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Timothy Welp and Dr. Gary Ray

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Abstract: Restoration of Louisiana's marshes and other coastal habitats will, in many cases, require dredged sediments. Potential restoration sites are often at great distances from the sediment source that will require special efforts, referred to as long distance conveyance (LDC), to pump sediment to the sites. In this report, LDC projects are defined as those Louisiana coastal restoration projects that involve hydraulic transport of slurry (mixture of sediment and water) through pipelines for distances of 16 km (10 miles) or greater. Long distance transport is a mature technology that has been used efficiently for applications like coal and iron ore transport. At the workshop "Long-Distance Pipeline Transport of Dredged Material to Restore Coastal Wetlands of Louisiana," the consensus of national and international experts in the field of long-distance transport of dredged sediment and other materials by pipeline, was that there were no fundamental technological challenges to the delivery of sediment via LDC (Hales et al. 2003). Engineering challenges will be to optimize LDC design, operation, and maintenance to achieve respective strategic restoration goals in the most efficient, cost-effective, and environmentally acceptable manner possible.

This report describes dredging and transport methodologies in relation to state-of- practice LDC design and economic considerations, and discusses respective potential environmental impacts of long distance pipeline transport across Louisiana wetlands. Scientific and engineering uncertainties related to the optimization of LDC of dredged sediment for Louisiana coastal restoration are identified. Uncertainty, as used in this context, implies a lack of predictability, structure, and information (Rogers 1995). The objective of this report is to identify these uncertainties to personnel involved in planning, designing, constructing, monitoring, and assessing future LDC demonstration projects. If efforts are applied to reduce the levels of these uncertainties in future LDC demonstration projects by applying an adaptive management approach, then the increased predictability, structure, and information gained from these demonstrations may be used to optimize subsequent full-scale LDC Louisiana coastal restoration projects.

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Preface

The objective of this report is to identify scientific and engineering uncertainties involved with the long distance conveyance (LDC) of dredged sediments for Louisiana coastal restoration. Uncertainty, as used in this context, implies a lack of predictability, structure, and information (Rogers 1995). Pertinent technical literature was reviewed and interviews with personnel involved in LDC-related projects conducted to summarize state-of-practice LDC dredging project information and knowledge.

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Unit Conversion Factors

Non-SI units of measurement in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
Acres	0.4047	hectares
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons	0.003785	cubic meters
gallons per minute	0.06308	liters per second
inches	0.0254	meters
horsepower	0.7457	kilowatts
miles (U.S. statute)	1,609.347	meters
pounds per square inch	0.6895	bars

1 Introduction

The Louisiana Coastal Area (LCA), Louisiana Ecosystem Restoration Study (U.S. Army Engineer District, New Orleans and State of Louisiana 2004) reported that coastal Louisiana has lost over 1.2 million acres (1,875 square miles) since the 1930s; in the 1970s, the loss rate for Louisiana's coastal wetlands was as high as 25,200 acres per year (39.4 square miles/year); and from 1990 to 2000 the loss rate was about 15,300 acres per year (23.9 square miles/year). Much of this loss was due to the residual effects of past human activity (Barras et al. 2003). As poignantly stated by Lindquist and Martin (2007) about a land loss rate of approximately 24 square miles per year, "at this rate, an area the size of a football field is lost every 38 min." This loss of coastal wetlands and ecosystem degradation threaten the continued productivity of Louisiana's coastal ecosystems, the economic viability of its industries, and the safety of its residents (U.S. Army Engineer District, New Orleans and State of Louisiana 2004).

Beneficial use of dredged material represents an important option to restore degraded wetlands along the Louisiana coast. Unfortunately, in many coastal Louisiana restoration projects, the distances that the sediments need to be transported (16-50 km (10-30 miles) or more) are greater than those typically conveyed by using conventional dredging technology (Hales et al. 2003). Long distance conveyance (LDC) may offer a viable solution to address these longer transport distances requirements, but additional elements such as increased costs incurred by more extensive infrastructure and labor requirements and environmental impacts must be considered in relation to the restoration project objectives. For the purposes of this report, LDC projects are defined as those Louisiana coastal restoration projects that involve hydraulic transport of slurry (mixture of sediment and water) through pipelines for distances of 16 km (10 miles) or greater.

Pumping slurry through a long pipeline is a mature technology for bulk transport that has been used efficiently for applications like coal and phosphate transport (one of the best known LDC projects being the Black Mesa pipeline that transports coal slurry 400 km) (Wilson et al. 2006). At the workshop entitled "Long-Distance Pipeline Transport of Dredged Material To Restore Coastal Wetlands of Louisiana," the consensus of panelists and the audience (that consisted of national and international experts in the field of long-distance transport of dredged and other materials by pipeline) was that there were no fundamental technological challenges to the delivery of sediment via LDC (Hales et al. 2003). LDC shows promise as a way of cost-effectively moving large amounts of sediment to relatively remote restoration sites and the flexibility of the pumping system to allow access to sites impractical for barge transport. LDC of the quantities of sediment that will be required to significantly impact Louisiana's wetlands loss rate, on the temporal and spatial scales necessary to achieve restoration goals, has never been conducted anywhere in the world before. The scientific, technical, and engineering challenges in effectively using LDC for sediment transport will be in optimizing its design, construction, and operation to achieve respective strategic goals in the most efficient, cost effective and environmentally acceptable manner possible.

While no LDC projects have been executed to date, various LDC project-pertinent activities such as sediment source identification, evaluation of hydraulic placement technologies, etc., have been conducted. These activities have been performed under initiatives that include, but are not limited to programs such as the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) (http://www.lacoast.gov/cwppra/), LCA Ecosystem Restoration Program (http://www.lca.gov/index.aspx) and Beneficial Use of Dredged Material (BUDMAT) Program, and the Coastal Impact Assistance Programs (CIAP). For a more detailed description of these initiatives refer to Appendix A. But significant amounts of baseline LDC information and knowledge gained from these respective efforts have not been summarized and made readily accessible for optimizing future LDC projects. Sources of information include proceedings from various workshops, consultant and academic reports, and planning, design, and project documentation.

A review of the scientific and technical literature and interviews with personnel involved in LDC-related projects (list of interviewees provided in Appendix B) were conducted in order to produce a of state-of-practice summary. Literature databases listed in Table 1 were also searched for pertinent documentation. These results were synthesized to identify scientific, technical, and engineering uncertainties (used in the context that uncertainty implies a lack of predictability, of structure, of information, Rogers 1995) related to LDC of dredged sediments for wetlands restoration. The objective of this report is to identify these uncertainties to personnel involved in planning, designing, constructing, monitoring, and assessing future LDC demonstration projects. If efforts are applied to reduce the levels of these uncertainties in future LDC demonstration projects by applying a adaptive management approach, then the increased predictability, structure, and information gained from these demonstrations may be used to optimize subsequent full-scale LDC Louisiana coastal restoration projects. Adaptive management, as described by CH2M HILL (2006) is applicable to pipeline conveyance alternatives for Louisiana wetlands restoration and “refers to the systematic process of continually improving management policies and practices by learning from the outcomes of operational programs.”

Table 1. List of literature databases searched.

American Society of Civil Engineers (ASCE) Civil Engineering Database
Conference Papers Index
JSTOR
Construction Criteria Base
EBooks: SpringerLink
GeoRef
GeoRef In Process
Oceanic Abstracts
Defense Technical Information Center

The information presented in this report will be described within the context of a framework constructed on a systems approach where an understanding of the system is framed by examining the linkages and interactions between the elements (or components) that compose the entirety of the system (basically an assortment of objects working together to produce a result, or results). The system will be defined as the evolution of a construction project using long-distance conveyance by pumping slurry (water and sediment) for coastal wetland restoration.

At the core of this system, there exists three basic components: (1) sediment supply where the sediment will be removed from (e.g., a “borrow” area like Ship Shoals or a navigation channel maintenance dredging project in the Mississippi River), (2) pipeline corridor that is the route that the slurry pipeline will be constructed and operated upon (over open water, wetlands, etc.), and (3) placement site where the sediment will be transported to and placed upon. The specific configuration and characteristics of these three core components are, in turn, dependant upon interactions with the other components illustrated in Figure 1. These components are discussed in the following chapters.

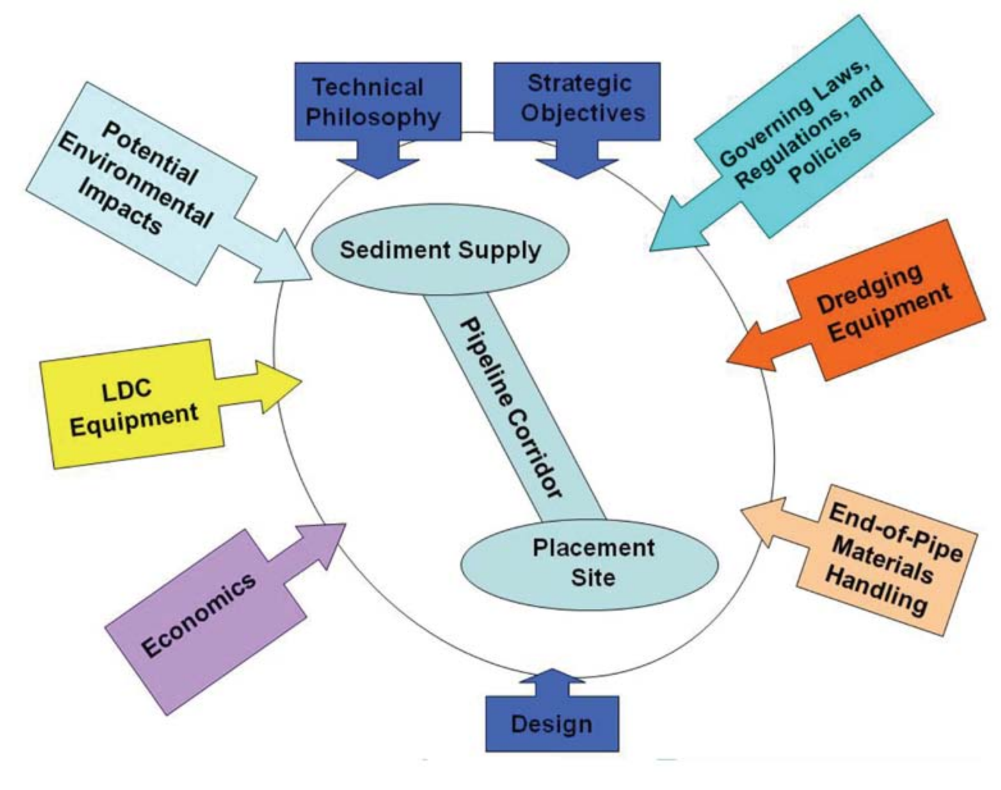


Figure 1. The LDC project "system".

In order to identify the scientific, technical, and engineering uncertainties within this system, the following questions were applied to the data, information, and knowledge compiled on the system components and their respective linkages and interactions between each other.

- Are all the components that influence the system known, or are there others?
- How well are these components' processes, and interactions understood?
- How much data, information, and knowledge are available on these components?
- How well can these components and their respective interactions with other components be analyzed and predicted?

The LDC system with respective components is illustrated in Figure 1.

Understanding the performance and costs of a range of alternatives conceptualized, formulated, evaluated, and compared through a systematic approach would assist Federal and State Coastal Managers in taking broad cost-shared actions to advance development and implementation of alternatives involving physical plant on a large scale. This would require extensive analyses to characterize the sources of variability and uncertainty in models, knowledge, information, and data collectively used to estimate excavation, materials transport, and placement requirements as a function of attendant considerations.

These considerations include, but are not limited to aspects such as sediment type, hydro-meteorological parameters, sediment transport modes/rates, location parameters, physical plant operating parameters for materials excavation, transport, and initial placement fate, as well as evaluation of long-term performance under physical forcings such as coastal storm action and localized subsidence.

Some aspects, such as achievement of appropriate elevations for marsh vegetation and functioning channels for fisheries habitat, are common to conventional (less than 10 mile pumping distance) dredging projects; where germane to LDC related issues, are included in this report for completeness.

Another critical aspect that, while not a technical issue, involves land rights and the *major* impacts that they can have on restoration projects (CH2M HILL 2006; Woodward Clyde Consultants 1991; Suhayda et al. 1991; Hales et al. 2003; Pyburn & Odom, Inc. 1993). Permissions and agreements must be obtained to remove sediment from the borrow site, easements for the land to set the pipeline corridor upon, and permission from the land owners to place the dredged material upon. As per Mr. Van Cook of the Louisiana Department of Natural Resources (LDNR) (Hales et al. 2003), a study was conducted by the LDNR by Pyburn & Odom, Inc. (1993) to determine the potential feasibility of using abandoned oil and gas pipelines and, if proven potentially feasible, prepare a conceptual design and an estimated cost for a pilot project to demonstrate practical feasibility. The study determined that it was potentially feasible to use abandoned pipelines to restore Louisiana's wetlands and a conceptual design based on a project at Tiger Pass near the Tidewater Facility was evaluated. It was determined that that while abandoned pipelines do exist, no pipelines identified in the study were found to be unconditionally available, and that the pipelines that were identified to be conditionally available had diameters less than optimal size for transporting large quantities of dredged sediments. “The use of abandoned pipelines was found to be potentially feasible, but practical feasibility was not proven. Cost per acre was exceedingly high, and abandoned pipelines of an appropriate size and in the appropriate location are believed to be essentially nonexistent” (Hales et al. 2003).

As per Dr. Joseph Suhayda (Hales et al. 2003): “Abandoning a pipeline eliminates removal impacts and associated costs, but also entails legal ramifications. Thus, the use of existing right-of-ways for formerly-used pipelines to construct a new system of pipelines for long-distance transport of dredged material to restore coastal Louisiana may be feasible.” The aspect of co-locating a slurry pipeline in the same corridor as an existing pipeline right-of-way (ROW) has been mentioned (personal communication Mr. Al Levron, Terrebonne Parish Consolidated Government), and was used as an assumption for pipeline corridors in a reconnaissance-level evaluation by CH2M HILL (2006), but no available studies investigating the feasibility of this pipeline co-location aspect were identified. Another concern regarding slurry pipeline interactions with oil and gas pipelines is whether slurry pipelines can be laid over top of oil and gas infrastructure, and if so, how much cover (separation material), if any, would be required to avoid any damage to the underlying pipeline (personal communication Mr. Gordon Thomson, Coastal Planning & Engineering, Inc.).

