4.1.4.3 Conclusions Regarding Appropriate Sediment Processing Methods

Many other methods of dewatering hydraulic slurry exist, including mechanical dewatering such as screens, hydro-cyclones, clarifiers, and press systems. These methods are typically more expensive due to high procurement or rental costs, energy consumption, and the need to actively manage them during dredging. The benefits of mechanical dewatering systems include faster dewatering rates and greater reduction in water content.

As part of this assessment, both geotubes and impoundments were assessed for cost, with the impoundment option yielding a considerably reduced cost for sediment processing. Potentially being able to reuse the impoundments for future dredging projects is an additional benefit of the impoundment option.

Requirements for sediment processing and dewatering are site-specific. Land availability and proximity to the dredging area will greatly influence the selected approach to dewatering, as will duration and processing needs. While the recommendations presented reflect the information available at the candidate reservoir sites, further refinement should be expected as the design progresses.

4.2 Transportation

The cost of transporting sediment from a reservoir to the paired coastal resiliency project will be one of the most crucial aspects of assessing economic feasibility. This is due to the high cost of transporting bulk material. Multiple pathways for transporting the dredged material can be envisioned, including transport via slurry pipelines, haul trucks, barges, rail, or combinations of these methods.

4.2.1 Slurry Pipeline

In some circumstances, it may be feasible to convey hydraulically dredged sediment from the dredge site to the final disposal location in a slurry pipeline. Transport using slurry pipelines is commonly used in ship channel dredging projects and other dredging projects located in coastal areas. An appropriately sized slurry pipeline is required between the dredge site and the final disposal location.

Booster pumps may be required to be installed along the pipeline to convey the flow over long distances, or to increase the flow rate for dense slurries.

The use of slurry pipelines as a primary transportation method is frequently limited by both the distance of transport and the ability to run a pipeline between the dredge site and disposal location. For inland reservoir projects, the installation of a pipeline between two locations presents challenges. Factors such as road crossings, securing temporary easements, and traversing private property significantly complicate the process of temporary installations.

Hydraulic pipelines of up to 20-miles in length, or greater in limited circumstances, have been used for primary material transport, but this may require multiple booster pumps. It is more common for pipelines to be less than 5 miles in length. Slurry pipelines and booster pumps must be optimized for the required slurry density, grain size distribution, and pipeline length. Improperly sized or specified equipment may generate pipeline clogs or scouring conditions that can require pump repair or replacement. The economics of the system will also determine feasibility. Transport via pipelines is usually only cost-effective for projects with large dredging volumes and relatively short transport distances, as alternative transportation methods may be less expensive.

The use of transport via slurry pipeline does not appear feasible at any of the candidate reservoir-coastal resiliency site pairings due to transport lengths and the feasibility of installing pipelines between the reservoirs and coastal sites. Limitations at the candidate site pairings may be similar to other reservoir-coastal resiliency site pairings but the potential cost reduction associated with pipeline transport should be considered during future feasibility studies.

4.2.2 Trucks

Hauling dredged material using trucks is common for reservoir dredging projects, and in some cases may be the only feasible option. Trucks used for hauling dredge material include transfer dump trucks or end/side-dump trucks. End or side-dump trucks can transfer their loads without additional equipment, which greatly improves transport productivity. Trucks used for this purpose have a range of volume capacity, as well as weight capacity. Weight capacity can range from 10 to 25 tons while volume capacity can be up to 18 cubic yards. Haul trucks with greater capacities exist but may not be feasible due to highway limitations for volume and weight.

Loading trucks occurs at the sediment processing area, after the sediment has been sufficiently dried to prevent material loss during transport. Material is loading into the trucks using earthwork equipment, usually front-end loaders or excavators.

Costs associated with truck usage are dependent on the transport distance involved. Longer haul distances can greatly increase transportation costs. In order to increase transportation production, additional trucks are used, which can further increase costs. Logistically, trucked transportation of dredged material is relatively straightforward as no additional infrastructure is required. One-way transportation distances between the reservoir dredging sites and their paired coastal resiliency sites are listed below:

- Lake Livingston—East Bay Living Shorelines and Wetlands Restoration Project: 109 miles
- Lake Texana—Harbor of Refuge Protection and Restoration Project: 29 miles
- Lake Corpus Christi—Nueces Delta Marsh Restoration Project: 28 miles

4.2.3 Barges

Barged transportation serves as an alternative method for relocating dredged material. However, its feasibility depends upon the presence of an adequately sized shipping channel or corridor. The dimensions of the transport channel, including depth and width, must meet requirements to enable filled barges to navigate between locations reliably. Many reservoirs do not discharge sufficient flow rates to allow for barged transport in downstream river stretches. Similarly, many river systems do not have sufficiently maintained channels or adequate flow rates for barged transport to be feasible.

Barged transportation of dredged material is more commonly used at mechanical dredging projects than hydraulic dredging projects due to higher solids content. Hydraulic dredging projects may pump slurry into transport barges but the process is relatively inefficient as hydraulically dredged slurries contain low solids contents (usually in the range of 5 to 20% solids). This causes the barges to fill with mostly water instead of sediment, resulting in the need for more barge trips than if the solids content were higher. While barges can passively dewater dredged material, this is not a common practice with hydraulic dredging due to the time requirements. Barges can be used for transport after the material is dewatered, although an additional material handling and loading step is required.

Barged transport, where feasible, may prove beneficial for offloading and construction at coastal resiliency sites. Many coastal resiliency projects are located in areas that are not easily accessible by road, and imported material is frequently conveyed to projects via slurry pipeline or in barges. By transporting dredged material in barges, some of the offloading logistics may be simplified but the benefits must be assessed on a project-by-project basis. Coastal access may prove challenging for material transport barges due to draft requirements of loaded barges.

None of the rivers associated with any of the candidate reservoirs are currently suitable for barged transport due to lack of maintained channels, low bridges, and other obstructions. The only partial exception to this is along the Trinity River below Lake Livingston. The stretch of Trinity River between the historic location of the Port of Liberty (POL) and Trinity Bay, referred to as the Trinity River Channel to Liberty, had previously been a maintained shipping channel. POL ceased operations, and the shipping channel has not been recently maintained. The upper stretch of the river between POL and Lake Livingston has never been maintained for shipping, and it contains sharp meanders, goosenecks, extensive sand bars, and several low rail and road bridges, all of which results in unrealistic navigation conditions for loaded transport barges.

USACE, in collaboration with the TRA, is evaluating the potential for restoring the Trinity River Channel to Liberty, as well as Anahuac Channel, to return navigation from the Galveston Bay region to POL (USACE 2023b). This project, if approved and completed, could allow barge transportation to travel from near the town of Liberty to the East Bay Living Shoreline and Wetlands Restoration Project. Utilizing barged transport for Lake Livingston would require additional material handling and an intermediate trucking step (up to 28 miles) between the reservoir and the town of Liberty, where material would be loaded on barges and transported the remaining 58 miles to the coastal resiliency site. While feasible, this transportation configuration would require multiple additional material transfer steps, as well as increased coordination between the transportation methods.

4.2.4 Rail

Transportation via railways is common for bulk commodities and construction materials. Rail transport has been successfully implemented at several large-scale dredging operations to reduce transportation costs and improve constructability. Many railways are located in the coastal Texas region and usually terminate at port facilities along the coastline. Rail transport would require sediment to be loaded onto rail cars, likely open-top hopper cars or intermodal cars, at a rail station before transport to a terminal located near the coastal resiliency project.

Transportation by rail could result in reduced transportation costs compared to trucked transportation alone, especially at project pairing locations, which are considerable distances apart. The difficulty in using railways for dredging transport is related to the distance between the dredging site and an existing rail yard, as well as the distance between the terminal rail yard and the coastal resiliency site. Some large-scale inland dredging projects have constructed temporary rail spur lines to connect the dredging area to the main rail lines. While this may be feasible in certain locations, the costs associated with constructing spur lines frequently eliminates the opportunity unless a substantial volume of sediment must be transported.

If no rail spurs exist, and the volume of sediment being dredged and transported does not justify the investment in rail spur construction, the remaining option is to utilize existing rail yards for loading train cars. This would involve trucking sediment from the dredging/sediment processing area to the rail yard for loading onto rail cars. The same conditions would apply at the terminal end of rail transport; material would again require either trucked or barged transport from the terminal rail yard to the coastal resiliency project site. Each time sediment is transferred from one transportation mode to another, handling costs increase. A further discussion of intermodal transportation options is in Section 4.2.5.

Railway mapping created by the Texas Department of Transportation illustrates the distribution of rail lines near the candidate reservoir-coastal resiliency project sites (TXDOT 2021). The following railroad segments were identified for the candidate projects:

- Lake Livingston—East Bay Living Shorelines and Wetlands Restoration Project: Union Pacific railroads between the town of Livingston, travel through Houston area, terminal location near the Morgan's Point area
  - Approximately 93 miles of rail transportation
- Lake Texana—Harbor of Refuge Protection and Restoration Project: Point Comfort and Northern Railway between La Ward and Point Comfort
  - Approximately 12 miles of rail transportation
- Lake Corpus Christi—Nueces Delta Marsh Restoration Project: Union Pacific railroads between Mathis and the Port of Corpus Christi. Option to transfer to the Corpus Christi Terminal Railroad.
  - Approximately 39 miles of rail transportation

While railroads could be used for transportation of dredged material at the candidate reservoir-coastal resiliency project sites, the logistics of intermodal transportation may reduce the economic feasibility for the reasons described in Section 4.2.5.