2 Technical Philosophy/Strategic Objectives/Governing Laws, Regulations, and Policies

Technical philosophy relates fundamentally to how a project is scoped and executed in fulfilling strategic objectives. For example, one technical philosophy is building "instant marsh" that can yield less-than optimum results due to lack of constructability precision, expense, and less-than-desirable short-term ecosystem value. Alternatively, the technical philosophy of "getting sediment in the system" focuses more on delivering the basic ingredients for vertical accretion in the coastal environment, worked over in time by natural forces to shape features more likely to be sustainable relatively longer than under competing technical philosophies. Dredging for beneficial use and dedicated dredging can often be planned and executed in a sub-optimal manner due to application of inadequate technical philosophies, mainly missing opportunities for "Working with Nature". “Working with Nature” is a philosophy promoted by the World Association for Waterborne Transport Infrastructure (PIANC, 2008) that is “an integrated process which involves working to identify and exploit win-win solutions which respect nature and are acceptable to both project proponents and environmental stakeholders. Working with Nature is about more than avoiding or mitigating the environmental impacts of a pre-defined design. Rather, it sets out to identify ways of achieving the project objectives by working with natural processes to deliver environmental protection, restoration or enhancement outcomes. Fundamentally, therefore, Working with Nature means doing things in a different order:

- establish project need and objectives
- understand the environment
- make meaningful use of stakeholder engagement to identify possible win-win
- opportunities
- prepare initial project proposals/design to benefit navigation *and* nature”

Strategic objectives of plan formulations and attendant policies of Louisiana coastal restoration will be primary drivers for selecting design approaches and operational methodologies used to achieve LDC-related restoration. In turn, these design approaches and operational methodologies will determine ecosystem impacts and construction costs. The plan formulation rational used by U.S. Army Engineer District, New Orleans and State of Louisiana (2004) to ensure that sound decisions are made with respect to alternatives "should be formulated in consideration of four criteria: completeness, effectiveness, efficiency, and acceptability.

Completeness is the extent to which a given alternative plan provides and accounts for all necessary investments or other actions to ensure the realization of the planned effects.

Effectiveness is the extent to which an alternative plan alleviates the specified problems and achieves the specified opportunities.

Efficiency is the extent to which an alternative plan is the most cost-effective means of alleviating the specified problems and realizing the specified opportunities, consistent with protecting the Nation's environment.

Acceptability is the workability and viability of the alternative plan with respect to acceptance by state and local entities and the public and compatibility with existing laws, regulations, and public policies."

The LCA project delivery team compiled the following guiding principles for plan formulation in coordination with key stakeholder groups and with public comments provided during the scoping process (U.S. Army Engineer District, New Orleans and State of Louisiana 2004).

1. "It is evident that management of Louisiana's coast is at a point of decision. Only a concerted effort now will stem this on-going degradation, and thus alternatives must include features which can be implemented in the near-term and provide some immediate benefits to the ecosystem, as well as those which require further development and refinement of techniques and approaches.
2. Appreciation of the natural dynamism of the coastal system must be integral to planning and the selection of preferred alternatives. This should include assessing the risks associated with tropical storms, river floods, and droughts.

3. Alternatives that mimic natural processes and rely on natural cycles and processes for their operation and maintenance will be preferred.
4. Limited sediment availability is one of the constraints on system rehabilitation. Therefore, plan elements including mechanical sediment retrieval and placement may be considered where landscape objectives cannot be met using natural processes. Because sediment mining can contribute to ecosystem degradation in the source area, such alternatives should, to the extent practicable, maximize use of sediment sources outside the coastal ecosystem (e.g., from the Mississippi River or the Gulf of Mexico).
5. Plans will seek to achieve ecosystem sustainability and diversity while providing interchange and linkages among habitats.
6. Future rising sea levels and other global changes must be acknowledged and incorporated into planning and the selection of preferred alternatives.
7. Displacement and dislocation of resources, infrastructure, and possibly communities may be unavoidable under some scenarios. In the course of restoring a sustainable balance to the coastal ecosystem, sensitivity and fairness must be shown to those whose homes, lands, livelihoods, and ways of life may be adversely affected by the implementation of any selected alternatives. Any restoration-induced impacts will be consistent with NEPA in that actions will be taken to avoid, minimize, rectify, reduce, and then, only if necessary, compensate for project-induced impacts.
8. The rehabilitation of the Louisiana coastal ecosystem will be an ongoing and evolving process. The selected plan should include an effective monitoring and evaluation process that reduces scientific uncertainty, assesses the success of the plan, and supports adaptive management of plan implementation.
9. Recognizing that disturbed and degraded ecosystems can be vulnerable to invasive species, implementation needs to be coordinated with other state and Federal programs addressing such invasions, and project designs will promote conditions conducive to native species by incorporating features, where appropriate, to protect against invasion to the extent possible without diminishing project effectiveness.
10. Net nutrient uptake within the coastal ecosystem is maximized through increased residence time and the development of organic substrates, and thus project design should promote conditions that route riverine waters through estuarine basins and minimize nutrient export to shelf waters.”

In view of these criteria (completeness, effectiveness, efficiency, and acceptability) and with regard to the guiding principals, the supposition is presented that use of LDC implies the selection of a restoration alternative that involves transport of a *very* significant amount of sediment compared to past restoration projects. A study conducted by Suhayda et al. (1991) that "proposed that slurry pipelines be considered as modern surrogates for natural distributary channels in a subsiding delta tightly managed for navigation, flood control, fisheries, and energy development" is described for discussion purposes. Suhayda et al. (1991) presented a 20 year scenario as an example of how funding might be used to stabilize Louisiana's wetland loss by pumping sediment through a pipeline-based infrastructure; it was predicted that after 16 years, no-net-loss of wetlands could be achieved. To achieve the "ambitious goal" to replace an (estimated) annual marsh loss rate of 10,000 ha/year (24,700 acres), while maintaining 1,000,000 ha/year (2,470,000 acres) of threatened (sediment deprived) wetlands, the total demand for dredged sediments was estimated to be 80,000,000 cu m/year (104,000,000 cu yd/year).

A more recent reconnaissance-level study of the Third Delta Conveyance Channel (TDCC) Project by CH2M HILL (2006) consisted of the evaluation of a TDCC concept (that involves creating a new delta by sediment carried through a constructed channel conveyance) and compared it to three LDC alternatives. As per CH2M HILL (2006) "To reduce the current land loss in coastal Louisiana and reclaim previously lost land, massive quantities of sediment must be delivered to the coastal marshes." In order to be able compare the pipeline delivery alternatives on about the same sediment delivery scale as the large conveyance channel, annual transport rates of the three pipeline alternatives ranged from approximately 13,700,000 to 36,700,000 cu m/year (18,000,000 to 48,000,000 cu yd/year) over a project life span of 50 years.

A workshop was held on 14 October 2003 (Hales et al. 2003) that focused on LDC and clarified for many in the Louisiana restoration community that the movement of dredged material many miles across the coast to areas of need was technologically feasible. Reed (2004) noted that "Concerns remained, however, regarding the use of large quantities of dredged material to create functional marsh habitat on a large scale (i.e., thousands of acres)."

To further explore issues related to LDC for large scale coastal restoration, another workshop was held on 8 September 2004 with a focus on "developing concept proposals for the large scale use of dredged material to restore some of the most degraded areas of the Louisiana coast – those areas where large open-water areas that must be filled before marsh habitats can be regained and where remaining marshes are extremely fragmented" (Reed 2004).

U.S. Army Engineer District, New Orleans and State of Louisiana (2004) has recognized, and is addressing, this constraint in the development and evaluation of restoration alternatives within coastal Louisiana as a significant category of constraints consisting of scientific and technological uncertainties inherent in large-scale aquatic ecosystem restoration projects (Type 3 - uncertainties about ecological processes, analytical tools, and ecosystem response, U.S. Army Engineer District, New Orleans and State of Louisiana 2004). "Although numerous scientific studies have been conducted within the coastal environments, a considerable degree of uncertainty remains about ecological processes. Limitations in analytical tools to assess ecosystem responses also exist" (U.S. Army Engineer District, New Orleans and State of Louisiana 2004).

Other specific research/technology needs identified in Reed (2004) include:

1. "Wetlands restoration efforts involving LDC and placement of sediments on the scale proposed by Suhayda et al. (1991), or one even considerably less in size, has never been completed in the world before. Wetland restoration efforts that have been, or are being, conducted on much smaller scales than described above, along with attendant data, information, and knowledge learned from them, may, or may not, be applicable, or scaleable (non-linear) to projects on a much larger scale.
2. The impact of the 'transport' water used to slurry sediments and discharged within them during placement needs to be considered. This water is likely to be either fresher or more saline than the ambient salinity in the area depending on the source of dredged material (the River or offshore). The effects of this water on the local ecosystem should be explicitly considered in restoration planning.
3. Questions remain regarding the effects of massive sediment removal from the Mississippi River on river channel dynamics (e.g., reoriented flow directions and potential levee erosion). These must be explored prior to long-distance pipeline projects that rely on the River for sediment. Also, what is the likely volume and availability of sediment from the River?

4. Pipeline conveyance allows the import of sediment from outside the estuarine basins for use in ecosystem restoration. While this material could be used directly for project construction, an alternative approach is to use local material for projects and refill the borrow areas with the pipeline. The economic and ecological costs and benefits associated with both alternatives should be explored to maximize efficiency of sediment pipelines.
5. Dredged material placement projects that seek to achieve appropriate elevations for marsh vegetation and functioning channels for fisheries habitat, provide opportunities to explore the costs and ecological outcomes associated with the design features. Evaluations across a range of placement approaches would inform future marsh creation projects."

As previously stated, another critical aspect that has major impacts on wetlands restoration projects is that of land rights. Permissions and agreements must be obtained to remove sediment from the borrow site, easements for the land to set the pipeline corridor upon, and then permission from the land owners to place the dredged material.

Given the scientific and technological uncertainties inherent in large-scale aquatic ecosystem restoration projects, the concept of "adaptable expectations" should be considered in concert with "adaptive management". The notion of adaptable expectations relates to project goals and objectives and that they should not be considered immovable once established. If initially, those parties involved in project development decide to aspire to a certain set of goals and objectives, and find during construction and/or post-construction monitoring, natural forces are more overwhelming to counter even for adaptively managing the project for sustaining these initial values sought, the project may need to be modified and/or abandoned. An example is the NOAA Fisheries attempt to close a cut on Timbalier Island under a CWPPRA project. The cut-to-fill ratio during pumping got so high (10:1 and higher) that there was no physical way the dredge could have closed off the pass without implementing extraordinary coastal engineering measures. This feature was abandoned from the project, as an example of adapting expectations (personal communication Dr. Edmond Russo, Chief, Ecosystem Evaluation and Engineering Division Environmental Laboratory, ERDC).

3 Dredging Equipment

While optimization of future LDC projects will depend upon the integration and interaction between a wide variety of system components as illustrated in Figure 1. One of the critical aspects will involve, given project goals, how well the dredging components mesh with respective pipeline transport and placement components with regard to maximizing production rates, while minimizing costs and environmental impacts. In this section, fundamental descriptions of different dredge types are presented to identity general production characteristics in the context of their respective influences on subsequent LDC and placement operations.

Dredging can be defined as the process of excavating sediments and other materials from underwater locations, and transporting and placing this material for purposes such as constructing new waterways, maintaining existing waterway dimensions, obtaining fill for land reclamation, beach nourishment, dike and levee construction, creating wetlands and marshes, obtaining materials from borrow areas, or other beneficial uses. In essence, dredging is the act of excavating submerged or saturated sediment from one location and transporting it in another. A wide variety of dredge plants (the dredge and auxiliary equipment) excavate, transport, and place (or dispose of) sediment in many different ways to accomplish the numerous tasks stated in the definition above. During extraction, energy is applied to the sediment by mechanical and/or hydraulic means to alter sediment physical characteristics. Mechanical dredges generally use some type of bucket for digging the sediment, then hoist or boom the load to the surface. Most common hydraulic methods use a centrifugal pump to convert kinetic energy into a pressure gradient to create a water flow that erodes and entrains sediment into a slurry.

Dredged sediment is transported from the dredge site to placement area by hydraulic or mechanical methods. In hydraulic applications, the centrifugal pump discharge can either be collected in a temporary storage container (usually a barge or scow) for later transportation to the placement area, or it can be conveyed directly into the placement area via the discharge pipeline. Mechanical dredges usually dump the bucket load within swing radius directly into the placement area, or into a transportation unit (i.e., barge, truck, conveyor belt, etc.) for haulage to the placement area.

General dredge classification is based on the way that the dredge extracts the submerged sediment (hydraulic or mechanical). There are other varieties of specialized dredges that use different combinations of physical mechanisms to perform dredging (e.g., pneumatic), but they are much less common. Overviews of different types of dredges are presented next. For detailed information on particular types of dredges the reader is directed to works by Headquarters, U.S. Army Corps of Engineers (HQUSACE, in preparation); Bray et al. 1997; and Herbich 2000.

Mechanical dredges

Most mechanical dredges scoop sediment into a bucket-shaped container and bring it to the surface where it is dumped into a placement area or transportation unit. These dredges usually consist of an excavator (i.e., clamshell bucket, dragline, power shovel, or backhoe) mounted on the deck of a non-self-propelled barge. Some versions use conventional track or rubber-wheel-mounted excavators (used on land) that are driven onto barges for temporary use, while others have the excavator's turntable (horizontal swivel point) directly mounted to the barge deck. When mobilizing to and from a project site, the dredge is usually pulled or pushed by tug. In operation, the dredge holds its position by taking tension on anchors deployed around the barge, and/or by dropping spuds (vertically-oriented large-diameter steel pipe) into the bottom sediment. The anchors are set by onboard cranes or auxiliary work vessels (tenders). Once the dredge has excavated all the sediment it can reach to the required depth at one station, it is repositioned to a new location to begin digging again. This relocation can be accomplished in a variety of ways, i.e., an anchor/winch system, tug, movable spud system, or even by using the bucket itself as an anchor point.

Clamshell (bucket) dredge

A clamshell dredge lowers the opened clamshell bucket from the end of a crane boom into the sediment (as shown in Figure 2). After penetrating the sediment, the bucket jaws are closed in order to “grab” a load of sediment. The loaded bucket is hoisted to the surface and side dumped into a transportation unit, or into the disposal site. Transportation units are usually barges (scows) that are towed or pushed by tugs. Barges dispose of dredged material in a variety of methods: dumping through doors mounted in the hull bottom or having the hull split open, pumping out the material in slurry form (direct-pumpout), or unloading by other bucket, auger, or conveyor machinery.