4.2.5 Intermodal Transportation

Intermodal transportation is the use of multiple forms of transportation to move a load from one location to a final location. In the context of transporting dredged material, intermodal transportation would involve the use of trucked transport with either barge or rail transport. Important considerations associated with intermodal transportation include transferring material between forms of transport, demurrage, and project coordination among transportation services.

4.2.5.1 Sediment Transfer

Sediment must be transferred between the various forms of transportation, which requires labor and equipment to effectively perform the transfer. Sediment transfer may require the use of laborers along with front-end loaders or excavators to move the material from stockpiles to containerized transport. Each transfer step will require a crew and equipment, and multiple transfer steps may be involved. In the situation described in Section 4.2.4, which involves railroad transport, the following material transfer steps would be required:

1. Transfer material from the sediment processing area to trucks.
2. Transfer material from trucks to railcars at an appropriate railyard or spur line.
3. Transfer material from the railcars to trucks for transport to a location near the coastal resiliency site.
4. Offload material from trucks for transport to the coastal resiliency project area.

While costs are discussed in more detail in Section 5, performing multiple transfers can increase construction and management costs. The location where the transfer can occur must also be considered, as many railyards cannot easily accommodate the transfer of bulk materials. With regards to railroads, certain logistics companies specialize in transloading, which refers to the transfer of goods from one form of transport to another. Transloading companies specialize in the logistics associated with intermodal transportation and could be used to facilitate the transport process. Alternatively, the design and planning for transloading would be the responsibility of the contractor, who would likely pass along additional management and organization costs to the project owner.

4.2.5.2 Demurrage and Intermodal Coordination

Demurrage is a term used in both the railroad and shipping industry to refer to costs or fees associated with a failure to load or unload a car or ship within an agreed-upon timeframe. It may also refer to costs associated with barges or railcars that are awaiting loading or unloading. As it relates to dredging projects, demurrage is another cost that may add fees to a given project if the transportation operation is production-limited by certain steps. For example, if a material transfer step is slowed due to inadequate personnel staffing, additional fees may be levied by rail or barge companies, which can add up over the cost of the project.

Demurrage, while potentially a minor cost, should be considered when planning the logistics of dredged material transport. Each step of the intermodal transport process must be coordinated effectively to avoid unnecessary fees or charges, as well as to improve the overall production rate.

Using intermodal transportation can provide a pathway towards reduced project costs but the costs associated with management and coordination are likely to increase. Of the options discussed in Section 4.2, trucked transportation is considerably easier to coordinate, since coordination is limited to the dredging general contractor and likely a trucking company. Intermodal transportation may involve coordinating not only the sediment processing personnel, but also the trucking company, material transfer crews, railway companies, transloading companies, and potentially barge transport companies. The use of external logistics companies may improve this coordination but it can be a considerable undertaking with challenges on a day-to-day basis. While a single form of transportation may be cheaper than another for a particular transport segment, the logistics involved in changing forms of transport must be accounted for to determine cost feasibility for individual project pairings.

4.3 Regulatory Permitting Considerations

Dredging activities within navigable waters, including lake and reservoir features such as Lake Livingston, Lake Texana, and Lake Corpus Christi, typically require acquisition of federal, state, and local regulatory permit authorizations prior to initiation of work. Types of regulatory permits required are dependent on many factors including, but not limited to, type and method of dredging, location of dredging, disposal of the material, discharge of effluent, designation of the waterbody, ownership of the water, threatened and endangered species issues, archaeological and historical sites within dredging areas, zoning ordinances, and access. The following sections describe potential federal, state, and local regulatory permits that could potentially be necessary to conduct dredging activities within Lake Livingston, Lake Texana, or Lake Corpus Christi.

4.3.1 Federal Permitting Overview

4.3.1.1 U.S. Army Corps of Engineers

USACE is the primary federal agency responsible for issuing permits associated with dredging and fill-related activities within navigable waters of the United States, including wetlands. USACE regulates dredging and the installation or removal of structures within waters of the United States under Section 10 of the Rivers and Harbors Act of 1899 (RHA 1899). Fill-related activities, such as the discharge of sand, rock, or other material, within waters of the United States are regulated by USACE under Section 404 of the Clean Water Act of 1972 (CWA 1972). Lake Livingston, Lake Texana, and Lake Corpus Christi are located within the USACE Galveston District Regulatory Division area of responsibility.

USACE Galveston District issues several types of General Permits (GP) that authorize routine, specific activities that have no more than minimal individual and cumulative adverse effects to the aquatic environment. Types of GP authorizations include Nationwide Permits (NWPs), Regional General Permits (RGPs), and Programmatic General Permits (PGPs). NWPs are a type of general permit issued every 5 years by USACE for nationwide activities. RGPs are a type of general permit that authorizes categories of activities in a specific geographic area. PGPs are a type of RGP founded on an existing state, local, or federal agency program, designed to avoid duplication with that program. Should a proposed project be too complex to qualify for one of the GPs listed above, a more comprehensive Individual Permit (IP) process would be required.

With the exception of NWP 19, which authorizes minor dredging activities of no more than 25 cy below the Ordinary High Water Mark (OHWM) and NWP 35, which authorizes maintenance dredging in existing previously authorized marina basins, access channels to marina basins, and boat slips, there are no other NWPs that allow large-scale dredging within jurisdictional Section 10 waters of the United States. A larger dredging program would not qualify for NWP 19 due to the limited cy of sediment removal. NWP 35 would only be applicable if dredging occurs in a singular event within an existing, previously authorized marina basin.

Review of the USACE Galveston District's regulatory website indicates the following active RGPs and PGPs to conduct dredging and installation of structures within Lake Livingston, Lake Texana, and Lake Corpus Christi:

Lake Livingston

- RGP (Administered by USACE): SWG-2013-00422—Authorizes the general public to conduct mechanical dredging within Lake Livingston of no more than 500 cy.
- PGP (Administered by the TRA): SWG-2007-00720—Authorizes the general public to conduct work associated with the construction of pile-supported single-family and multi-family recreational piers including boat houses, shelters, storage buildings, lifts, hoists, personal watercraft ramps/platforms and dry hydrants.

Lake Texana and Lake Corpus Christi

- PGP (Administered by the GLO): SWG-2002-02904—Authorizes the general public to construct, repair, rehabilitate, maintain, modify, and replace single, pile-supported piers at single- and multi-family properties and lodging facilities within all navigable waters within the USACE Galveston District Regulatory Division area of responsibility, except Louisiana.

Although individual minor dredging and structure installation events can fall under one of the RGPs, PGPs, or NWPs listed above, a single larger dredging program combined with use of land space for sediment management and stockpiling would be subject to a more comprehensive IP process, typically used for projects anticipated to result in greater than minimal individual and cumulative impacts. Federal requirements that would apply to dredging within Lake Livingston, Lake Texana, or Lake Corpus Christi would be based largely on requirements of the RHA of 1899 and the CWA of 1972. Ultimately, USACE determines what regulations apply to a proposed sediment management activity. Specific sections of each act are relevant, as follows:

- Section 10 of the RHA of 1899 requires USACE authorization for construction of any structure or performance of any work in, under, or over any navigable waters of the United States. Thus, excavation and dredging or installation of any structures (piers and docks, dikes, bulkheads, jetties, etc.) or alteration to a navigable water is regulated under Section 10 of the RHA of 1899.
- Section 404 of the CWA regulates requires USACE authorization for the discharge of dredged and/or fill material into waters of the United States, including navigable waters of the United States. Discharge or fill material can include placement of earthen fill (sand, dirt) or structural material such as riprap (rock), should either be needed to facilitate offloading of sediment to the landside sediment management area. If dredged sediment is transported to an upland area that is outside waters of the United States, then a Section 404 permit may not be

required, unless return water from the dredged sediment is allowed to flow back into the reservoir (considered a discharge under the Section 401 of the CWA).

- Section 401 of the CWA regulates water quality impacts that may be associated with in-water construction work, including dredging and return water from the landside (upland) sediment management area. TCEQ is responsible for CWA Section 401 certification review of projects applying for CWA Section 404 permits for the discharge of dredged or fill material. The state reviews the projects to determine whether they comply with state water quality standards.

The standard IP process typically includes preparation of a NEPA Environmental Assessment (EA), including an Alternatives Analysis, a Biological Assessment (BA) to initiate informal or formal consultation for protection of threatened and endangered species potential with U.S. Fish and Wildlife Service (USFWS), consultations with the Texas Historical Commission (THC) related to protection of cultural and historic resources, a 30-day Public Notice, and a public review period, among other steps as dictated by USACE and consulting federal and state resource agencies. Submittal of the USACE IP application can typically be accomplished at a point where project extents and details have been reasonably well defined—often represented by a 30%-level engineering design—and the overall USACE IP process can take 12 to 18 months (if it goes smoothly), although a longer duration could be necessary if an environmental impact statement (EIS) is required, if there is state and federal resource agency or public opposition, or if other complicating conditions arise.