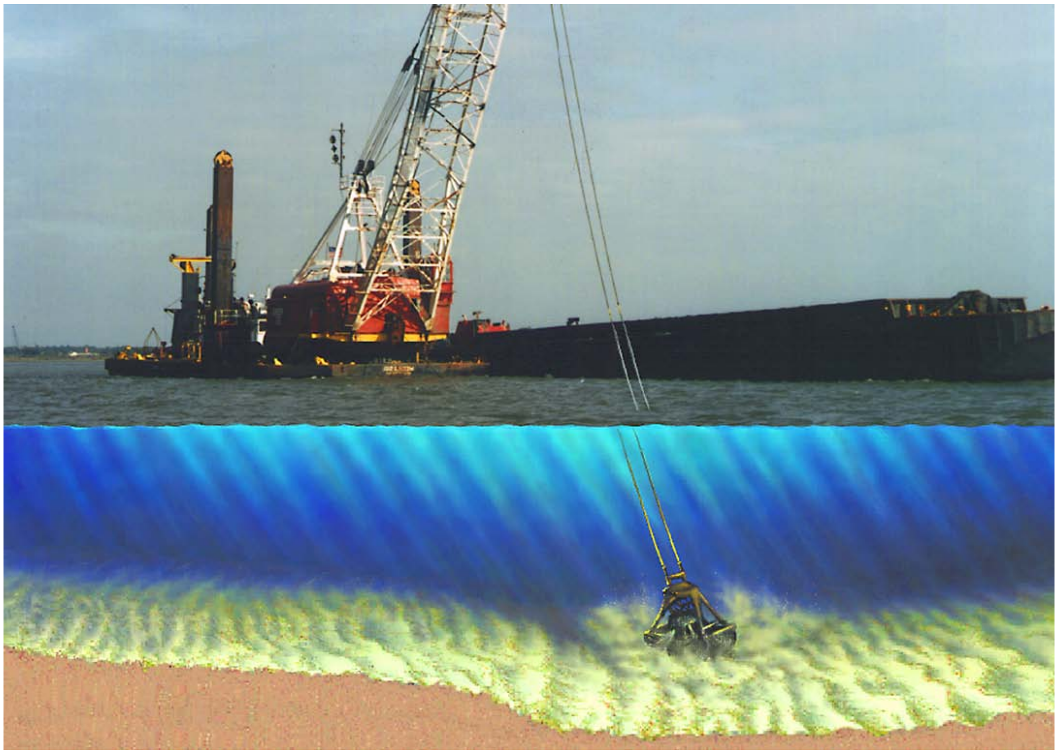


Figure 2. Clamshell (bucket) dredge.

Various bucket configurations with different digging characteristics (i.e., toothed vs. smooth edged jaws) are used to optimize production rates for site-specific conditions. Where compatible, these different types of buckets can be changed-out in the field relatively quick to increase production. Because the clamshell is mounted on a flexible wire rope, its weight heavily influences the maximum digging force that can be applied to the sediment. Except for the most cohesive consolidated sediments, coral, and rock, clamshell bucket dredges can excavate most types of material.

The production rates of all types of dredges depend on the interaction between dredge-specific and site-specific parameters. Production rate will be defined as the (in situ) volume of material removed from the dredging area and transported to the placement or treatment area per unit time. Dredge-specific parameters include dredge type, size, power, and operating methodology, etc. Site-specific parameters include sediment characteristics, hydrodynamic conditions (depth, current, waves), and distance between dredge site and placement area. While a clamshell dredge's maximum operating depth is limited by the length of wire rope on the hoist drum, its maximum effective working depth is about 30 m (100 ft). Clamshell dredges use a variety of bucket sizes ranging from 0.6 cu m (0.75 cu yd) to 38 cu m (50 cu yd). A production rate of 30 to 60 bucket loads (or dredging cycles) per hour is typical, but these numbers can significantly vary as a function of dredging depth and sediment characteristics. The density of sediment excavated can about equal its in situ density. Clamshell dredges can operate efficiently in natural and manmade debris. This type of dredge can also operate close to structures (piers, jetties, etc.) because of the amount of control provided to the operator. But the clamshell's operating cycle produces a relatively uneven bottom surface, and its production rate is usually less than that of a hydraulic dredge. Table 2 summarizes the dredge's excavation, removal, transport, and placement processes.

Table 2. Dredge excavation, removal, transport, and placement processes.

Dredge Type	Excavation Method	Removal Method	Transport Method	Placement Method
Hydraulic Dredges				
Hopper Dredge	Hydraulic suction, Hydraulic erosion, Mechanical dislodgement using knives or blades	From bottom to dredge vessel in hydraulic pipeline as a sediment-water slurry	Sediment settles in hopper; vessel moves to placement site	Bottom discharge or pumpout
Cutterhead Dredge	Mechanical dislodgement using rotary cutter, Hydraulic suction, Hydraulic erosion	From bottom to dredge vessel in hydraulic pipeline as a sediment-water slurry	From dredge vessel to placement site in pipeline as a sediment-water slurry[1]	Direct discharge on land, water, or beneficial use site
Dustpan Dredge	Direction suction, Impingement scour using water			
Mechanical Dredges				
Bucket Dredge	Mechanical dislodgement, scooping with bucket	Wire rope with clamshell or dragline	Barge, land based conveyor belt, trucks, material may be sidecasted	Bottom discharge, pumpout, or mechanically to unload; Direct discharge from belt, truck, or bucket
Backhoe Dredge	Mechanical dislodgement, scooping with backhoe bucket	Rigid structural members with backhoe bucket		

[1] May be pumped into barges and moved to placement site.

Backhoe dredges

Backhoe dredges are basically land excavators that have been modified for use on water. A mobile (tracked or wheel-mounted) backhoe excavator can be temporarily secured to a barge deck (like the clamshell dredge), or the more permanent versions have the excavator's turntable welded to the deck. The bucket is usually hydraulically-activated on a boom/stick configuration as shown in Figure 3. While working, the barge is usually held in place by spuds to provide reaction forces to the digging-induced forces. The maximum bucket size that can be used for a specific project will depend on the excavator's rated capacity, sediment characteristics, and water depth. Average bucket sizes generally range from 0.6 cu m (0.75 cu yd) to 4 cu m (5 cu yd).

Figure 3. Backhoe dredge New York (courtesy of Great Lakes Dredge and Dock Company).

Larger backhoes have a bucket capacity of approximately 19 cu m (25 cu yd) and can excavate to a maximum depth of approximately 25 m (80 ft). Because a backhoe's bucket is connected by rigid structural-members more force can be applied to it, allowing these types of dredges to work in more stiff materials than cable-connected buckets (relatively cohesive consolidated materials, weak rock, and debris). Backhoe operational characteristics provide relatively high excavation accuracy and they can work closely around structures. The density of sediment excavated can about equal its in situ density, but, like other conventional mechanical dredges, it generates a relatively large amount of sediment resuspension at the dredge site.

Hydraulic dredges

A hydraulic dredge generally uses a centrifugal pump to transport the dredged material in the form of a slurry (water and sediment mixture).

The centrifugal pump's purpose is to convert mechanical energy (usually provided by a diesel engine or electric motor) into hydraulic pressure required to transport slurry through the pipeline. Major components of a centrifugal pump include: (1) the rotating element called an impellor (or runner) that imparts energy to the slurry, (2) the volute (or case) that encloses the rotating impeller and slurry, (3) an opening in the center of the volute that the suction pipe is connected to, and (4) the discharge opening on the volute's circumference that the discharge pipe is connected to. The most common types of hydraulic dredges used, hopper and pipeline, are classified by their respective means of transporting material to the disposal site.

Hopper dredges

Hopper dredges (Figure 4) are self-propelled vessels that pump slurry into onboard hoppers for transportation to the disposal site. Hopper dredges have propulsion power adequate for required freerunning speed and dredging against strong currents and excellent maneuverability for safe and effective work in rough, open seas. While excavating, the dredge uses centrifugal pumps to generate low head/high volume water flow rates into specially-designed suction mouths, or dragheads, that slide along the bottom entraining sediments. These dragheads determine the hydrodynamic flow field (and resultant slurry intake) going into the suction pipe. Because of their impact on production rates, a variety of draghead types have been designed for different sediments by incorporating mechanical and/or hydraulic agitators. Normal configuration has two dragarms, one on each side of the ship. A dragarm is a pipe suspended over the side of the vessel with a suction opening called a draghead. The dragarm is connected to a dredge pump, usually located inside the hull. In some cases, the dredge pump is located on the dragarm to increase its hydraulic efficiency. The draghead is moved along the channel bottom as the vessel moves forward. The dredged material is entrained into the draghead, up the dragpipe, and deposited and stored in the hoppers of the vessel. Discharge of the centrifugal pumps is conveyed into the hoppers via a distribution system.

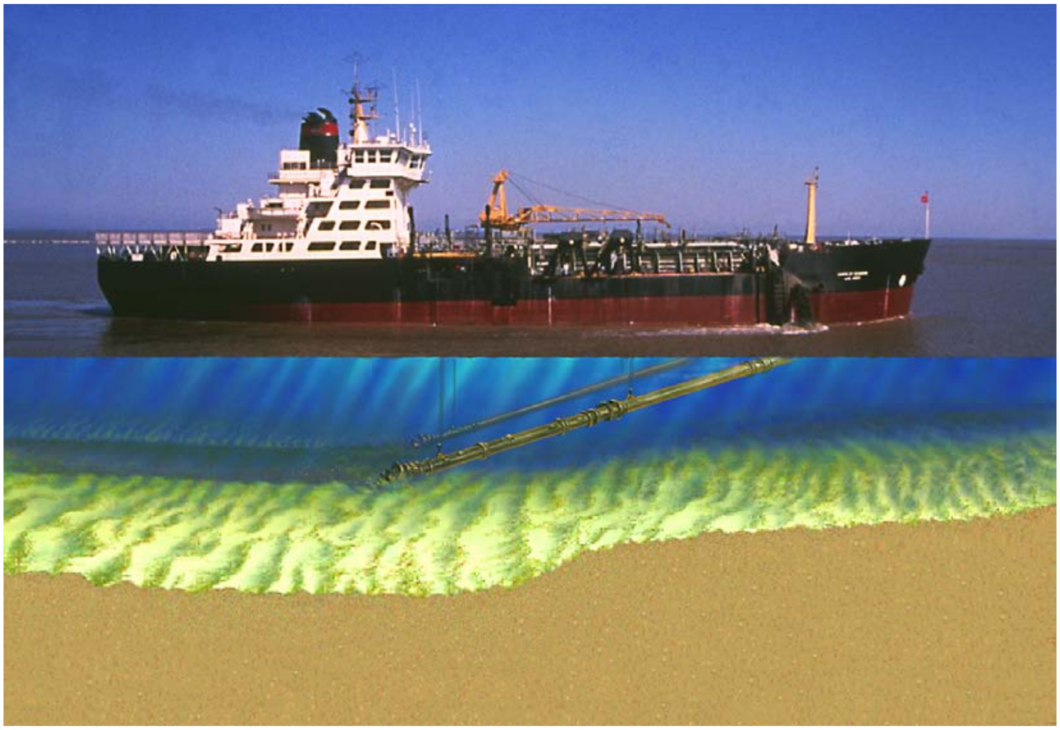


Figure 4. Self-propelled hopper dredge.

Hopper dredges are usually unloaded by either gravity discharge through bottom dump doors (or split hulls), or they can be offloaded hydraulically through a quick connect bow discharge pipeline. When unloading hydraulically through a discharge pipeline (often called a “pumpout”), water is added to the hopper load to re-fluidize the sediment to make it pumpable. Generally, the average slurry solids content will be higher than that described for a cutterhead dredge in the next section, but the solids content variability can be lower because of a more constant sediment feed rate to the discharge pump(s). On even less frequent occasions, hopper dredges discharge slurry through a bow discharge nozzle for “rainbowing” material.

Hydraulic pipeline dredge

The hydraulic pipeline dredge also uses a centrifugal pump to entrain the sediment into a slurry, but instead of using a hopper for transporting dredged material to the placement site, it conveys the material through a pipeline connected to the pump discharge. This type of dredge is typically comprised of a hull, main pump and engine, ladder, suction pipe, spuds, and hoisting and hauling equipment. During operation, the sediment is entrained into the suction mouth, transported up through the suction pipe, then through the dredge pump(s), then transported through the discharge pipeline. The discharge pipeline can consist of one or a combination of the following types: (1) a floating line constructed of either steel or rubber-based materials (Figure 5), (2) a shore line constructed of steel or high-density polyethylene (HDPE) laid upon the ground (Figure 6), or (3) a submerged line that lies on the bottom of a waterbody (ocean, river, lake, canal, etc.).

Figure 5. Floating line constructed of steel (see forefront) and rubber-based (see background) material.

Figure 6. Shore line constructed of steel.

If the pumping distance is longer than the dredge pump(s) can efficiently pump, then booster pump stations are added in the pipeline as needed (discussed in more detail in Chapter 4). Most hydraulic pipeline dredges are barge-mounted without propulsion and require dredge tenders for mobilization to the dredge site. The conventional method of advancement into the face is controlled primarily by a system of winding gear, anchors, and spuds. When positioned on station, the port and starboard swing anchors (connected to the winches by wire rope) are set out a distance from the bow by the dredge's own anchor booms or payed out by derrick barges. The dredge is equipped with two stern spuds that can be raised or lowered (one at a time) into the bottom to function as pivot points. During dredging, one of the spuds is set in the bottom as a pivot point and the leverman moves the cutterhead across the channel in a circular arc by taking in one swing anchor cable while slacking off the other. The dredge advances, or steps, forward in the channel by alternating spud sets (i.e., swing to starboard on the starboard spud, then swing to port on the port spud). This sequence of swinging and spud setting (stabbing) in the channel has many variations, including traveling spud carriages that physically push the dredge forward, but the technique is fundamentally the same for the majority of hydraulic pipeline dredges.

The cutterhead dredges available in the United States are, in general, limited for working in open-water areas without endangering personnel and equipment. The dredging ladder on which the cutterhead and suction pipe are mounted is rigidly attached to the dredge; this causes operational problems in areas with high waves. The dredge size, described by the diameter of the discharge pipe, for USACE projects ranges from 203 mm (8 in.) to 860 mm (34 in.). Usually a diesel engine drives the dredge pump (or pumps), but other prime movers can include direct or alternating electric motors, gasoline engines, reciprocating steam engines, steam turbines, or gas turbines (Turner 1996). Some dredges use submerged pumps, sometimes called ladder pumps, to increase production rates at deeper depths. There are hydraulic dredges that were built in the 1930s that are still operating today with basically the same production instrumentation (i.e., vacuum and pressure gage) as used on their maiden voyages, while others are equipped with modern dredging technologies and instrumentation. These facts illustrate the wide range of age, size, and level of instrumentation that exists in the hydraulic dredge fleet today.

Sub-classes of pipeline dredges are defined by the mechanical and/or hydraulic attachments used to loosen and convey bottom material into the suction mouth. Plain suction dredges have no attachments on the suction mouth, while dustpan dredges use a relatively wide-flared dredging head supplemented with water jets. Cutterhead dredges use a rotating mechanical array of cutters over the suction mouth as shown in Figure 7.

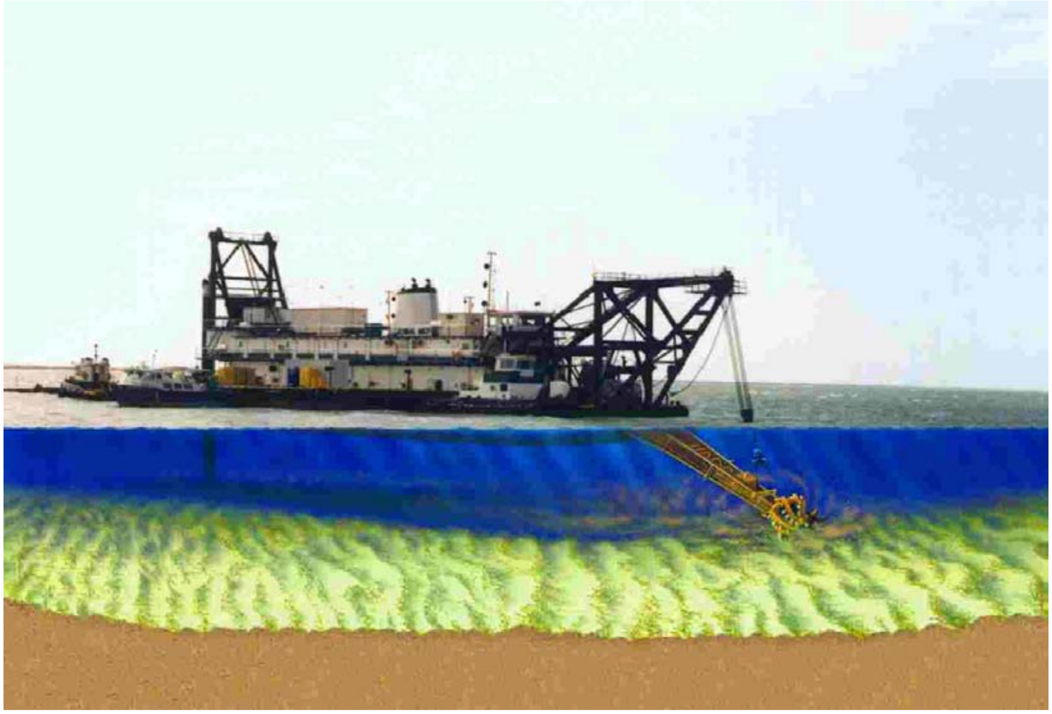


Figure 7. Hydraulic pipeline cutterhead dredge.

Plain suction dredges can be used in free flowing sediments, but as the material's shear strength increases, the production rates decrease. The dustpan dredge's flared suction head with water jets enhances its production by directing the water jets downward into the sediment to loosen (fluidize) the soil prior to its entrainment into the suction mouth (Figure 8). Dustpan dredges typically transport the dredged material through a short floating line approximately 1,200 ft long or less and place the material back into the river (in water placement). A cutterhead dredge's mechanical cutting action allows these dredges to operate in sediments with higher shear strengths, even certain types of rocks. Hydraulic dredge production can be more sensitive to debris-related impacts than mechanical dredges because of their susceptibility to clogging.

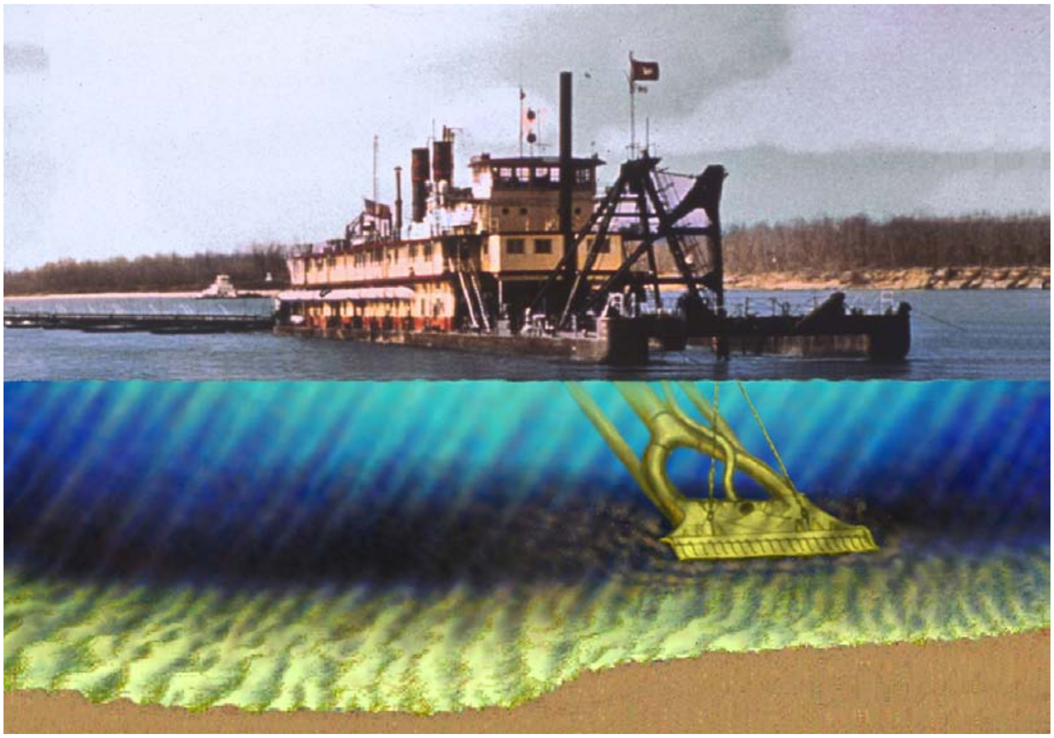


Figure 8. Hydraulic pipeline dustpan dredge.

Cutterhead dredges are by far the most common type of dredge, with hundreds of cutterheads available in the United States (though most are smaller than 600 mm (24 in.). Some smaller cutterhead dredges (approximately 500 mm (20 in.) down to 150 mm (6 in.) are classified as "portable" in that they can be moved from site to site overland either in one piece, or in modules that can be assembled and disassembled.

Because water is used to entrain the sediment into a slurry like a hopper dredge, the percent solids (by weight) of this slurry typically ranges between 10 and 20 percent. Production for a cutterhead dredge is dependent on suction and discharge line diameter, pump horsepower, cut face height (thickness of sediment layer being excavated), sediment characteristics, ladder swing width and speed, digging depth, and discharge line length and vertical lift. When the cutterhead is working, percent solids in the slurry will not remain constant, but will vary in relation to changing site conditions encountered such as cut face height, sediment characteristics. Palermo et al. (2008) report that average solids contents of conventional hydraulic dredges can routinely vary "as much as 0 to 30 percent solids during a single dredge cycle." Table 2 presents a summary of these types of hydraulic dredges' operating characteristics. Because the suction mouth is enclosed by the cutterhead, no debris larger than the space between individual cutters will be introduced to the suction mouth.

In addition to transporting dredged material into the placement site via discharge pipeline, a hydraulic pipeline dredge can also place material in barges for placement in open water or in confined areas that are remote from the dredging area. Slurry has been transferred into barges using “spider” barges. A spider barge (Figure 9) without transportation barges alongside) is named for its spider-like shape upon the water. It is attached to the dredge discharge pipeline and is usually designed to reduce slurry flow turbulence by diffusing it to enhance solids settlement in the transportation barge. The use of multiple discharge points allows the cutterhead dredge to be operated in a more continuous manner due to the capability of the spider barge to have more than one transportation barge tied up alongside.

Figure 9. Spider barge connected to hydraulic pipeline dredge.

Barges may be purposely built as dump scows of the hopper type with bottom doors or the split-hull type. They may be simply flat deck barges modified to carry the dredged material. The material may be unloaded using gravity dump methods (bottom dump doors or split-hull), by any mechanical means to offload the material directly into the placement area, or by a hydraulic unloader. The hydraulic unloader (Figure 10) usually consists of a barge-mounted submersible pump or jet pump that unloads the dredged material and pumps it to the placement site. This operation (similar to a hopper dredge pumpout) usually involves adding additional water to the dredged material in the barge to allow it to be entrained and pumped through the pipeline. Also similar to a hopper dredge pumpout, the average slurry solids content of a hydraulic unloader can be higher than that described for a cutterhead dredge, but the solids content variability maybe be lower because of a more constant sediment feed rate to the discharge pump(s).

Figure 10. Hydraulic unloader (courtesy of Great Lakes Dredge and Dock Company).

Hydraulic dredge instrumentation

The need for accurate evaluation of production in hydraulic dredging operations has been around for a long time. In the 1960s, the hydraulic dredge operator had only the measurements of pump revolutions per minute, power used, and suction and discharge pressures to estimate production. As there are no simple relations between pump speed, slurry density, discharge pressure, and solids flow rate, production metering systems have been developed that measure instantaneous values of flow velocity and slurry density and respective interaction with each other to affect solids production rate. Many dredges now have full instrumentation with “computer systems for sensing, monitoring, and controlling operation, and, in more sophisticated application, for producing a historical production record and for on-line maintenance planning” (Wilson et al.

2006). Creosote-contaminated sediments at the Bayou Bonfouca Superfund site used a mechanical dredge in conjunction with a computer-based monitoring system (slurry density and velocity meters, water content control, etc.) to control the water content (or slurry density) of the pumped dredged sediment to meet requirements of the processing facility (Taylor 1995).

The Silent Inspector (SI) (http://spatialdata.sam.usace.army.mil/ organizations/SI/) is an automated dredge contract monitoring system comprised of both hardware and software that was developed by USACE as a low-cost, repeatable, impartial system for automated dredge monitoring. The hopper, scow and hydraulic pipeline dredge SI systems integrate various automated systems to record digital dredging and disposal activities for both government-owned and contractor-owned dredges.

4 Long Distance Conveyance (LDC) Equipment and Projects

Hydraulic conveyance of solids through pipelines in a slurry is based on the principal of solids being transported by the forces of a flowing carrier medium. In LDC projects where changes in elevation between beginning and end of pipe are minimal, these forces will have to be sufficient to primarily overcome the resistance (or friction) of the slurry moving through the pipeline. As slurry moves through the pipe, its composition and relative velocity determine its respective flow characteristics, as described by Randall et al. (2000):

"Sediment transport in pipelines is divided into three categories of flow: homogeneous, heterogeneous, and flow with a moving bed (Figure 11). In homogeneous flow, the sediment particles are uniformly distributed over the cross-sectional area of the pipeline. Heterogeneous flow occurs when there is some stratification of particle sizes, but all particles are in suspension or moving by "saltation" that is a sort of rolling and jumping motion along the pipe bottom. Flow with a moving bed consists of fully stratified sediment layers with the larger particles at the bottom sliding along the pipe surface below. Both homogeneous flow and flow with a moving bed cause large frictional head losses, and it is therefore desirable to operate in the heterogeneous flow regime."

A settling slurry (or flow) can be generally considered to consist of more coarse-grained sediment (e.g., sands and gravel) where the solids will move to the bottom of the pipe at a discernable rate if not kept in suspension by the water's turbulence, while a non-settling slurry (or flow) consists of fine-grained sediment (e.g., silts and clays) where the solids will remain in suspension for long periods of time without agitation from water turbulence. As per Hales et al. (2003) "Critical velocity of the slurry in the pipeline is that velocity below which material can settle to the bottom of the pipeline and cause blockage. Critical line velocity varies with pipeline diameter and nature of the material. The greater the particle size the greater the line velocity necessary to prevent blockage. Critical line velocity is also important for pumping hard clays since such materials tend to ball up (in some cases 12 in. (30 cm) in diam) and can plug a line easily if velocity is too low."

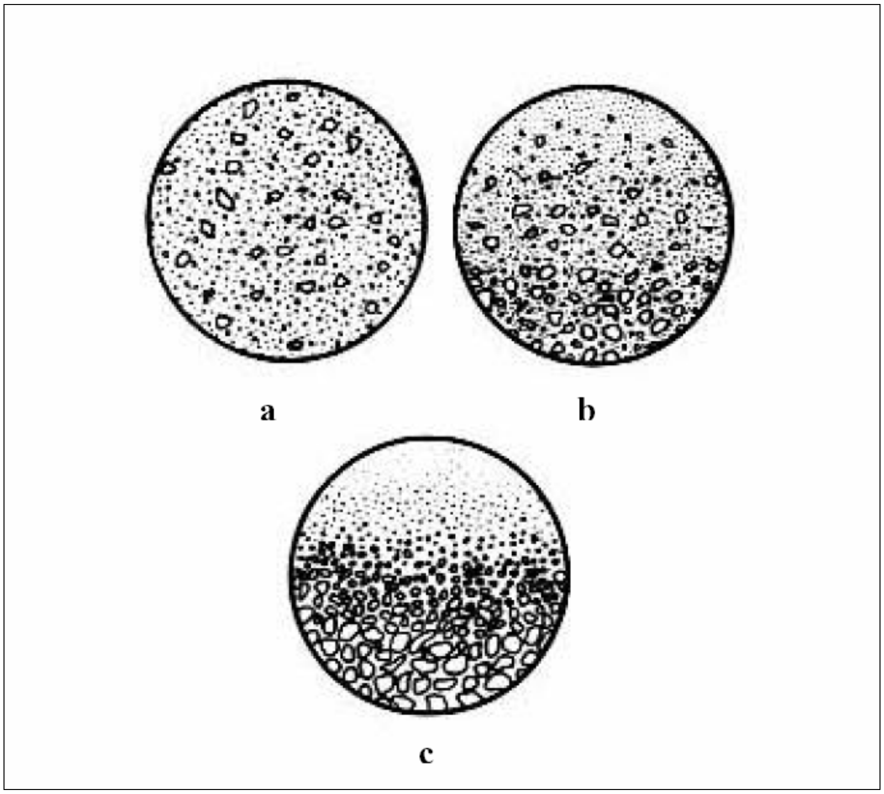


Figure 11. Sediment distribution in a pipeline (Herbich 2000): (a) homogeneous flow, (b) heterogeneous flow, (c) flow with a moving bed; (source: Randall et al. 2000).

Two basic categories of pumps, dynamic and displacement, are generally used to create pressure differentials that force the slurry through the pipeline. These two categories are based on the manner that the pump adds energy to the fluid and Karassik et al. (1976) define them as follows:

“Dynamic, in which energy is continuously added to increase the fluid velocities within the machine to values in excess of those occurring as the discharge such that subsequent velocity reduction within the pump or beyond the pump produces a pressure increase.”

Displacement, in which energy is periodically added by the application of force to one or more movable boundaries of any desired number of enclosed fluid-containing volumes, resulting in direct increase in pressure up to the value required to move the fluid through valves or ports in the discharge line.”

The distance a given centrifugal pump can efficiently transport material depends on pump, pipeline, and slurry physical characteristics. As cogently described by Randall et al. (2000):

"When pumping the material long distances, the main pump may not have enough "head" to reach the disposal area. Simply stated, a pump's head is the distance a pump can force a liquid through a vertical pipe. When the pipeline is horizontal, as is the case for these dredging operations, the friction forces caused by the slurry traveling through the pipeline take the place of the gravitational forces in the vertical pipe illustration. The horizontal distance that the dredged material can be transported is therefore a function of the pump head. The friction effects on the slurry (sediment/water mixture) in the pipeline are quantified as head losses."

Important slurry characteristics that influence its interaction with the pump(s), pipeline, and fittings with regards to these head losses include:

- Slurry specific gravity.
- Solids concentration.
- Solids (particle) size distribution.
- Solids specific gravity.
- Carrier medium density.
- Slurry rheological properties.