4.3.2 State and Local Permitting Overview

In addition to federal regulatory permit authorizations, several state and local approvals would likely also be required, as follows:

4.3.2.1 Texas Parks and Wildlife Department

A Texas Parks and Wildlife Department (TPWD) Sand and Gravel Permit may be necessary prior to commencing dredging operations, should the state of Texas own the river or lake bottom where dredging will occur. Any perennial stream or lake in Texas that is more than 30 feet wide between the banks is typically state-owned, including the sand and gravel within the stream or lakebed. Any activity that disturbs or removes sediment from state-owned waterways is required to obtain a Sand and Gravel Permit.

Lake Livingston and Lake Texana are owned and operated by TRA and LNRA, respectively. Lake Corpus Christi is owned and operated by CoCC. According to TPWD, it is likely that dredging work occurring within expanded areas of these lakes and reservoirs will require permits from the respective river authority or City. However, TPWD may have jurisdiction over the historic river portion of the lake or reservoir (prior to expansion) that could require acquisition of a TPWD Sand and Gravel Permit.

Should a TPWD Sand and Gravel Permit be required, dredging activities would likely be covered under an IP (31TAC § 69.119), which authorizes activities that disturb or remove more than 1,000 cubic yards of sedimentary material. The permitting process involves providing information to TPWD regarding the following: a description of dredging operations, duration of project, anticipated volume of removed sediment, dates of construction, fate of removed sediment, any state or federal listed threatened or endangered species that might be affected by the project, any USACE permits that have been filed, and a completed and approved Sedimentation Impact Assessment (Parks and Wildlife Code chapter 86, §86.003[c][3]). This final requirement involves assessing the effects of sediment disturbance near the proposed dredging locations and must be approved by TPWD prior to submitting the Sand and Gravel Permit.

4.3.2.2 Texas Commission on Environmental Quality

Dewatering of dredged material results in the discharge of return water effluent. In many cases, the discharge of return water is directed back to the water body where dredging took place, provided the return water is within threshold levels of suspended solids and chemical impacts. TCEQ issues individual 401 Water Quality certifications for return water and other fill-related discharges. Coordination is completed with TCEQ as part of the USACE IP process. Initial review of available TCEQ regulations indicate that no additional discharge restrictions are in place for Lake Livingston, Lake Texana, and Lake Corpus Christi associated with routing return water effluent back into these lakes. However, during project permitting, coordination with TCEQ and the respective lake owners and operators should be conducted to determine whether additional discharge restrictions are present. If water discharge back to the lakes is restricted or prohibited, then identifying and implementing alternative water disposal or storage strategies would add further costs to the project (not currently represented in this report).

Potential chemical contamination of lake sediments would not only affect beneficial use options, as discussed in Section 4.1, but could also impact the preparation, use, and restoration of any land area used for sediment management and stockpiling.

4.3.2.3 Texas Historical Commission

Dredging activities within reservoirs or lakes that require a federal permit will also need to be cleared for historical and cultural resources protected under Section 106 of the National Historic Preservation Act of 1966 (NHPA 1966). Coordination with the THC will occur as part of the USACE IP process discussed under the Federal Permitting Overview. NHPA of 1966, as amended, requires that federal agencies consider effects of their undertakings on historic properties. In addition to direct actions of the federal government, federal undertakings include projects involving a permit or license, funding, or other assistance or approval from a federal agency. Section 106 of the NHPA and its implementing regulations at 36 Code of Federal Regulations (CFR) Part 800 lay out review procedures that ensure historic properties are considered in federal planning processes.

4.3.2.4 Trinity River Authority

The TRA was formed in 1955 by the Texas legislature and is responsible for managing water supply and conservation within the Trinity River Basin, which includes Lake Livingston. Dredging and construction activities within Lake Livingston, including beneath and around the lake in areas owned and controlled by TRA, will require a permit from TRA. The issued permit must be recorded in the deed records of the county in which the improvements are to be constructed. TRA requires a Joint Use Agreement and Permit for proposed construction in the flowage easement areas and for excavations in or beyond the flowage easement areas.

4.3.2.5 Lavaca-Navidad River Authority

The LNRA was formed in 1941 by the Texas legislature and is responsible for water supply and conservation within the Lavaca and Navidad river basins within Jackson County, Texas, including Lake Texana. Dredging and construction activities within Lake Texana, including beneath and around the lake in areas owned and controlled by LNRA, will require a permit from LNRA. In addition, coordination with the Lavaca Regional Water Planning Group (LRWPG), responsible for comprehensive regional water planning by state law, included in Texas Water Code Chapter 16 and TWDB rules, must be undertaken prior to implementation of dredging and construction activities within Lake Texana.

4.3.2.6 City of Corpus Christi

CoCC owns and operates Lake Corpus Christi as a water supply source for CoCC. Dredging and construction activities within Lake Corpus Christi will require coordination with CoCC prior to project implementation. TPWD manages Lake Corpus Christi State Park, which is located along the southeastern portion of the lake. Ingress and egress to the site through the state park would need to be coordinated with the TPWD State Parks Division.

4.3.2.7 Local Watershed Ordinances

Lake Livingston and Lake Texana do not appear to be included within a watershed ordinance. Lake Corpus Christi is included within the Lower Nueces River Watershed Protection Plan (WPP), which was accepted by the U.S. Environmental Protection Agency (EPA) in 2016. The WPP is implemented by the Lower Nueces River Watershed Partnership (LNRWP), CoCC, and NRA. The WPP includes management measures to address all water quality issues and concerns within the WPP jurisdictional boundaries, which include Lake Corpus Christi. Prior to dredging, construction activities should be coordinated with the LNRWP, CoCC, and NRA.

4.3.2.8 State and Local Land Use Approvals

Land use for sediment management and stockpiling would be subject to approvals relevant to the type of land area selected. For example, ownership of land selected for stockpiling of material near Lake Livingston would need to be confirmed as being part of TRA facility and available for the described use. This location, and others that may be identified in the future, would need to be confirmed as being consistent with existing agreements or deed restrictions, whether the land's use is impacted by previous remedial work or closure and to what degree any other land use restrictions would apply. Other factors to consider when selecting land for stockpiling would include the presence of jurisdictional waters or wetlands regulated by USACE, threatened and endangered species, and historical and cultural resources.

4.3.2.9 Local Water Rights Approvals

Withdrawals of water from the lakes as part of a hydraulic dredging process would need to be evaluated under TRA, LNRA, and CoCC water supply contracting requirements.

4.3.2.10 State and Local Public Notifications and Outreach Requirements

Regulatory processes could also include Public Notice requirements, including notices posted in relevant newspaper(s) and by mail. Public hearings may also be required for community members and landowners to discuss concerns about project activities.

In addition to the permitting and approval considerations listed in this section, implementation of this project might be subject to further regulatory requirements. These could include environmental and community factors such as stormwater protection, air emissions, and floodplain management. A full review of regulatory requirements, land use opportunities and restrictions, and community needs would be a necessary part of up-front project definition and planning.

The best approach to permitting is to engage the appropriate regulatory agencies and relevant stakeholders early in the planning process. A pre-application meeting would provide the opportunity to discuss proposed project components and design features for identification of areas of concern from the regulatory agency perspective, determine pathways and required studies for addressing those concerns, and obtain a better sense of what permitting mechanisms are most appropriate.

5 Financial Feasibility

Cost projections for the three candidate reservoir-coastal resiliency project pairings have been prepared to assess financial feasibility. These cost projections have been developed to a conceptual pre-design level and represent a level of uncertainty consistent with the pre-design nature of this work. Project costs would be refined as design progresses to improve accuracy and to capture the decisions and requirements that each dredging project entails.

A key objective of this effort is to estimate the cost of transporting sediment from a reservoir to a coastal resiliency site, so that the cost of using material dredged from a reservoir can be compared to the cost of other sediment sources (e.g., coastal ship channel dredging, off-shore dredging, or commercial suppliers). The cost of constructing the beneficial use project itself is not a factor when making this comparison. Accordingly, the costs estimated in this report are strictly to get sediment to the beneficial use site and do not include the cost to construct the beneficial use project.

During preparation of this assessment, several other consultant reports of reservoir dredging feasibility studies were reviewed. During this review, many of these reports only included construction costs associated with dredging, material processing, and transportation. While construction unit costs can be useful to compare different cost projections, they do not fully capture the full cost of a project as they may exclude critical elements such as construction management, project management, engineering design, permitting, contractor overhead and profit, or owner contingency. The costs presented in this section include these "soft costs" that are frequently neglected in reservoir dredging feasibility studies. Care must be taken when comparing these total project costs with other reservoir dredging projects, as the elements included in the cost estimate may differ. It is the intention of these cost projections to be "all-in" project costs that represent the total cost to perform the dredging and deliver the material to a specific coastal resiliency project.