As per Berry (2007), the following minimum information is required when applying a solids handling pump:

- "Total dynamic head
- Volume of material to be transported
- Slurry specific gravity
- Particle size of material to be transported"

The total dynamic head required by the pump to move slurry from one place to another includes calculation of considerations such as changes in elevations between "feed" pipeline entrance and discharge, entrance losses in suction pipeline, discharge velocity head, and friction losses induced by pipeline, valves, etc. The volume of material to be transported includes the carrier medium (water) and solids, that, when used in conjunction with the slurry specific gravity, is applied to the calculation of horsepower requirements. The particle size of material to be transported is required to ensure that the pump will pass the largest particle size that is expected to be pumped. Particle size is even more critical for pipe selection because the “optimum pipe size is the maximum size pipe which gives a velocity in excess of the settling or minimum velocity and stable pump operation” (Berry 2007).

Specific energy consumption (SEC) (reported inconsistently in units such as kilowatt-hours per tonne-kilometer, horsepower-hours per ton-mile, etc.) is a measure of the amount of energy required to transport a given quantity of sediment over a given distance (Wilson et al. 2006). The dimensionless ratio SEC can be calculated by incorporating various parameters, or different forms of these parameters presented above into an equation, that in turn can be used to compare relative merits of different transport systems. The lower the SEC value, the more energy efficient the pipeline is as a means of transport (Wilson et al. 2006).

In certain circumstances, formation of clay balls can reduce pumping hydraulic efficiency, but the prediction of the formation and behavior of clay balls (or lumps) is not well understood. Existing engineering soil descriptors are not oriented towards dredging operations and, therefore, cannot be used for accurate behavior predictions and usage of these predictors in practice often leads to disputes between the parties involved in the dredging project (Leshchinsky et al. 1994).

Per Bain and Bonnington (1970), the choice of pump type for hydraulic transport systems “probably owes more to practical considerations than to purely economic requirements of maximum efficiency.” Overall assessment of pumping plant selection will include many of the following topics (modified after Bain and Bonnington 1970).

- Will the pump pass the slurry’s design maximum-sized solids and viscosity?
- Are the pump head-flow characteristics suitable to give stable operation given the hydraulic system’s total dynamic head requirements?
- What would be the maintenance requirements given the pump design and slurry material properties?
- Do the site-specific installation conditions impose limitations on the pumps?

- If a choice does exist, which pump offers the lowest operation costs when considering power and labor costs?

Given a respective hydraulic system's characteristics (pumping capacity, pipeline diameter, etc.) and site-specific slurry characteristics, the length of pipeline that the slurry can be transported can be increased up to a certain distance where the system's maximum pump power is reached. As additional pipe is added past this certain line length (assuming constant slurry density), pump horsepower limitation is experienced because of the additional friction losses incurred by the additional pipe, and slurry velocity starts to drop until it becomes so low that solids start to settle out. Booster pumps are added when the pipeline length exceeds the power capability of the initial hydraulic system (e.g., the hull pump of a cutterhead dredge). When a booster pump is added to the pipeline, then the head provided by this pump is added to the head provided by the initial hydraulic systems pumping capacity. Basically the booster pumps add pumping power to the hydraulic system to overcome the system head losses (friction effects on the slurry in the pipeline) created by the additional pipeline lengths.

This concept is illustrated in Figure 12 that was presented by Mr. Rick Smith (Weeks Marine, Inc.) at the Long-Distance Pipeline Transport of Dredged Material to Restore Coastal Wetlands of Louisiana Workshop (Hales et al. 2003). The graphic shows how pumping distance is increased as a function of adding booster pumps in a concept based on renourishing Plaquemines Parrish with: (a) dredge alone, (b) dredge and one booster pump, and (c) dredge and two booster pumps.

But as these booster pumps are added to the hydraulic circuit to increase pumping distances, operating complexity, logistical considerations, and attendant costs go up. They are separate major pieces of plant that increase the probability for breakdown. Diesel engine-powered boosters require fuel to run and a constant supply of cooling water to maintain operating temperatures within limits. Precautions must be taken when starting and shutting down pumps that are in series on a long pipeline and standard start up and shutdown procedures should be developed to deal with both planned and unplanned pumping interruptions. Depending on the hydraulic grade line (pressure vs. relative location along the length of pipeline), improper operating conditions can cause excessive positive (over) pressure or negative pressure (subsequently causing cavitation or water hammer) that can cause severe damage to pumps and pipeline.

Pipeline "plugging" can be a danger if a sufficient amount of solids in the slurry matrix are allowed to drop out of suspension, settle in sections of the pipeline (e.g., inclined section), and effectively clog the line that subsequently requires cleaning before production can be reestablished. Pyburn & Odom, Inc. (1993) recommend that the slurry pipeline system includes a water pump to avoid clogging during dredge shutdown.

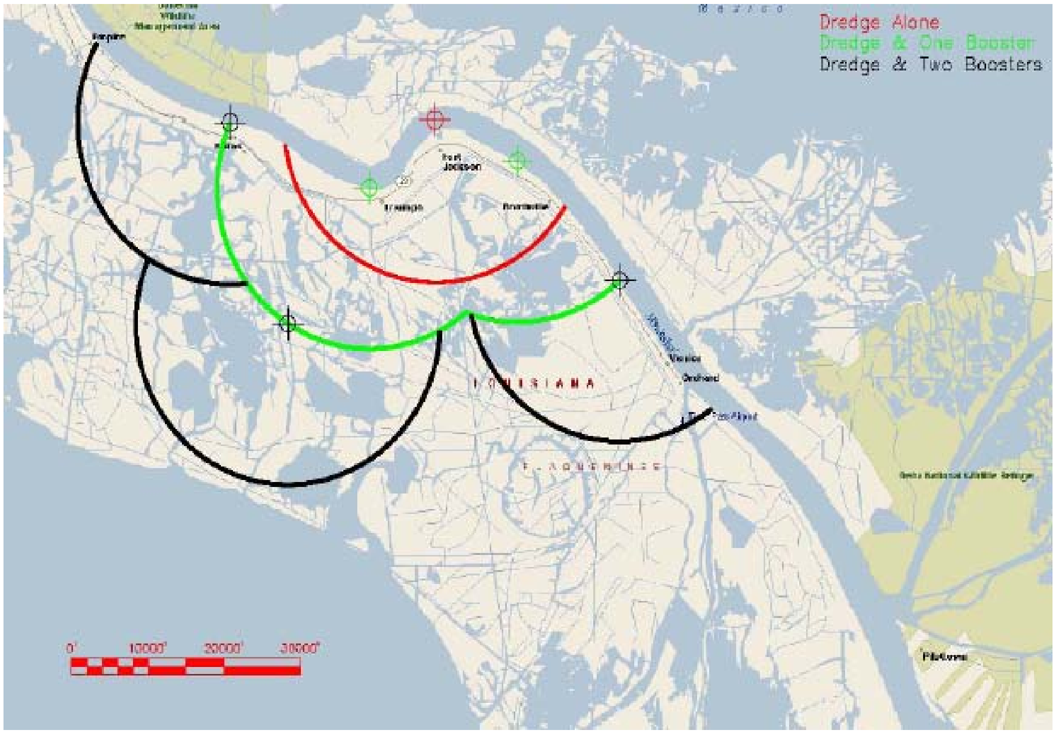


Figure 12. Pumping distance as function of adding booster pumps (source: Hales et al. 2003).

Because access to booster pump stations will be a concern for maintenance and refueling purposes, LDC design should be evaluated for potential optimization by strategically placing booster pumps in locations with relatively easy access to minimize logistical requirements. For example, the design could possibly locate several pumps closely together in series (in a convenient location) to generate sufficient head to transport long pumping spans over remote locations, but this, of course, would be in comparison to the extra cost of the required higher-pressure rated pipe.

An investigation of a dredging project using a 10-km- (6.25-miles-) long pipeline with three (centrifugal) booster pumps and a fluctuating input slurry density identified the generation of "long density waves with high amplitudes" (Matousek 1996). This phenomena has effects on the internal structure of slurry flow in a long conveying pipeline that has not been explicitly observed and analyzed. The aggregation of material along a long pipeline and the behavior of the sediment settled at the bottom of the pipeline may have an influence on the efficiency and safety of the hydraulic system (Matousek 1996).

To optimize operations, various booster pump operating parameters (such as diesel engine temperature and oil pressure, electric motor load, inlet and discharge pressures, service water pressure, etc.) have been transmitted (wireless and/or hard-wired) to the dredge (or other locations) and automated controls and remote control capabilities have been developed and used (Hales et al. 2003; Derammelaere 2001; Rock Products 1998; IHC Systems BV 1991). Supervisory control and data acquisition (SCADA) systems are used to operate long distance slurry pumping systems that can be integrated with leak detection systems (Derammelaere 2001). Artificial intelligence, a “kind of computer programming that tries to urge computers ‘reasoning’ instead of computing” that takes into account pump limitations such as maximum pump power, pump torque, pump speed, pipeline pressure, etc., has been developed to optimize production by manipulating set points for slurry velocity and maximum allowed density (IHC Merwede 2007).

Pipelines have been used to hydraulically convey solids since the invention of the centrifugal pump (classified as a dynamic pump as per Karassik et al. 1976) and the number of solids pumping applications continues to rise along with the increasing throughputs, transport distances, and range of solids being pumped (Bain and Bonnington 1970). One of the earliest and longest pipeline lengths pumped, as described by the Colorado School of Mines Research Foundation, Inc. (1963) is that of the Consolidated Coal Company. A 174-km- (108-mile-) long pipeline pumped coal slurry from a washing plant near Cadiz, OH, to a power plant at East Lake Ohio. Consolidation undertook an “extensive research program” to improve the competitive position of coal in the energy sector that was being threatened by cheaper fuel sources. When it was realized that 50 percent of the coal’s cost was due to transportation, a 6 year, $2 million research program successfully delivered a less expensive means of transportation. In 1954, the decision to build the pipeline was made and by midsummer 1958, was in continuous operation (Colorado School of Mines Research Foundation, Inc. 1963). Since construction of this pipeline “dozens of long distance (i.e., each several hundred kilometers long) pipelines have been developed commercially, with many still operating” (Derammelaere 2001).

Back in 1969, the U.S. Army Engineer District, Philadelphia, conducted a study to examine the technical and practical feasibility, and the advantages which might accrue, from pumping dredged material (25-50 miles) from the intensely developed port complex where disposal areas had become filled, to locations where the dredged material would be at least acceptable, if not clearly advantageous. The results of the study determined that it was feasible and practical to move large amounts of dredged material great distances by pipeline, and that such an operation would permit emptying the limited disposal areas that were able for dredged material in highly developed areas and thereby increase their useful life. However, given the context of the navigation dredging project to which the study applied, this technique could only be justified under circumstances where there would be enhancement value by delivery of material to a far distant location, or when such disposal would be cheaper than any alternate means (USACE Philadelphia District 1969).

While not classified as LDC projects as per this report's definition, the following dredging projects (Interstate 10 construction between Baton Rouge and New Orleans Project, I-370 Highway Fill St. Charles Mo Project, Hart-Miller Island Placement Dredging Project, Betuwe Route Project, and the Dallas White Rock Lake Project) are summarized to illustrate state-of-practice aspects of pumping dredged material through pipelines longer than 10 miles.

Interstate 10 construction between Baton Rouge and New Orleans LA Project

The following project description is summarized from Starring (1971). During construction of a segment of Interstate 10 between Baton Rouge and New Orleans, the Louisiana Department of Highways awarded a contract that, with the exception of placing sediment for highway construction instead of wetland creation, can be considered an LDC project. A 610 mm (24 in.) (discharge pipeline diam) hydraulic dredge was used by the Bauer Dredging Company to excavate sand from the Mississippi River and transport it 16 to 24 km (10 to 15 miles) to the highway route where it was placed for suitable load-bearing substrate. The pipeline dredge's water jetting system fluidized the sand from a maximum water depth of 24 m (80 ft) and a 3,355 kW(4,500 hp) driven centrifugal pump used to pump sand from an approximately 2-mile-long reach in the river. As per Starring (1971) "Silt deposits on the bottom were continually being replenished through river flow, allowing Bauer to recover materials within the same location over long intervals." The dredge reportedly had an approximate production rate of 765 cu m/hr (1,000 cu yd/hr) with a solids content (by volume) of 14 to 18 percent. A 660 mm (26 in.) (outside diam) oil pipeline with a wall thickness of 21 mm (5/6 in.) was used for the discharge pipeline that, although it was expected to be "chewed up" by the transport of sand during the project, the steel stood up so well that the pipe was used for subsequent projects (Starring 1971).

The dredged material was pumped through the pipeline from the dredge at approximately 8.6 bar (125 psi) and transported approximately 1.6 km (1 mile) where, with the receiving pressure of approximately 1.4 bar (20 psi), the first booster pump was installed. This booster pump increased the pressure back to approximately 8.6 bar (125 psi) again, and the slurry was subsequently transported through five additional "permanent" booster pump stations and a "floating" booster station before final placement. Although these booster pumps varied in size and capacity, they were synchronized and placed at approximately 3 to 5 km (2 to 3 mile) intervals depending on respective pump capacity and elevation changes. The prime mover for these booster pumps was either electric or diesel motors that ranged in size from 1,305 to 2,680 kW(1,750 to 3,500 hp), and each booster site required a cooling water supply for the large engines that generally consisted of wells with 150 to 255 mm (6 to 10 in.) diam (Starring 1971).

At the highway route placement site, the pipeline was extended as the sand was deposited. An energy dissipater was used on the end of the discharge line to spray the dredging material upward in order to allow the coarser particles (sand) to deposit in the embankment and finer grained particles (silt) to float out into the open excavation. The silt material was subsequently removed from in front of the fill operation by small 255 mm (10 in.) hydraulic dredge that was used in continuous process for 24 hr a day. A Y-shaped connection was also placed near the end of the discharge line and each respective branch fitted with the gate valve to control the flow to either side of the 60-m- (200-ft-) wide embankment corridor. A bulldozer was used to spread the material laterally and to form small dikes at the extreme edges of the embankment corridor to prevent material being pumped from flowing off into adjacent swamp (Starring 1971).

Based on information obtained during this project, it was determined that it would be economically feasible to transport the embankment material up to 40 km (25 miles) by this method. "Technically, the only limit is reliability of the system - the longer the pipeline, the more pumps, and the increased likelihood that one will malfunction" (Starring 1971).

I-370 Highway Fill St. Charles, MO Project

While not LDC projects as defined in this report, the following two dredging projects describe the application of the different types of dredging equipment that would be used on LDC projects.

The following project description is modified after Lowry and Adams (2004). The State of Missouri Highway Department opted to build a 3.5-mile section of Interstate 370 (see project map Figure 13) with fill material dredged from the nearby Mississippi River. The 3.1 million cu yd material dredged by Great Lakes Dredge and Dock (GLDD) was augmented with another 1.3 million cu yd of trucked clay. At the time, it was the largest hydraulic highway fill project in the state's history, the next largest being about a quarter of the size of this project. The alternative method of constructing the roadway — trucking material mined from a dry borrow site — would have taken longer, added another $5 million to the cost of the $23 million project, and would also have entailed added safety hazards and wear on the state's highways.