Cost projections have been prepared for each project pairing using trucked transportation for a baseline scenario. None of the project pairings were amenable to solely pipeline, barge, or rail transportation. Intermodal transportation alternatives are provided as a point of comparison to trucking. Costs associated with each project pairing are presented in this section, along with a final comparison against the cost of importing non-dredged material from quarry sources to the coastal resiliency sites.

5.1 Costing Assumptions

Due to the conceptual pre-design level of each of the projects, several assumptions were required to develop the cost projections. Major costing assumptions are described as follows:

- The volume of dredging at each candidate project pairing was assumed to be 100,000 cy. At this time, the volume of sediment required at the coastal resiliency projects is uncertain, as is the need for material removal at each of the reservoirs. 100,000 cy is a volume of material that is generally scalable, meaning that if additional material is needed to be removed from a given reservoir, the equipment required to dredge 100,000 cy would be appropriate to remove a much greater quantity. Furthermore, the use of a consistent 100,000 cy project across all three project pairings facilitates a cost comparison among them.

- Dredging is assumed to be performed using a hydraulic cutterhead dredge.
- Conceptual locations were selected for dredging and sediment processing in areas that appear constructible and feasible. Selected dredging areas were selected that contained thicker areas of sediment deposition, as discussed in Section 4.1.1.2, and were generally located in proximity to shorelines to reduce the required length of slurry pipelines. Sediment processing areas were selected where open land, and preferably public land, is close to the dredging areas. The sediment processing areas were identified for cost estimating purposes only (namely, to estimate the distance to the coastal resiliency site) and do not imply that these lands are targets for purchase, lease, or other transaction.
- Sediment processing is assumed to be conducted using temporary constructed impoundment areas. The impoundment is assumed to be constructed using a mixture of on-site soils, suitable dredged material, and a portion of imported material. Water conveyance was included in the conceptual costs using piping. For passively dewatering 100,000 cy of dredged material, a rectangular area of 14 acres was used to provide an efficient height and length of berms constructed for the impoundment.
- Land rental costs are included to represent the use of private property for equipment staging and sediment processing. Current mortgage rates and agricultural land values were used to estimate rentals costs. Land restoration costs, including earthwork and reseeding, were included to represent the need to restore the rented land back to its original condition.
- Due to the conceptual nature of these cost projections and the use of the same sediment removal volume at each location, the costs associated with land procurement, site preparation, dredging, and material processing are nearly identical across all three paired project sites.
- Trucked transport of dredged material is assumed to occur as a baseline transportation condition. Additional estimates for intermodal transport are provided for comparison purposes. For the intermodal cost projections, the costs associated with dredging remain unchanged from the baseline condition using trucked transport. Trucking distances for each location, by reservoir, are as follows:
  - Lake Livingston: 109 miles
  - Lake Texana: 29 miles
  - Lake Corpus Christi: 28 miles
- After transportation, it is assumed that the dredged sediment will be stockpiled at a location near the coastal resiliency project. These cost projections do not include any aspect of design,

construction, or management of the coastal resiliency project. It is assumed that this would be comparable to a situation where new material is imported to the coastal project.

- A complete suite of project soft costs, including construction management, project management, engineering design, permitting and approvals, contractor overhead and profit, and an owner's contingency has been applied to the construction subtotal to represent a complete project cost. These percentages are derived from EPA and USACE guidance documents, as well as professional experience in dredging projects, for feasibility-level cost projections.
- The intermodal transportation cost projections include rail transport costs derived from the Surface Transportation Board's Uniform Rail Costing System Phase III estimating procedures (STB 2022). These costs represent anticipated costs associated with rail transportation and include relevant usage fees and tariffs.
- All costs presented in this assessment reflect dollars in 2024.

These assumptions are intended to provide conservative cost projections at each of the project pairings.

5.2 Cost Projections

This section includes summary tables of the baseline cost projections, as well as summaries for alternative intermodal transportation, and import of alternative sediment sources. Due to the assumptions discussed in Section 5.1, costs for land procurement and site preparation, dredging, and material processing are consistent between candidate site pairings. Transportation costs, which differ between the sites due to transport distances, are the main differentiator in the cost projections.

5.2.1 Lake Livingston—East Bay Living Shorelines and Wetlands Restoration Project

Table 1
Cost Projection Summary for Lake Livingston—East Bay Living Shorelines and Wetlands Restoration Project Using Trucked Transportation

Task No.	Task Description	Units	Quantity	Unit Cost	Total Cost*
1.0	Mobilization	LS	1	$95,000	$95,000
2.0	Land Procurement and Site Preparation				
2.1	Land Rental for Staging/Dewatering	LS	1	$30,000	$30,000
2.2	Clearing and Grubbing	AC	15	$6,700	$101,000
2.3	Access Road Construction	LF	500	$50	$25,000

Task No.	Task Description	Units	Quantity	Unit Cost	Total Cost*
2.4	Site Facilities	MO	14	$6,700	$94,000
3.0	Hydraulic Dredging				
3.1	Hydraulic Dredging	CY	100,000	$7	$700,000
3.2	Surveying	EA	7	$7,000	$49,000
4.0	Material Processing				
4.1	Dewatering Area Construction	LS	1	$659,000	$659,000
4.2	Dewatering Operations	LS	1	$84,000	$84,000
4.3	Site Restoration	AC	15	$13,000	$195,000
5.0	Off-Site Transportation and Offloading				
5.1	Transportation (Trucked)	TON	154,000	$25	$3,850,000
6.0	Demobilization	LS	1	$60,000	$60,000
7.0				**Construction Subtotal**	$5,942,000
8.0			Construction Management	6%	$357,000
9.0			Project Management	5%	$297,000
10.0			Engineering Design	6%	$357,000
11.0			Permitting and Approvals	5%	$297,000
12.0			Contractor Profit and Overhead	15%	$891,000
13.0			Contingency	30%	$1,783,000
14.0				**Total Cost**	$9,924,000
15.0				**Rounded Total**	$9,900,000
16.0				**Unitized Project Cost ($/CY)**	$99
17.0				**Total Cost Range (+50%)**	$14,900,000
18.0				**Total Cost Range (-30%)**	$6,900,000

Notes:
*Total costs have been rounded to the nearest $1,000.
This is a feasibility-level cost projection only; no technical design has yet been performed. Specifics of design and site and sediment conditions, and market conditions at the time of contractor bidding and construction (including market competition, inflation, and variations in pricing for labor, fuel, and materials) will all affect actual project costs, such that actual implementation costs may differ from this projection.
AC: acre
CY: cubic yard
EA: each
LF: linear foot
LS: lump sum
MO: month

5.2.2 Lake Texana—Harbor of Refuge Restoration Project

Table 2
Cost Projection Summary for Lake Texana—Harbor of Refuge Restoration Project Using Trucked Transportation

Task No.	Task Description	Units	Quantity	Unit Cost	Total Cost*
1.0	Mobilization	LS	1	$95,000	$95,000
2.0	Land Procurement and Site Preparation				
2.1	Land Rental for Staging/Dewatering	LS	1	$30,000	$30,000
2.2	Clearing and Grubbing	AC	15	$6,700	$101,000
2.3	Access Road Construction	LF	500	$50	$25,000
2.4	Site Facilities	MO	13	$6,700	$87,000
3.0	Hydraulic Dredging				
3.1	Hydraulic Dredging	CY	100,000	$7	$700,000
3.2	Surveying	EA	7	$7,000	$49,000
4.0	Material Processing				
4.1	Dewatering Area Construction	LS	1	$659,000	$659,000
4.2	Dewatering Operations	LS	1	$84,000	$84,000
4.3	Site Restoration	AC	15	$13,000	$195,000
5.0	Off-Site Transportation and Offloading				
5.1	Transportation (Trucked)	TON	154,000	$8	$1,232,000
6.0	Demobilization	LS	1	$59,000	$59,000
7.0	**Construction Subtotal**				$3,316,000
8.0	Construction Management			6%	$199,000
9.0	Project Management			5%	$166,000
10.0	Engineering Design			6%	$199,000
11.0	Permitting and Approvals			5%	$166,000
12.0	Contractor Profit and Overhead			15%	$497,000
13.0	Contingency			30%	$995,000
14.0	**Total Cost**				$5,538,000
15.0	**Rounded Total**				$5,500,000
16.0	**Unitized Project Cost ($/CY)**				$55
17.0	**Total Cost Range (+50%)**				$8,300,000
18.0	**Total Cost Range (-30%)**				$3,900,000

Notes:
*Total costs have been rounded to the nearest $1,000.
This is a feasibility-level cost projection only; no technical design has yet been performed. Specifics of design and site and sediment conditions, and market conditions at the time of contractor bidding and constriction (including market competition, inflation, and

variations in pricing for labor, fuel, and materials) will all affect actual project costs, such that actual implementation costs may differ significantly from this projection.
AC: acre
CY: cubic yard
EA: each
LF: linear foot
LS: lump sum
MO: month

5.2.3 Lake Corpus Christi—Nueces Delta Marsh Restoration Project

Table 3
Cost Projection Summary for Lake Corpus Christi—Nueces Delta Marsh Restoration Project Using Trucked Transportation

Task No.	Task Description	Units	Quantity	Unit Cost	Total Cost*
1.0	Mobilization	LS	1	$95,000	$95,000
2.0	Land Procurement and Site Preparation				
2.1	Land Rental for Staging/Dewatering	LS	1	$30,000	$30,000
2.2	Clearing and Grubbing	AC	15	$6,700	$101,000
2.3	Access Road Construction	LF	500	$50	$25,000
2.4	Site Facilities	MO	13	$6,700	$87,000
3.0	Hydraulic Dredging				
3.1	Hydraulic Dredging	CY	100,000	$7	$700,000
3.2	Surveying	EA	7	$7,000	$49,000
4.0	Material Processing				
4.1	Dewatering Area Construction	LS	1	$659,000	$659,000
4.2	Dewatering Operations	LS	1	$84,000	$84,000
4.3	Site Restoration	AC	15	$13,000	$195,000
5.0	Off-site Transportation and Offloading				
5.1	Transportation (Trucked)	TON	154,000	$8	$1,232,000
6.0	Demobilization	LS	1	$59,000	$59,000
7.0	**Construction Subtotal**				$3,316,000
8.0	Construction Management			6%	$199,000
9.0	Project Management			5%	$166,000
10.0	Engineering Design			6%	$199,000
11.0	Permitting and Approvals			5%	$166,000
12.0	Contractor Profit and Overhead			15%	$497,000
13.0	Contingency			30%	$995,000

Task No.	Task Description	Units	Quantity	Unit Cost	Total Cost*
14.0	**Total Cost**				$5,538,000
15.0	**Rounded Total**				$5,500,000
16.0	**Unitized Project Cost ($/CY)**				$55
17.0	**Total Cost Range (+50%)**				$8,300,000
18.0	**Total Cost Range (-30%)**				$3,900,000

Notes:
*Total costs have been rounded to the nearest $1,000.
This is a feasibility-level cost projection only; no technical design has yet been performed. Specifics of design and site and sediment conditions, and market conditions at the time of contractor bidding and construction (including market competition, inflation, and variations in pricing for labor, fuel, and materials) will all affect actual project costs, such that actual implementation costs may differ from this projection.
AC: acre
CY: cubic yard
EA: each
LF: linear foot
LS: lump sum
MO: month

5.2.4 Intermodal Transportation Alternative

Costs were developed to consider the economic feasibility of using an intermodal alternative to strictly trucked transportation. These cost projections, summarized in Tables 4, 5, and 6, focus exclusively on transportation costs. For purposes of this report, it is assumed that the dredging and sediment processing activities would be conducted in the same fashion as with trucked transportation. The projections in Tables 4, 5, and 6 include three successive stages of intermodal transport:

1. Trucked Transport to convey material from the sediment processing area to the nearest existing rail yard
2. Rail Transport from the rail yard nearest to the dredging area to a terminal rail yard near the coastal resiliency site
3. Barged transport from the terminal rail yard to the coastal resiliency site

The last barged transport step is included due to the location of the assessed terminal rail yards. The identified rail yards in proximity to the candidate coastal resiliency projects are all located near port facilities with capacity to transfer material to awaiting haul barges. At all three candidate sites, the transport distance from the terminal rail yard to the coastal restoration site is closer if the final transportation step uses barges instead of an additional trucked transportation step.

Material handling represents the costs associated with material transfer between the intermodal transportation steps. This cost was developed based on labor and equipment required to effectively transfer the dredged material between forms of transport.

Table 4
Cost Projection Summary for Lake Livingston—East Bay Living Shorelines and Wetlands Restoration Project Using Intermodal Transportation

Task No.	Task Description	Units	Quantity	Unit Cost	Total Cost*
5.0	Off-Site Transportation and Offloading				
5.1	Material Handling	LS	1	$444,000	$444,000
5.2	Trucked Transport	TON	154,000	$8.00	$1,232,000
5.3	Rail Transport	TON	154,000	$3.90	$601,000
5.4	Barged Transport	CY	100,000	$8.80	$880,000
				Transportation Subtotal	$3,157,000
				Unitized Transportation Cost ($/CY)	$32
				Unitized Transportation Cost ($/TON)	$21
				Trucked Transportation Cost from Table 1 for Comparison ($/TON)	$25

Notes:
*Total costs have been rounded to the nearest $1,000.
This is a feasibility-level cost projection only; no technical design has yet been performed. Specifics of design and site and sediment conditions, and market conditions at the time of contractor bidding and construction (including market competition, inflation, and variations in pricing for labor, fuel, and materials) will all affect actual project costs, such that actual implementation costs may differ from this projection.
CY: cubic yard
LS: lump sum

Table 5
Cost Projection Summary for Lake Texana—Harbor Of Refuge Restoration Project Using Intermodal Transportation

Task No.	Task Description	Units	Quantity	Unit Cost	Total Cost*
5.0	Off-site Transportation and Offloading				
5.1	Material Handling	LS	1	$444,000	$444,000
5.2	Trucked Transport	TON	154,000	$4.40	$678,000
5.3	Rail Transport	TON	154,000	$2.70	$416,000
5.4	Barged Transport	CY	100,000	$3.90	$390,000
				Transportation Subtotal	$1,928,000
				Unitized Transportation Cost ($/CY)	$19
				Unitized Transportation Cost ($/TON)	$13
				Trucked Transportation Cost from Table 2 for Comparison ($/TON)	$8

Notes:
*Total costs have been rounded to the nearest $1,000.
This is a feasibility-level cost projection only; no technical design has yet been performed. Specifics of design and site and sediment conditions, and market conditions at the time of contractor bidding and construction (including market competition, inflation, and variations in pricing for labor, fuel, and materials) will all affect actual project costs, such that actual implementation costs may differ from this projection.
CY: cubic yard
LS: lump sum

Table 6
Cost Projection Summary for Lake Corpus Christi—Nueces Delta Marsh Restoration Project Using Intermodal Transportation

Task No.	Task Description	Units	Quantity	Unit Cost	Total Cost*
5.0	Off-site Transportation and Offloading				
5.1	Material Handling	LS	1	$444,000	$444,000
5.2	Trucked Transport	TON	154,000	$3.20	$493,000
5.3	Rail Transport	TON	154,000	$2.90	$447,000
5.4	Barged Transport	CY	100,000	$8.80	$880,000
Transportation Subtotal					$2,264,000
Unitized Transportation Cost ($/CY)					$23
Unitized Transportation Cost ($/TON)					$15
Trucked Transportation Cost from Table 1 for Comparison ($/TON)					$8

Notes:
*Total costs have been rounded to the nearest $1,000.
This is a feasibility-level cost projection only; no technical design has yet been performed. Specifics of design and site and sediment conditions, and market conditions at the time of contractor bidding and construction (including market competition, inflation, and variations in pricing for labor, fuel, and materials) will all affect actual project costs, such that actual implementation costs may differ from this projection.
CY: cubic yard
LS: lump sum

Based on this assessment, the costs associated with intermodal transportation are higher than just trucked transportation, as are the unitized costs. The increase is predominantly due to the costs associated with the transfer of bulk material between forms of transportation. The final transportation step, from the terminal rail yard to the coastal restoration site, also adds costs.

While these cost projections do not support intermodal transportation as more economically feasible than trucked transportation alone, the process at specific sites could be optimized. Logistics and transloading specialists could be utilized to reduce the material handling costs but a more advanced dredging and sediment management design would be required to understand construction schedules, dewatering procedures, and coordination details before engaging with such logistics specialists. Alternatively, dredged material could be containerized prior to intermodal transportation to reduce the need for earthwork equipment to transfer material between modes of transport. Additionally, the use of rail could prove to be more economically viable for very distant project pairings or at locations that have railyards or transfer locations located in proximity to both the candidate reservoir site and coastal resiliency site.

It is important to note that Tables 4 to 6 do not include project management costs. As discussed in Section 4.2.5, project and construction management costs are anticipated to be greater for coordinating intermodal transportation than with trucked transportation alone. Increased management costs can be anticipated due to the need to coordinate between multiple different transportation modes and material transfer crews.

5.2.5 Alternative Sediment Sources

GLO provided a unit cost estimate for sand delivery to coastal resiliency sites to serve as a point of comparison with the dredging project costs. Importing non-dredged material for coastal resiliency projects could greatly simplify the project, with the tradeoff of benefits to performing dredging at the reservoir site. If material imported from commercial suppliers such as quarry or aggregate sources were used instead of dredging, the majority of construction costs presented in Tables 1 to 3 are eliminated. Sand import would likely become a part of the coastal resiliency project and no additional engineering design or contractor activities would be required to supply the material.