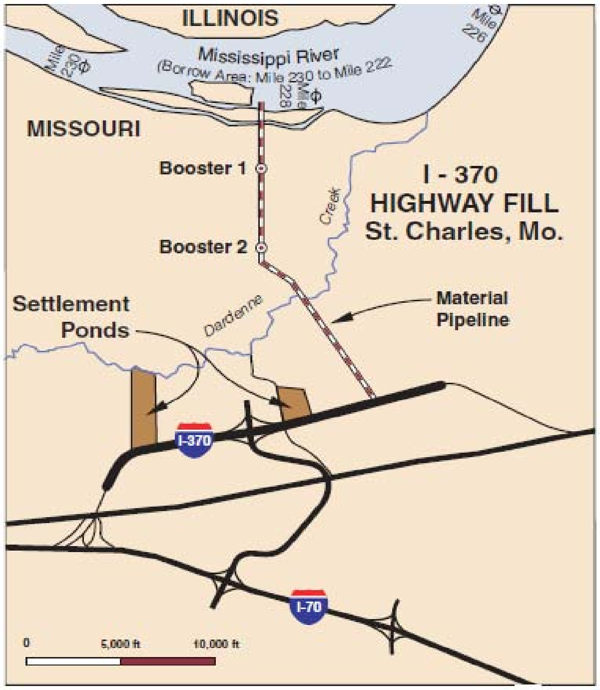


Figure 13. I-370 Highway Fill St. Charles MO site map (courtesy of Great Lakes Dredge and Dock Company).

The pre-construction meeting was held in June, 2004, construction of containment berms began in early July, and pipeline assembly — some 25,000 feet of it — ensued in August of that year. The dredge, the California, was towed up-river from Freeport, Texas, and the newly-assembled boosters were trucked to the site. The California (Figure 14) is a 30 inch discharge pipeline diam. cutterhead dredge with a 8,000 hp main pump motor and is electric-powered. Figure 15 shows a truckbed-mounted transformer mounted that provided the connection between the all-electric dredge California and shorebased sources of power. The dredge commenced pumping material in early November and borrowed material from as deep as 60 feet in the river bed, pumping up to 40,000 cu yd per day. The project also set a distance record: the material was pumped through as much as seven miles of pipeline; two booster pumps augmented the power of the California (one shown in Figure 16), creating an extensive hydraulic pumping arrangement not often seen.

The boosters arrived at the site on special 130-foot-long, 21-axle trucks. These vehicles were thus able to distribute the weight of the boosters so they could safely cross the small bridges that traverse the creeks and streams on the back roads near the river. The first booster was positioned approximately 7,000 feet from the dredge, and the second another 5,000 feet further down the line. These were 3,600-hp engines driving 30-inch pumps. The roadway fill was between 18 and 30 feet thick, which raised the highway about five feet above the 100-year-flood level, dictated by the fact that the highway crosses a stretch of the Mississippi flood plain which during the 1993 500-year flood was under twelve feet of water.

Figure 14. Cutterhead dredge California (courtesy of Great Lakes Dredge and Dock Company).

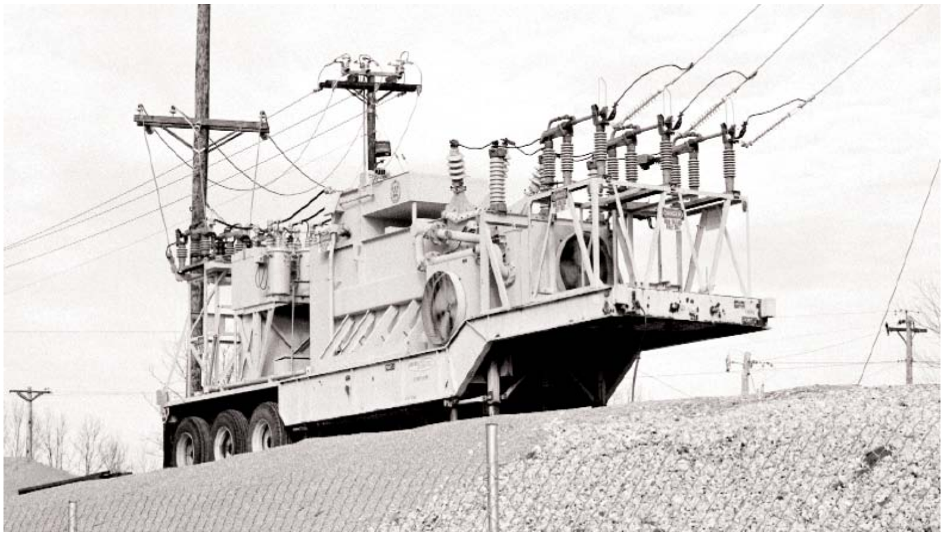


Figure 15. Truck-bed mounted transformer for the dredge California (courtesy of Great Lakes Dredge and Dock Company).

Figure 16. One of two booster pumps used in the I-370 Highway Fill Project (courtesy of Great Lakes Dredge and Dock Company).

In the center section of the highway, plans called for the construction of a standard diamond roadway interchange. Approximately 800,000 cu yd of sand were needed for this portion of the project. Once the sand had been pumped and dewatered, it was shaped with dozers to form the needed structures above culverts and drains put in place by a subcontractor.

On either side of the placed sand, clay dikes were built. During construction, the dikes provided a means of controlling the drainage of the fill (Figure 17). About 35,000 gallons of water per minute entered the fill site with the sand.

This water flowed back toward the Mississippi within the dikes, then into one of two settlement basins (one of 40 acres, the other of 80 acres) into Dardenne Creek and thence back to the river.

Figure 17. Opening in the containment dike designed to allow runoff of excess water without erosion of the fill material (shown in background). (courtesy of Great Lakes Dredge and Dock Company).

An important component of the program was securing the cooperation of about a dozen property owners whose land was adjacent to the state's property. Some of these individuals leased land for use as settlement ponds; others allowed use of their roadways, construction of temporary roads across their land, or permitted pipeline to run through it. They played a significant role in bringing the project to fruition.

Hart-Miller Island Placement Project

The dredging contractor T.L. James conducted a dredging project in Baltimore MD in the early 1990's where fine-grained channel maintenance dredged material was pumped directly to Hart-Miller Island on 30,000 to 50,000' of discharge pipeline (see Figure 18). The 30 inch diam. cutterhead dredge Tom James (6,000 hp capacity pump) started with one Atlas booster pump (7,200 hp), and as the discharge pipeline got longer, the first pump (3,600 hp on one pump) of a double pump booster was added in first, and then the second pump (3,600 hp on one pump) was added to finish the project. So in effect, the project started up with 13,200 hp on 30,000 ft of 30 inch diam. pipeline and finished with 20,400 hp on 50,000 ft of 30 inch diam. pipeline. Given the sediment characteristics, and these pipeline lengths and horsepower requirements, the contractor had a 2.25 to 2.5 ratio of pipeline length to horsepower. As per personal communication with Mr. Rick Smith (formerly of T.L. James) if they were pumping river sand instead of fin-grained material, that ratio would not have been greater than 2.0 (for 30 inch diam. pipeline).

Figure 18. Hart-Miller Island Placement Project approximate pipeline corridor.

Beach Renourishment Project, U.S. Army Engineer District, Wilmington

A beach renourishment project conducted for the Wilmington District was described by Coastal Planning & Engineering, Inc. (2004) as follows:

"Bean-Stuyvesant, LLC was contracted to pump sand up to 70,000 ft in 2001 for a project with the Wilmington District Corps of Engineers. In this project they used up to five booster pumps, including the use of a hydraulic dredge as one booster. The project called for dredging 9,000,000 cu yd at a bid price of $64,727,900 (USACE 2004), for a total unit price of $7.19/cu yd. The project called for the placement of sand on beaches adjacent to a harbor, with pipeline transport distances of up to 70,000 ft. The pipeline was built for long distance transport, but ultimately the sand was placed by hopper dredge methods. The long distance pipeline transport was stopped due to system reliability and productivity. Pumping distances of over 8 miles were achieved, but a hopper was used for the longer distances. The coarseness of the sand and the unreliability of one booster appears to have been the problem. In addition, a hopper was a feasible alternative."

Betuwe Route Project

The following description of this project was modified after Dr. Willem Vlasblom's presentation, Delft University, The Netherlands at the Long-Distance Pipeline Transport of Dredged Material to Restore Coastal Wetlands of Louisiana Workshop in Hales et al. (2003).

The Betuwe Route project (Figure 19) was the construction of a 2-track railway bed by centrifugal hydraulic dredge and boosters for up to approximately 100 miles for bulk transport from the port of Rotterdam to the German border. Approximately 3.2 million cu m of sand dredged from the River Maas were transport by pipeline, of which about 0.9 million cu m were barged across a river and rehandled. A dredge with three pumps (total power 4,440 kW (5,950 hp) (Figure 20), and four booster stations with one pump each (total power 6,220 kW (8,300 hp)) (see examples in Figures 21, 22, and 23) were installed along a pipeline of mostly 700 mm diam pipe. The pipeline route was mostly on ground level to present less visual hindrance, laid next to highways (Figure 24) to avoid urban areas as much as possible.

Figure 19. Betuwe Route Project pipeline route (source: TU Delft).

Figure 20. Dredge Nordland at River Maas borrow area (source TU Delft).

Figure 21. Barge booster station “Bevert” (source: TU Delft).

Figure 22. Booster station “Maasvlakte”(source: TU Delft).

Figure 23. Booster Station “Duinjager” (source: TU Delft).

Figure 24. Betuwe Route Project pipeline
(source: TU Delft).

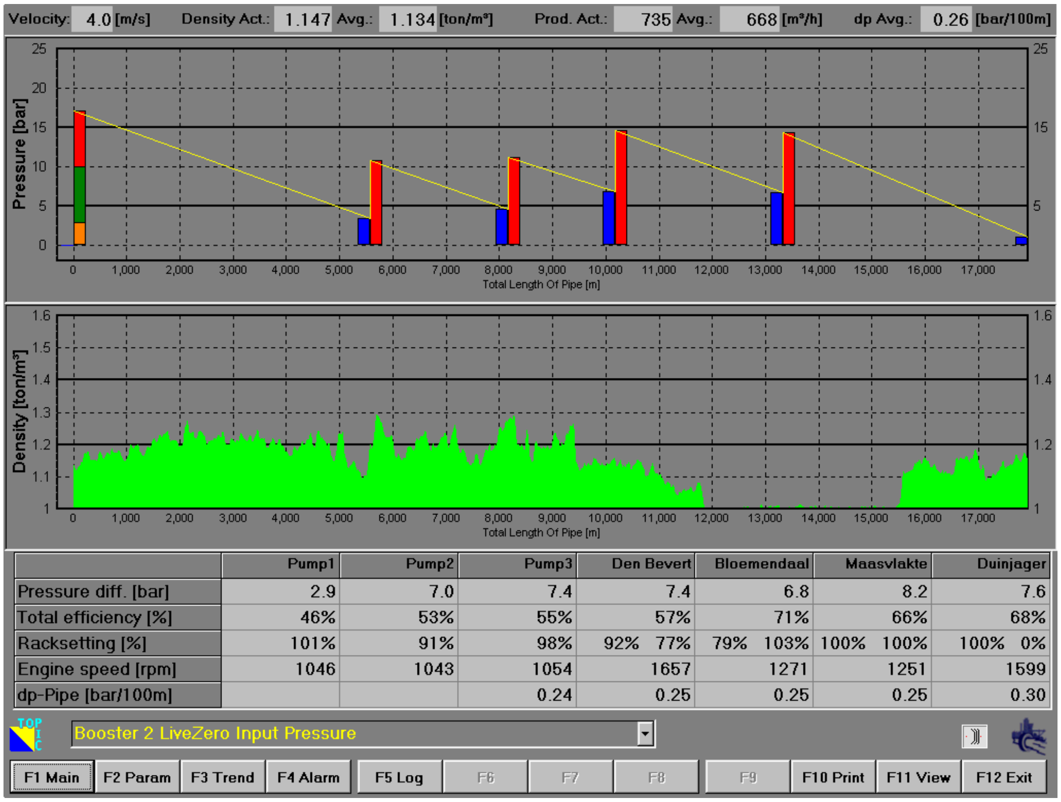
The booster stations were remotely controlled from the dredge. Booster station locations were located where the pressure at the pump suction side was at least 1 bar (14.5 psi). The station was relatively accessible and cooling and gland water were available.

Pump interruption was a major consideration. Vertical and steep inclines were avoided because of high probability of system blockage if the system should shut down for any reason. Starting the pumps with clear water was a series one-by-one operation, beginning at the dredge pump. Actually dredging began when the flow velocity throughout the system reached its required value. Clearing a blocked pipeline would be virtually impossible. The system was shut down by ceasing the dredging process, and pumping clear water until all dredged material had been discharged from the pipeline. All pumps were then sequentially stopped opposite from the starting procedure. The mean velocity of the slurry during operation of the

Betuwe Route Project was between 4.5 and 4.9 m/sec (15 to 16 ft/sec) producing a mixture flow between 1.49 and 1.63 cu m/sec (1.9 and 2.1 cu yd/sec) (Figure 25).

Figure 25. Pipeline discharge at dredged material placement area (source: TU Delft).

Hydraulic circuit data instrumentation included operating pressures, and slurry density and velocity (Figure 26). The total pressure provided by all pumps was 40 to 45 bars (580 to 650 psi). The highest local pressure was just behind the third pump on the dredge of about 17 bars (246 psi). The lowest pressures were in front of the booster pumps of about 3 to 5 bars (44 to 73 psi). The pressures just behind the boosters were 9 to 13 bars (130 to 188 psi). The pressure in the pipeline never fell below atmospheric pressure (1 bar) (14.5 psi). The flow was partially stratified, as a portion of particles occupied the bed. The pipeline was operated around the deposition limit velocity. There was a stationary bed at velocities below approximately 4.7 to 4.8 m/sec (15.4 to 15.7 ft/sec). The presence of this stationary bed led to an interaction between the bed and the suspension stream that resulted in an aggregation process. The largest density peaks developed at the lowest mean velocities in the pipeline. The density peaks may grow to very dense masses if the velocity remains low for a long time.


Velocity: 4.0 [m/s] Density Act.: 1.147 Avg.: 1.134 [ton/m³] Prod. Act.: 735 Avg.: 668 [m³/h] dp Avg.: 0.26 [bar/100m]

	Pump1	Pump2	Pump3	Den Bevert	Bloemendaal	Maasvlakte	Duinjager
Pressure diff. [bar]	2.9	7.0	7.4	7.4	6.8	8.2	7.6
Total efficiency [%]	46%	53%	55%	57%	71%	66%	68%
Racksetting [%]	101%	91%	98%	92% 77%	79% 103%	100% 100%	100% 0%
Engine speed [rpm]	1046	1043	1054	1657	1271	1251	1599
dp-Pipe [bar/100m]			0.24	0.25	0.25	0.25	0.30

Booster 2 LiveZero Input Pressure

Figure 26. Example of data acquisition screen shot (source: TU Delft).