The GLO provided a general unit cost of $45 to $50 per cy of imported sediment, which includes delivery up to 20 miles from supplier to the placement site. The unit cost for sediment import serves as a point of economic comparison with dredge-sourced material. Comparing the total project unitized costs, the use of material dredged from Lake Texana and Lake Corpus Christi appears to be only slightly more expensive than using commercially imported material at $54 and $55 per cy, respectively. The relatively high unitized cost for the Lake Livingston pairing, $103 per cy is predominantly due to the substantial distance between the lake and the candidate coastal resiliency project. This comparison to trucking costs from a quarry provides a level of corroboration to the dredging cost estimates. It is reasonable that dredging will cost more than a quarry, else quarry operators would be requesting permits to dredge the lakes for profit. However, a quarry operator has applied for a permit to dredge sand from Lake Lyndon B. Johnson (LBJ) (upstream of Austin) for the express purpose of making a profit (Dredge Wire 2021). Hence, it is also reasonable to expect that reservoir dredging is not substantially more expensive than a quarry.

The cost projections illustrate that pairing reservoir dredging with coastal resiliency projects may be feasible if the material transportation distance is not too far. Although the dredging project unitized costs are somewhat more expensive than new material import, the reservoir would greatly benefit from sediment removal, bringing in one or more entities that may be willing to share in project costs.

5.3 Port of Liberty—East Bay Living Shorelines and Wetlands Restoration Project

As discussed in Section 4.2.3, TRA and USACE are currently assessing the feasibility of rebuilding and maintaining the Trinity River between Galveston Bay and POL along the Trinity River (USACE 2023b). A feasibility study was prepared in 2017 to determine required dredging volumes to return navigation back to the channel up to the POL (Freese and Nichols 2017). While the dredge volumes will be dependent on the selected geometry of the navigation channel, estimated removal volumes for the 50-year maintenance cycle could total up to 35.7M cy.

The POL navigation project is an excellent example of a known sediment removal project that could pair well with a coastal resiliency project. In this example, the navigation channel that will be targeted for dredging is much closer to the East Bay Living Shorelines and Wetlands Restoration Project than Lake Livingston, which could greatly reduce transportation costs. Additionally, the POL navigation project includes dredging in the Anahuac Channel, which is located 20 miles from the East Bay restoration project. If the POL navigation project decides to pursue a 9-foot by 130-foot navigation channel, approximately 153,000 cy of material will be targeted for dredging from the Anahuac Channel.

Two additional cost projections were assembled, which use dredged material from the Anahuac Channel for beneficial use at the East Bay project. The two projections represent different options for material transport from the dredging area; transport with a hydraulic slurry pipeline and transport using barges. Both options appear feasible and the projections are used to illustrate cost differences between them. A 10-mile long hydraulic slurry pipeline was included in the projection to represent a median distance for slurry transport from the Anahuac Channel to the East Bay project site. Barged transport was considered as an alternative due to the high costs involved in installing and maintaining long slurry pipelines. For both transportation methods, costs associated with sediment processing were excluded. It is assumed that due to the proximity of the dredging and placement area that sediment processing would not be necessary.

The POL cost projection using slurry pipeline transport is summarized in Table 7, and the projection using barged transport is summarized in Table 8.

Table 7
Cost Projection for Port of Liberty Dredging of the Anahuac Channel Using Slurry Pipeline Transport

Task No.	Task Description	Units	Quantity	Unit Cost	Total Cost*
1.0	Mobilization	LS	1	$184,000	$184,000
2.0	Site Preparation				
2.1	Site Facilities	MO	6.0	$6,700	$40,000
3.0	Hydraulic Dredging				
3.1	Pipeline Procurement and Install	LS	1	$2,550,000	$2,550,000
3.2	Slurry Pipeline Operation	CY	100,000	$5.90	$590,000
3.2	Hydraulic Dredging	CY	100,000	$4.60	$460,000
3.3	Surveying	EA	7	$7,000	$46,000
4.0	Demobilization	LS	1	$184,000	$184,000
5.0	**Construction Subtotal**				$4,054,000
6.0	Construction Management			6%	$243,000
7.0	Project Management			5%	$203,000
8.0	Engineering Design			6%	$243,000
9.0	Permitting and Approvals			5%	$203,000
10.0	Profit and Overhead			15%	$608,000
11.0	Contingency			30%	$1,216,000
12.0	**Total Cost**				$6,770,000
13.0	**Rounded Total**				$6,800,000
14.0	**Unitized Project Cost ($/CY)**				$68
15.0	**Total Cost Range (+50%)**				$10,200,000
16.0	**Total Cost Range (-30%)**				$4,760,000

Notes:
*Total costs have been rounded to the nearest $1,000.
This is a feasibility-level cost projection only; no technical design has yet been performed. Specifics of design and site and sediment conditions, and market conditions at the time of contractor bidding and construction (including market competition, inflation, and variations in pricing for labor, fuel, and materials) will all affect actual project costs, such that actual implementation costs may differ from this projection.
CY: cubic yard
EA: each
LS: lump sum
MO: month

Table 8
Cost Projection for Port of Liberty Dredging of the Anahuac Channel Using Barged Transport

Task No.	Task Description	Units	Quantity	Unit Cost	Total Cost*
1.0	Mobilization	LS	1	$88,000	$88,000
2.0	Site Preparation				
2.1	Site Facilities	MO	6	$6,700	$40,000
3.0	Hydraulic Dredging				
3.1	Hydraulic Dredging	CY	100,000	$4.60	$460,000
3.2	Barge Transport	CY	100,000	$12.20	$1,220,000
3.3	Surveying	EA	7	$7,000	$46,000
4.0	Demobilization	LS	1	$88,000	$88,000
5.0	**Construction Subtotal**				$1,942,000
6.0	Construction Management			6%	$117,000
7.0	Project Management			5%	$97,000
8.0	Engineering Design			6%	$117,000
9.0	Permitting and Approvals			5%	$97,000
10.0	Profit and Overhead			15%	$291,000
11.0	Contingency			30%	$583,000
12.0	**Total Cost**				$3,244,000
13.0	**Rounded Total**				$3,200,000
14.0	**Unitized Project Cost ($/CY)**				$32
15.0	**Total Cost Range (+50%)**				$4,800,000
16.0	**Total Cost Range (-30%)**				$2,240,000

Notes:
*Total costs have been rounded to the nearest $1,000.
This is a feasibility-level cost projection only; no technical design has yet been performed. Specifics of design and site and sediment conditions, and market conditions at the time of contractor bidding and construction (including market competition, inflation, and variations in pricing for labor, fuel, and materials) will all affect actual project costs, such that actual implementation costs may differ from this projection.
CY: cubic yard
EA: each
LS: lump sum
MO: month

The unitized project cost shown in Table 8, which includes dredging the Anahuac Channel with barged transport to the coastal resilience site appears considerably lower than the alternative reservoir dredging locations and is even lower than the cost to import new material. The cost projection that utilizes pipeline transport is over double the cost for barged transport, which is due primarily to the cost to install and maintain the slurry pipeline. While the costs for barge transport are considerably lower than the use of the slurry pipeline, barge access to the East Bay project site might be limited due to low water levels near the coastline. Barges might not be able to directly access the coastline, and an additional pumping step may be required to convey the material to a final installation location.

Pairing the dredging of the Anahuac Channel with the East Bay Living Shorelines and Wetlands Restoration Project provides the most economically feasible project pairing considered in this report. This example, while it does not include reservoir dredging, provides a useful illustration of how certain projects can be effectively paired if the transportation distances between them can be reduced.

It is important to note that the cost estimates shown in Tables 7 and 8 focus exclusively on dredging and transport of material from the Anahuac Channel and not the more extensive Channel to Liberty. While both segments are being considered for dredging, the Anahuac Channel is much closer to the East Bay Living Shorelines and Wetland Restoration project site. We are dredging the Channel to Liberty to be assessed for economic feasibility, the total project costs would increase substantially due to the increased transportation distance. Therefore, where dredging occurs, and the transportation distances involved has a substantially impact on the economic viability of pairing a dredging project with a coastal resiliency project.

5.4 Opportunities for Optimization

There are several methods to optimize the pairing of dredging projects with coastal resiliency projects to improve feasibility, costs, or constructability. This section describes several avenues of optimization, which are summarized below:

- Identify reservoirs with critical needs for sediment removal.
  - Reservoirs with critical dredging needs provide the greatest opportunity for cost sharing between the reservoir owner (or other entities) and the GLO. In a best case scenario, the reservoir owner may undertake all costs associated with dredging and sediment processing, if the GLO or other party responsible for the construction of the coastal resiliency project were to organize and pay for transportation of the material.
  - Costs associated with transportation and material disposal for dredging projects frequently make projects infeasible, but if those costs could be offset to an extent by paring with a coastal resiliency project, both parties could benefit greatly from the relationship.
  - Dredging reservoirs to increase storage capacity can involve large removal volumes. In the case of Lake Livingston, as discussed in Section 4.1.1.2, 208M cy of sediment has accumulated since the impoundment was constructed. A project oriented towards increasing reservoir capacity could exceed the material needs for certain coastal resiliency projects. Therefore, finding reservoirs that have comparable volumetric needs to the coastal project(s) is in the best interest of the project pairings.

  - Reservoirs may require dredging to increase capacity for water supply, increase capacity for flood storage, decrease flooding in an arm with inflows, improve recreation, enhance property values, improve water quality, or uncover and protect water intakes or other important infrastructure. Each of these needs may be represented by an entity willing to contribute to dredging project costs. Projects that provide multiple benefits are mostly likely to have multiple entities willing to cost share.
- The sediment type, or types, available at a reservoir dredging site must be appropriate for use at the paired coastal resiliency site
  - As discussed in Section 4.1.1.1, dredged material may not be suitable for all types of beneficial use. The restoration type, and design of the restoration project, should be matched appropriately with the material available in the reservoir to increase the chances of a successful pairing. Examples include paring a reservoir that contains predominantly sand for beach nourishment projects. Reservoirs that contain predominantly fine-grained materials would be better suited to marsh restoration.
  - Because the grain size distribution often varies throughout a reservoir, a certain portion of a reservoir may provide the most suitable material for a particular coastal resiliency project.
  - Another option to take advantage of different grain sizes could occur if nearshore soils (adjacent to the reservoir) are sandy. These could be excavated and transported to the coast for a restoration project. Then sediment could be dredged from the reservoir and placed in the excavation area. This approach would require both digging and dredging, but would save transportation costs by transporting dry material, and would result in less complicated dewatering of the dredged sediment because truck transportation would not need to be synchronized with the dredging and dewatering operations.
  - None of the three reservoirs evaluated had grain size data at the spatial resolution needed to design a project. Such data are relatively inexpensive and should be collected early in a feasibility study of a particular reservoir.
- Upland confined disposal areas could be constructed as non-single use facilities.
  - Apart from transportation, sediment processing is a major project driver. The cost projections in Tables 1, 2, and 3 assume the use of a temporary impoundment for passively dewatering sediment. The impoundment would need to be constructed, operated, and removed at the completion of construction due to the assumption that the land it occupies would be leased and not purchased.
  - Project costs could be reduced if these impoundments could be reused for future dredging projects. Maintenance dredging in reservoirs may be performed on a recurring basis to maintain storage capacity and the reuse of impoundments would assist in reducing costs.

- Transportation should be optimized to reduce costs to the extent practicable.
  - Although the assessment of intermodal transportation did not provide reduced transportation costs, that may not be the case for every project pairing. Dredging sites and coastal resiliency project sites that are located in proximity to existing railyards could still be candidates for the use of railroads. The use of logistics and transloading companies could further reduce the costs associated with rail transport.
  - Projects that expect to have multiple years of dredging, or multiple years of placement at the restoration site, may find it cost-effective to build rail spurs.
  - Truck availability and contract conditions must be established to derive favorable costs for transportation. The number of operating trucks, duration of transportation, and daily working hours all influence trucking costs. Extending the duration of transportation while reducing the number of operating trucks may reduce total transport costs, which could impact economic feasibility.
  - Pipeline pumping can be very cost-effective for short distances, but all of the reservoirs considered were too far from the identified coastal resiliency sites to make this viable.
- Economies of scale have strong implications on financial feasibility.
  - Unit costs for dredging and dewatering are frequently reduced for larger dredging projects. This is due in part to the use of equipment capable of higher production rates, as well as the ability to spread certain costs over a larger removal volume, thus reducing the unit cost of dredging even if the total project cost increases.
  - The scale of dredging should be considered relative to the material needs of the coastal resiliency project. For example, if a coastal resiliency project requires only a few thousand cubic yards of material, then it will be unlikely that dredging would be a financially viable option compared to import of new source material. Conversely, if coastal resiliency project requires millions of cubic yards of material, it is a higher likelihood that pairing with reservoir dredging will be financially viable.

6 Conclusions and Recommendations

This assessment has considered the technical and financial feasibility of pairing reservoir dredging with beneficial use of dredged material for coastal resilience projects. Technical feasibility, including sediment characteristics, construction sequencing, and dredging methodology, were presented in a manner consistent with preliminary engineering studies for reservoir dredging. The sediment volumes and characteristics of the three candidate reservoirs were assessed using publicly available information. All three reservoirs contain significant quantities of sediment, which suggests that if costs are competitive with other sediment options (or can be shared with other entities) and the sediment is suitable for restoration, reservoir dredging should be a viable solution to the sediment needs of coastal resiliency projects.

The sediment within Lake Livingston, Lake Texana, and Lake Corpus Christi, appear relatively consistent and contain predominantly fine-grained material (with the exception of coarser grained sand in an area of Lake Corpus Christi) that is well suited to removal via hydraulic dredging. Due to the fine-grained nature of most of the monitored sediments, additional data collection would be necessary to try to identify areas of coarse-grained sand suitable for beach nourishment.

The financial feasibility of pairing reservoir dredging with beneficial use was assessed using several cost projections. These cost projections, developed to a pre-design level, indicate that reservoir dredging may prove financially feasible in comparison to import of new material to coastal resiliency projects, but this is dependent on the transportation distances between sites. While use of material from Lake Texana and Lake Corpus Christi appears to be financially feasible and comparable to the costs of importing new material to the candidate coastal resiliency project locations, the long transportation distance between Lake Livingston and the East Bay Living Shorelines and Wetlands Restoration project substantially contributed to high total project costs and may not be a financially feasible pairing.

While this assessment has focused on three candidate reservoir and coastal resiliency project pairings, several conclusions can be drawn that are relevant to other potential project pairings. Land must be available near the potential reservoir site, and also near a suitable lens of sediment to be dredged, to allow for cost-effective dewatering prior to trucked transport. Sediment processing and dewatering can be a major cost driver, and the use of passive dewatering impoundments can considerably reduce costs. The transportation distance between the reservoir site and coastal resiliency site strongly influences financial feasibility. Therefore, to increase financial viability, pairing reservoirs located in proximity to coastal resiliency projects should be prioritized. The cost projections for material transport using intermodal transportation indicate that in certain circumstances, such as all three candidate project pairings considered in this assessment, trucked transportation may be the most cost-effective form of transportation due to material transfer and logistics costs.

Importantly, the viability of beneficial use of material dredged from reservoirs could be greatly improved if a specific reservoir were to have a crucial need for dredging. If costs for dredging or transportation could be shared among several stakeholders, such as the reservoir owners and the GLO or alternative party, the financial feasibility would be substantially improved. It is recommended that outreach continue between reservoir owners and the GLO to identify potential dredging projects with immediate and critical dredging needs. The critical dredging needs may include restoring water storage capacity, protecting or maintaining the dam, water intakes, or water resources infrastructure, alleviating flooding (either downstream of the reservoir or in reservoir arms with inflows), improving recreation and water quality, and enhancing property values. The benefits of pairing dredging with beneficial use projects should attempt to provide benefits for multiple parties, which is feasible if critical reservoir dredging needs are identified.

The viability of pairing reservoir dredging with coastal resiliency beneficial use projects is site-specific. From the perspective of material types, sediment within reservoirs may not be suitable for specific coastal resiliency projects due to mismatches with sediment characteristics. Coastal resiliency projects that require coarse- or medium-grained material would not be adequately served with fine-grained sediment from a specific reservoir. Sediment needs at the candidate coastal resiliency projects currently align with the sediment type found within their respective paired reservoirs. However, modifications to the coastal resiliency design could render these pairings infeasible if construction requires predominantly sand or coarse-grained sediment.

Data on grain size and chemical concentrations should be collected early in the feasibility study phase of a project to identify the suitability of the material for coastal resiliency projects. From a cost perspective, the costs and sources for new material import will differ between coastal resiliency sites. Certain locations, especially in more remote or rural areas, may not have a financially feasible source of material import. Coastal resiliency sites that are located far from aggregate or sediment quarries may be well served by pairing with reservoir dredging.

Based on the study results, the following is a proposed list of next steps:

- Select one or more paired reservoir and coastal resiliency projects to evaluate further.
  - Based on supportive reservoir owners, multiple benefits that may accrue from dredging, the likely prevalence of sand, and the proximity of rail, it is recommended that Lake Corpus Christi and Nueces Delta Marsh Restoration be evaluated further.

- Identify likely dredge areas and shoreline construction staging.
  - Discuss potential dredge areas with the City of Corpus Christi, Nueces River Authority, and other stakeholders to initially identify the most beneficial area(s) to dredge (considering multiple benefits) and the most likely staging area.
- Collect data.
  - Collect sediment depth, grain size, and chemistry data in the area(s) deemed most beneficial to dredge.
- Refine likely dredge areas and shoreline construction staging.
  - Based on an analysis of the sediment data and further discussions with stakeholders, refine the most beneficial area(s) to dredge and the most likely staging area.
- Evaluate ownership.
  - Work with the City of Corpus Christi to identify ownership of the sediment areas and consider communicating the proposed project to these owners to solicit their support.
- Evaluate sediment need.
  - Discuss the total sediment volume needed and desired placement location at the Nueces Delta with Kiersten Stanzel of Coastal Bend Bays & Estuaries Program.
  - If significant sand is demonstrated to be available, identify other coastal restoration projects in the area that could benefit from sand.
- Refine cost estimates.
  - Based on the sediment available in the preferred dredging area(s) and sediment need at the restoration site, refine the cost estimates, including a cost estimate using rail transport, if the sediment volume is large enough to justify this approach.
- Research funding.
  - Identify grant funding opportunities that emphasize increasing water supply, protecting water intakes, reducing flood risk, increasing recreational opportunities, and restoring coastal habitats.