Dallas White Rock Lake TX Project

The following project description was modified after Mr. Graeme Addie’s presentation, Georgia Iron Works Industries, at the Long-Distance Pipeline Transport of Dredged Material to Restore Coastal Wetlands of Louisiana Workshop in Hales et al. (2003).

The Dallas White Rock Lake Project involved the transport of dredged sediment from a lake for 104,000 ft (32 km) (20 miles) to restore water supply capacity to the lake (Figure 27). The pipeline route went through urban locations where bullet-proof sheds enclosed pipeline control equipment and chain-linked fences, topped with barbed and razor wire protected its booster station (Rock Products 1998).

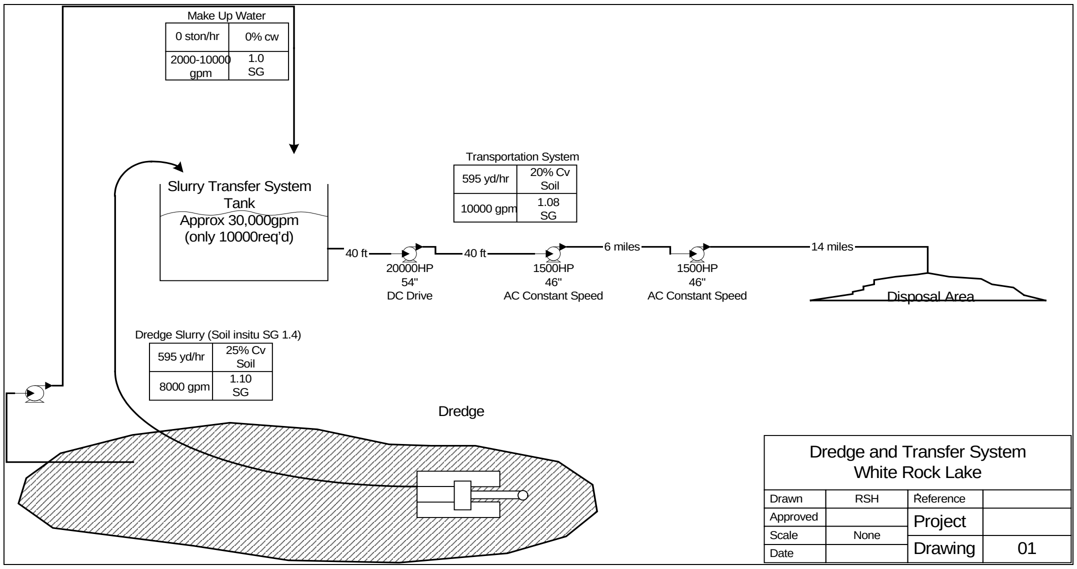


Figure 27. Dallas White Rock Lake dredge and transport system (source: GIW).

Slurry analyses were conducted by using an extrusion rheometer to predict pipeline friction. Here the material was silt, not sand. Sand would have required twice the velocity, cause 3.25 times the friction loss, and require 6.5 times the power as the silt. Results of these tests determined that three pumps would be adequate instead of nine pumps previously estimated. The result was that 3,730 kW (5,000 hp) pumps total were used instead of the 20,130 kW (27,000 hp) previously believed necessary, and a huge project dollar savings ensued. The hydraulic circuit transported 11,000 gpm (0.7 cu m/sec) (0.9 cu yd/sec) of slurry at a specific gravity of 1.3 or less and a total dynamic head of 750 ft. It was designed to be protected by a cavitation-prevention system that would automatically shut down the operation if any of the pumps cavitated. The 500 acre lake was dredged by an electric-powered pipeline dredge equipped with a 1,120 kW (1,500 hp) variable speed motor with a silicon controlled rectifier (SCR) drive control. While typically operated at 10 bar (150 psi), the pump was designed with a safety factor of 28 bar (400 psi) (hydrostatic test pressure was 41 bar (600 psi). The pump was designed to transport 10,500 gpm (0.66 cu m/sec) (0.86 cu yd/sec), but was equipped with “an automatic control system that adjusts the pump speed to maintain constant flow. Further, it provides stable mass flow balance between the transportation and dredge systems” (Rock Products 1998).

Slurry (about 30 percent sediment and 70 percent water) discharged from the dredge via a floating HDPE was transported to a 300,000-gallon (1,135 cu m) (1,485 cu yd) sump tank, where it was diluted to 80 percent water by a makeup water pump (Figure 28). This dredge-ladder pump made up the difference between the 10,500 gpm (0.66 cu m/sec) (0.86 cu yd/sec) pumped by the dredge pump and the 11,000 gpm (0.7 cu m/sec) (0.9 cu yd/sec) design flow of the transport LDC system. The slurry was then moved into the pipeline through a 500 mm (20 in.) discharge booster pump powered by a 1,490 kW (2,000 hp) direct current motor with SCR drive, then kept moving by two other booster pumps driven by 1,100 kW (1,500 hp), 585-rpm, 4,160-volt, constant speed alternating current (AC) motors (Figure 29). A spare pump was kept on site for use or parts. The pipeline was monitored by an electronic leak-detection system that, in addition to the control system, was monitored by an onshore operator. A two-way radio telemetry signals relayed information to and from the dredge, and telephone lines relayed information from magnetic flow meters installed at the beginning and end of the pipeline (Figures 30 and 31). These data, in addition to slurry density, were collected and analyzed to monitor dredge and transport system activities (Rock Products 1998).

The next section describes an LDC project currently under development in the CIAP (described in Appendix A) entitled the “Mississippi River Long Distance Sediment Pipeline.” This information is primarily summarized from a presentation by Ms. Laura Belden, CIAP, at a Stakeholders Meeting conducted 15 September 2009.

Figure 28. System make up water (source: GIW).

Figure29. Booster pump with AC constant speed motor (source GIW).

Figure 30. Radio link to dredge (source: GIW).

Figure 31. Main control, radio link to dredge, phone line link to remote booster (source: GIW).

Technical Assessment of River in Sand Mining to Support Scofield Island Restoration

A technical assessment of the potential for riverine mining of sand resources to support construction of the Scofield Island Restoration (Project BA40 of the Louisiana Coastal Wetlands Conservation and Restoration Task Force) and perhaps other areas near the Empire Waterway gulf entrance was conducted for NOAA. This assessment identified potential mining targets in the Mississippi River and major issues associated with use of these sand resources and developed conceptual construction methods for mining, transporting and placing riverine sand that were judged worthy of further consideration and development.

As per Coastal Planning & Engineering, Inc. (2004) this report :

- “Identifies & assesses potentially dredgeable sand resource targets which warrant investigation as part of future project engineering, including a geophysical framework. Potential sand sources identified are:
    - Sand sheets, bed load, or sand waves within the Mississippi River.
    - Relict and deltaic sand below the fluvial sand sheets.
    - Relict Point Bars.

- Summarizes major issues associated with utilizing these resources including conflicts with land owners, easements, rights-of-way; on-going Corps of Engineers' management of navigation, flood control, environmental restoration projects, and limitation on activities adjacent to the Corps project area in the region.
- Summarizes conceptual approaches to fluvial sediment mining, transportation, and placement procedures that merit further investigation, including various transport methods, routes, distances, and approaches to sediment placement in project fill areas. A range of costs are included.
- Develops an approach to geotechnical investigations to guide development of potential engineering-level assessment. This includes a conceptual approach to locating, delineating, and quantifying sand resources, and a recommended data acquisition and analyses method.

Island restoration, sand source, pipeline routes and construction methods were described in four alternatives that combined various dredging methods, sand sources, and pipeline routes (along with respective preliminary cost estimates).

The most feasible preferred construction method included the use of the Empire Waterway (USACE rights-of-way) as a pipeline and barge access route and the sand would be dredged by cutterhead or hopper dredging with a single pipeline with up to 2 to 5 boosters. Another transport alternative that was considered consisted of pumping river sands to the other side of the waterway locks and gates, that would be subsequently be loaded in barges that could transport the sand the remaining distance. LDC pipeline lengths for the alternatives ranged from approximately 10 to 19 miles with preliminary construction cost estimates (exclusive of mobilization and demobilization costs) ranging from $6.06/cu yd to $12.04/cu yd.

Mississippi River Long Distance Sediment Pipeline Project

The scope of this project is to design and construct an efficient sediment delivery pipeline system from a renewable resource in the Mississippi River to strategic locations in Barataria Basin. The project's current budget is $66.5 million ($31 million from the state CIAP program, ~$1 million each from Plaquemines, Jefferson, and Lafourche Parish CIAP programs, and $32.5 million from state surplus funds. The project is being implemented in phases with current efforts including crossover site selection, design and construction of these crossover sites and planning for the full pipeline. Planning level cost estimates for the full system are being completed, and river modeling, preliminary borrow sites analysis land rights assessment, and route and placement sites planning are all underway. The long-term pipeline infrastructure will run from the Mississippi River to a back levee (or start of Area of Need) and will include the River levee crossing, casings for road and railroad crossings, and the pipeline.

Other aspects being investigated in detail include:

- Construction methodology.
- Pipeline route.
- Landrights.
- Costs of recommended route and method.
- Design of pipeline.
- Placement sites.
- Sediment availability.
- Beneficial use opportunities.

The current total cost estimates for this project range from $600 million to $800 million that would average approximately $20 million/year to $100 million/year with the following design assumptions: (1) 50 million cu yd to be transported (cut volume), (2) the project life varies from 8 to 30 years depending on operating months that could range from 3 to 10 months per year, and (3) the pipeline length varies from 15 to 30 miles. Future efforts will include the complete planning of the project, detailed cost estimates and design of the complete pipeline to areas of need in the Barataria Basin.

Conclusions regarding costs depending on a number of factors that have been reached at this project's current stage of implementation include:

- Physical Pipeline Factors: size, distance, ground conditions, access issues.
- Operating Costs in dollars/cubic yard go up with distance due to booster operational costs, pipeline wear, and drop in dredge operating time with addition of boosters.
- Average operating dollars/cubic yard depends on distribution of quantity along length (i.e., pump west slowly or build pipe west and then pump).

- Capital cost of installation is very large and many cubic yards are needed to spread those costs over time.
- Costs can be lowered in the short term by paying contractors to mobilization/demobilization (mob/demob) their own pipeline and boosters; but it is much more cost effective in the long term (provided a sufficiently large volume of sediment will be delivered) to install the system once.
- Prudent decisions on how much pipe to install and how to contract it require an understanding of long term funding outlook.

Slurry pipeline systems using positive-displacement pumps

While centrifugal pumps are, by far, the most frequently-used pumps in dredging projects to transport slurry, positive displacement pumps have been applied in bulk-transport applications such as mining. In addition to the definition previously presented, Mr. Norwood (Pipeline Systems Inc.) in Hales et al. (2003) describes the positive displacement pump as follows:

> “the positive-displacement pump has an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pump as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. This principle applies to all types of positive-displacement pumps, whether the pump is a rotary lobe, progressing cavity, rotary gear, piston, etc. A positive-displacement pump, unlike a centrifugal pump, will produce the same flow at a given speed no matter the discharge pressure.”

Positive displacement pumps generally operate at higher pressures than centrifugal pumps. This operational characteristic requires that the pipeline be constructed to withstand the increased pressures. Because of these increased operating pressures, less intermediate pump stations will be required (personnel communication, Mr. David Stitt, PSI, Inc., 23 October 2006).

In Mr. Norwood’s presentation, (Hales et al. 2003), another difference between centrifugal and positive displacement pumps is the amount of solids that can be transported. For example, a centrifugal pump system can transport a slurry of approximately 80 percent water and 20 percent solids, where as a positive-displacement pump system may convey the reverse (i.e., 80 percent solids and 20 percent water). Key positive displacement system design issues include:

- "Optimization of slurry properties for long-distance transport.
- Material optimization for corrosion and erosion resistance.
- "Life-of-project" planning for configuration changes.
- Planning for upset conditions such as power outages.
- Environmental planning for design, construction, and operation).
- Staffing plans for central control, communications, and monitoring.
- Regulatory regimes."

One example of a dredging project where a positive displacement was used is the Peoria Riverfront Development, Illinois Upper Mid-sized Island Critical Restoration Project (Putzmeister America, Inc. 2009). A trailer-mounted concrete pump is being used in conjunction with a clamshell bucket dredge to reduce the amount of water transported in the pipeline to optimize placement into geotextile containers and also to address environmental concerns. The 6.0 cu yd (4.59 cu m) capacity bucket excavates sediment at near in situ densities and is dumped into a 16 cu yd (12 cu m) capacity hopper equipped with a grizzly screen to separate out over-sized debris (Figure 32). In turn, the sediment is being pumped at an operating pressure of approximately 1,146 psi (79 bar) by the positive displacement pump (powered by a 630 hp (470 kW) diesel engine) for a distance of 0.25 miles (0.4 km) and placed into geotextile containers. Production rates of 260 cu yd/hr (200 cu m/hr) are being achieved with the contract specification of pumping a 50 percent solids slurry being met (and exceeded) (Putzmeister America, Inc. 2009).

Figure 32. Peoria Riverfront Development, Illinois Upper Mid-sized Island Critical Restoration Project using mechanical bucket dredge and positive displacement (concrete) pump to transport high solids slurry for placement into geotextile containers (photograph courtesy of Cable Arm, Inc.).

Examples of long major slurry pipeline systems developed for transporting different kinds of materials described in Hales et al. (2003) include: (1) limestone transported through a 255-mm- (10-in.-) diam pipeline in Rugby, England, 92 km (57 miles) long), (2) phosphate concentrate transported through a 255-mm- (10-in.-) diam pipeline in Vernal, UT, 153 km (95 miles) long, (3) coal transported through a 457-mm- (18-in.-) diam pipeline in Black Mesa, AZ, 439 km (272 miles), (4) iron concentrate transported through a 510-mm- (20-in.-) diam pipeline in Samarco, Brazil, 395 km (245 miles), (5) copper concentrate transported through a 150-mm- (6-in.-) diam pipeline in Alumbrera, Argentina, 314 km (195 miles), and (6) copper tailings transported through a 305-mm- (12-in.-) diam pipeline in Hokuroku, Japan, 71 km (44 miles). Other slurry pipeline systems have been developed that use much larger diameter pipelines than these examples, but pumping distances were less than distances mentioned above (e.g., a 1,220-mm- (48-in.-) diam pipeline was used to pump copper tailings at Kennecott UCD, UT, 48 km 23 miles.

The next section describes an example of the use of displacement pumps to transport copper and zinc concentrates 302 km (188 miles) over two mountain ranges.

Antamina's copper/zinc slurry pipeline

The following project description is modified after Derammelaere (2001).