Following completion of these steps, if the project is still deemed feasible and funding is available, it can move forward with a formal engineering design, permitting, and construction process.

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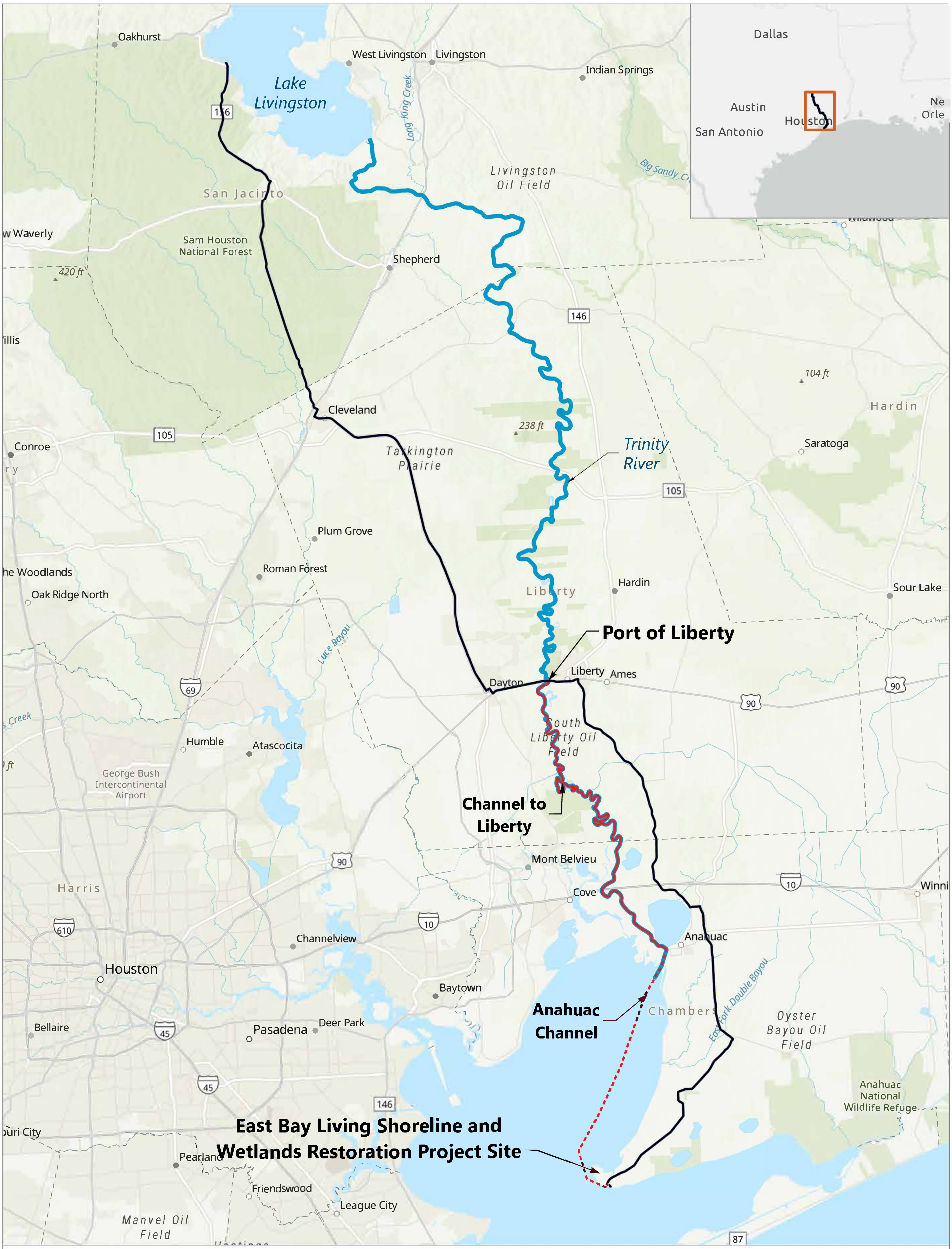
Figures



LEGEND:

- Trinity River
- NHD Waterbody
- Assumed Truck Transportation Route - 109 Miles One-Way

Barge Route

- Channel to Liberty
- Anahuac Channel

NOTES:

1. NHD: National Hydrography Dataset
2. NHD Source: United States Geological Survey

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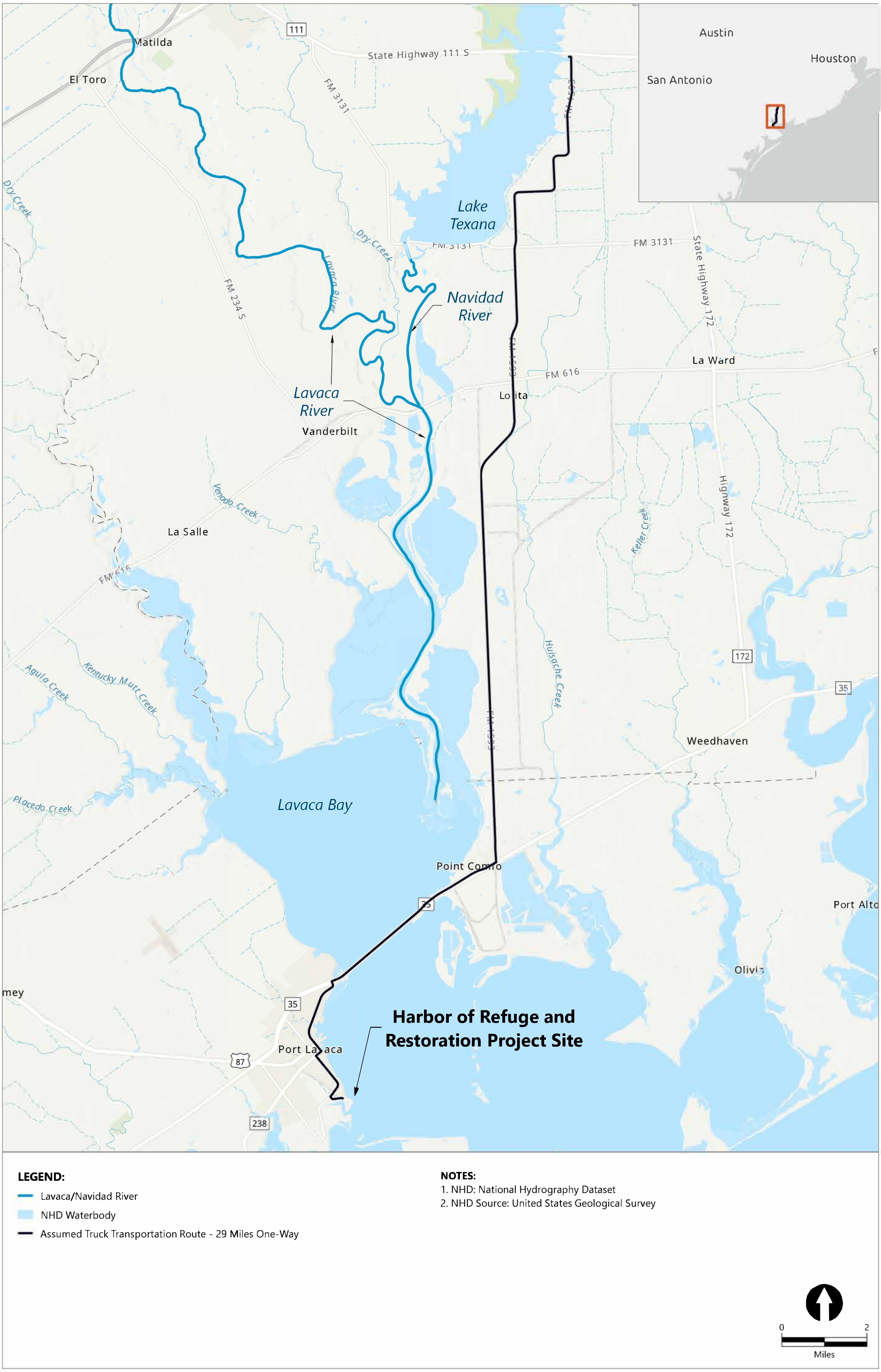
Figure 1
Lake Livingston - East Bay Project
Reservoir-Impounded Sediment Assessment
Texas General Land Office



LEGEND:

- Lavaca/Navidad River
- NHD Waterbody
- Assumed Truck Transportation Route - 29 Miles One-Way

NOTES:

1. NHD: National Hydrography Dataset
2. NHD Source: United States Geological Survey

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Figure 2
Lake Texana - Harbor of Refuge
Reservoir-Impounded Sediment Assessment
Texas General Land Office

LEGEND:

- Nueces River
- NHD Waterbody
- Assumed Truck Transportation Route - 37 Miles One-Way

NOTES:

1. NHD: National Hydrography Dataset
2. NHD Source: United States Geological Survey

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Miles

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Figure 3
Lake Corpus Christi - Nueces Delta
Reservoir-Impounded Sediment Assessment
Texas General Land Office