The Antamina slurry pipeline system (in Chile) pumps copper and zinc concentrates over two mountain ranges with the hydraulic system consisting of a pump station at the mine site (Figure 33) connected to the terminal via a 302-km- (188-mile-) long pipeline. Between these two stations, intermediate station installations consisting of four pressure monitoring stations have been positioned to monitor pressure. The concentrate is stored in five 18 m × 18 m (60 ft × 60 ft) agitated storage tanks. The mine pump station has four positive displacement 1,305 kW (1,750 hp) (piston) mainline pumps with three operating and one on stand-by. Normal throughput is approximately 250 tons/hr but the system is capable of operating at 350 tons/hr. The maximum discharge pressure for the selected pipeline route is 245 bar (3,550 psi). The discharge flange rating of the pump station is ANSI 1500# (259 bar or 3,750 psi), at ambient temperature rating.

Figure 33. Antamina's mine pump station consisting of four positive displacement 1,750 hp (piston) mainline pumps (source: Pipeline Systems, Inc.).

Pressure monitoring stations are used to measure pressures along the pipeline and to maintain optimized pipeline slurry flow conditions (e.g., avoid slack flow) and to provide input into the leak detection system.

The traverses through diverse terrain conditions from high mountainous areas (elevations approximately 4,200 m (13,780 ft)) to desert like conditions along the coastal sections at sea level (four "choke" (valve) stations are used to segment the pipeline during slurry shutdown). Pipeline diameters range from 273 mm (10.75 in.) OD, to 220 mm (8.625 in.) OD and manufactured from American Petroleum Institute (API) 5L Grade X65, carbon steel and is lined with HDPE. The pipeline was constructed by buttwelding the pipe sections together. Flanged joints (ANSI 1500#) were spaced at 400 to 1,200 m (1,312 to 3,940 ft) for the HDPE liner insertion process. The pipeline piping and components were designed and constructed in accordance ANSI B31.11#. All pipeline welds were ultrasonically tested and each flanged section was individually hydrotested.

A SCADA system is utilized to control and operate the pipeline. This system operates over the fiber optic cable telecommunications system installed parallel to the pipeline. The SCADA system includes a “Pipeline Advisor” (shown on the center monitor in the control room in Figure 34, which displays the profile, a real-time hydraulic gradient, and advises the operator of potentially critical situations, such as slack flow or overpressure. This will provide the operator’s indication to adjust pump speed, etc. Solids are on the order of 4.2 specific gravity and the top size, allowed into the pipeline, is controlled at 100 mesh. The fines level, defined as minus 325 mesh, varies from 65 to 75 percent, somewhat lower than for other concentrate pipelines. The solids concentration is held between 55 and 65 percent by weight. At the upper end of the concentration range, the viscosity is on the order of 12 mPas and the yield stress is between 2.5 and 3.5 Pa.

Figure 34. Antamina’s pipeline transport system control room (source: Pipeline Systems Inc.).

Commissioning of the Antamina pipeline took place from May 2001 through June 2001, approximately 2 years after detail design of the project started. The tests conducted during commissioning demonstrated that the pipeline system met all performance requirements. The capacity was shown to be in excess of the design, and shutdown tests of up to 24 hr, with successful restart, were performed. Also during commissioning, the pump station discharge pressures rose to over 238 bar (3,450 psi), the highest of any slurry pipeline as of September 2001.

Pipeline and pump wear and corrosion

As the slurry is transported through the pipeline, its inner wall (wetted passage) experiences wear from sliding abrasion and impact of solids. Wilson et al. (2006) state that "the useful life on most slurry transport equipment is limited by erosive wear of wetted passages. As a result, wear performance must often be evaluated in connection with the design or operation of slurry systems." Turner (1996) reports that "although literature on the dredging industry has become more prolific in the last three decades, good information on equipment wear is still scarce. This is unfortunate because wear is a source of high cost to the dredge operator." The life or wear rate of a pipeline and other hydraulic circuit components (pumps, pipe elbows, constrictions, etc.) can be rated as a function of volume of material passed (e.g., 0.001 in./million cubic yards). When the wear pattern is predominantly on the bottom, the pipe is "rolled over" to present a thicker section on the circumference to extend pipe life. Major variables involved with wear include solids concentration, slurry velocity, weight of solids, particle size, and particle angularity (Turner 1996).

Regarding wear in pumps Wilson et al. (2006) states:

> "As a result, wear performance must often be evaluated in connection with the design or operation of slurry systems. Wear is a common industrial problem, leading to frequent maintenance and replacement of components, and possibly also to reduced operating efficiencies. As the factors affecting wear performance are manifold, and the gamut of slurry applications broad, a good deal of wear-performance evaluation has occurred *post facto,* when the system is already in operation. A body of experience and insight gathered by this method has accumulated over time, and much of the current design for wear performance of slurry systems is based on this experience. Recent years have also seen the introduction of more rigorous approaches to wear-performance evaluation. These include standardized laboratory tests for ranking slurry abrastivities and material wear resistances, and electron microscopy for providing close examination of the micro-mechanisms of wear for both laboratory and field-collected samples. The approach of numerical modeling of slurry flow is also gaining

> popularity as more powerful computers become widely available, and as numerical techniques become more refined."

Pipelines for dredging projects that span wetlands are either constructed of steel or HDPE. These materials have their advantages and disadvantages. Due to its inherently higher strength, steel is predominantly used with larger dredge pumps in pipeline locations with higher operating pressures, and compared to HDPE, is easier to repair by welding. The addition of varying carbon and manganese content with the steel increases its hardness and improves resistance to wear. A study by Cornet (1975) concluded that the wear rate of a steel component varied approximately with the component's Brinell hardness, and that while other variables such as grain structure, etc. affected wear rates, hardness (measured by the Brinell test) was one of the most significant characteristics. The Brinell test determines the relative hardness of a metal by measuring the indentation diameter made by impacting a hardened steel ball into the metal under standard force.

Pyburn & Odom, Inc. (1993) report that information from the dredging industry indicates that steel pipe erosion rates can vary significantly, and range from an estimated 500,000 to 2,000,000 cu yd per 1/8 in. A study was conducted by USACE Philadelphia District (1969) entitled "Long Range Spoil Disposal Study" to evaluate the technical and practical feasibility, and the advantages which might accrue, of pumping dredged sediment 32 to 80 km (25 to 50 miles) from the intensely developed Philadelphia (Pennsylvania) Port complex where the disposal areas had become filled to locations where the dredge "spoil" is at least acceptable, if not clearly advantageous. This study concluded that it was feasible and practical to move large amounts of dredged sediments great distances by pipe line to increase the disposal area's life, "however, this technique could only be justified under circumstances where there would be enhancement value by delivery of material to a far distant location, or when such disposal would be cheaper than any alternate means." Regarding pipeline wear rates and respective economic impacts the study concluded:

> "Obviously, the service life of pipe would be a significant cost factor in a long line which would be carrying abrasive material. In view of this there was communication with all the major steel producers and pipe fabricators to identify the best material that could be obtained from the industry. A suggested requirement to them was for a pipe which would

> have sufficient life for the transport of 100,000,000 cu yd of a 10 percent sand mixture. The advice obtained from the Chief Metallurgist of the U.S. Steel Corporation, Mr. Hugh Tombs, was that long service life is most economically obtained by purchasing increased thicknesses of standard steel pipe rather than using the additional dollars for the abrasion resistant steels. Abrasion resistant steels also bring the disadvantages of brittleness and lack of weldability which is characteristic of hard steels. These disadvantages would be significant in the construction of a long pipe line. Mr. Tombs pointed out that use of abrasion resistant steel (such as T-1) could increase cost of pipe four times while only doubling t he life of the pipe."

HDPE is commonly used on smaller dredges or in locations of lower operating pressures (such as at the end of a pipeline). Results of laboratory tests comparing the abrasion resistance of HDPE, ultra high molecular weight high density polyethylene pipe, and conventional mild steel pipe was conducted with the results indicating that, under the test conditions HDPE outperforms mild steel significantly in wear characteristics. Comparisons between the performance of different types of HDPE suggested that higher molecular weight materials provide better resistance to abrasion (USACE 1986). A study by Pankow (1995) concluded HDPE pipe can be an efficient alternative or supplement steel pipe, noted that HDPE can last longer (than comparable steel pipe) in fine-grained material, but that it is not well suited for slurry containing rocks and gravels. The physical and mechanical properties are sufficiently different than steel and it must not be treated as a rigid pipe, but that its flexible, lightweight, abrasion resistance offers new freedom in pipeline design, life, cost, and maintenance (Pankow 1995; USACE 1986). Benefits have been realized by using smaller dredges in some wetlands restoration projects (e.g., Chaland Headlands Project) with HDPE pipe because, while they deliver less slurry volume that reduces risk of blowing out containment dikes, the lightweight pipe allowed rapid positioning of the discharge to optimize sediment placement in the project area (Louisiana Coastal Wetlands Conservation and Restoration Task Force 2007).

The Chaland Headland Restoration Project used the same dredge (Weeks Marine's 30" cutterhead dredge the *Tom James (*now renamed *Captain Frank*)) to construct both the beach fill and marsh fill. An HDPE pipe was used in the marsh because it would float in the marsh area and could be moved around more easily than the steel pipe using marsh buggies. Two

"Y" valves were used, one to redirect the flow between the beach and marsh and another to lower exit velocities at the end of the beach fill line. This was important because the steel submerged line and steel shore pipe were used closer to the dredge where operating pressures were higher. The HDPE pipe was used closer to the end where the operating pressures were lower (personnel communication Gordon Thomson, Coastal Planning & Engineering, Inc.).

Another advantage of HDPE over steel is that it does not corrode (rust). Corrosion of the steel pipe occurs both inside and outside the pipe. Typically there are two basic methods to control the corrosion process, insulation by protective coatings and wrappings, and cathodic protection by inducing an electric potential in the ferrous material.

Contract specifications for a permanent dredge pipeline installation by the USACE New Orleans District (2009a) in Cameron Parish required a 737 mm (29 in) (inside diameter) API 5L, Grade X60 minimum, carbon steel pipe with a minimum 1/2-inch wall thickness and with a fusion bonded epoxy coating for the buried sections of the pipeline. Vinyl paint was used for the aboveground sections. Coal tar epoxy was also allowed for the underground pipe, but the fusion bonded epoxy was chosen by the contractor.

This CWPPRA project is planned for the Sabine National Wildlife Marsh Creation Project and the pipeline expected life is 20 years. The reach of the Calcasieu River Ship Channel is dredged every 2 years, but the pipeline could also be used in conjunction with dedicated dredging at any time.

This projects contract was awarded 13 April 2009 for a permanent pipeline to carry dredged material from the Calcasieu River Ship Channel to the marshes in Cameron and Calcasieu Parishes to make it easier and less expensive to restore the marshes. The USACE New Orleans District awarded the $9 million contract to Wilco Pipeline Contractors, LLC, of Rayne, LA, to construct the 3.6-mile-long pipeline and is expected to complete the work in the first quarter of the calendar year 2010.

As per USACE New Orleans District (2009b), this CWPPRA project "includes the construction of the permanent pipeline and the creation of four marsh creation sites, two of which have already been constructed from material dredged from the Calcasieu River Ship Channel. The

907-acre marsh restoration effort in the Sabine National Wildlife Refuge is located in Cameron Parish west of Highway 27 in large open water areas that had formerly been vegetated marsh."

"This area is experiencing marsh degradation from saltwater intrusion and freshwater loss," said Fay Lachney, the Corps project manager for the CWPPRA Sabine Refuge Marsh Creation project.

> "We plan to install the permanent pipeline along the same route that previous temporary lines have taken to reduce the environmental impacts of the work," Lachney said. She added that by installing the permanent pipe the Corps and its partners will save approximately $2 million each time they pump material into the marsh.
>
> The Corps will use material from maintenance dredging in the Calcasieu River Ship Channel to create at least 200 acres of new marsh each time they dredge the channel for the next 20 years, Lachney explained. The CWPPRA Sabine Marsh Creation project will utilize the pipeline to create two more marsh sites within the Sabine National Wildlife Refuge. Future dredging cycles will use the pipeline to create additional marsh sites in Calcasieu and Cameron Parishes.
>
> At the end of that time, the USACE have restored approximately 2,500 acres of marsh using dredged material from the navigation channel. To date, the Corps, Fish and Wildlife Service and State Office of Coastal Protection and Restoration have created approximately 444 acres of marsh using temporary pipes."

Construction and maintenance of pipelines in wetlands environment

The following section describes activities involved with the construction (mobilization), maintenance, and demobilization of pipelines in the wetlands environment. In the past, the oil and gas industry has used two major construction methods to place pipelines through the coastal marshes: the "push" method and the "flotation" method. (Tabberer et al. 1985) describe these methods as follows:

> "The push method requires excavation of a relatively narrow and shallow ditch with a dragline or marsh buggy-mounted backhoe. The ditch ranges from 4 ft to 6 ft deep by 8 ft to 10 ft wide. Because of the high water table in coastal marshes, the ditch remains filled with water.

> Pipe sections are joined together at the beginning of the ditch and given temporary buoyancy by floats strapped to the pipe. The buoyant pipe is floated along the ditch. Up to 15 miles of pipeline can be installed from one push location using this method. Pipelines as large as 42 in. inside diameter have been installed in the Louisiana marshes using this method. Once floated into place, floats are removed and the line is submerged to the bottom of the ditch. The ditch may be left open or backfilled. ... The push method is preferred where possible because it results in less damage from the smaller ditch size and is less costly. The flotation method requires excavation of a flotation canal to provide access for the pipe and pipe-laying equipment. The canal may range in size from 40 ft to 50 ft wide by 6 ft to 8 ft deep and may have an additional trench in the bottom to provide 10 feet to 12 feet clearance above the top of the pipeline. The flotation method was the first one developed and is now used for extremely large pipe, in shallow open water, and where marshes will not support equipment. A standard 40-ft section of 36-in. diam pipe weighs approximately 8.000 1bs. After anti-corrosion coating and 3 in. to 4 in. of concrete are applied for negative buoyancy, a 40-ft section weighs approximately 34,000 lbs. Equipment to handle pipe of this weight cannot be supported by some marshes. The flotation method is not preferred because it is time consuming, costly, and highly destructive to the marsh."

For dredging projects involving pipelines over the wetlands environment, the dredging corridor is usually delineated in contract plans and the contractor is required to confine construction activities within the boundaries of the Project Construction Limits. For example, the pipeline corridor width for the Mississippi River Sediment Delivery System Bayou Dupont project is 100 ft, and the contractor will be required to return the pipeline corridor to pre-construction conditions prior to demobilization (LDNR 2008). Infrastructure such as railroad and highways are typically gone under by jack piping steel casings for the pipeline to run through (LDNR 2008) (USACE 2009a).

Construction equipment used to mobilize and demobilize the pipeline is a function of the pipeline corridor terrain. The selection of the appropriate method and equipment for soils handling at a wetlands project site is important if the project is to be conducted in an economical and environmentally acceptable manner. As per Hayes et al. (2000), four main factors affect the selection:

- Material factors. The type, properties, and variability of the soils to be moved. The type of end-product desired: disposal, storage, or fill.
- Terrain factors. The volume and location of the materials to be moved and the location to be deposited. The availability of haul roads or haul areas. The condition of the haul roads, including grade and trafficability. Environmental factors limiting temporary and/or permanent changes in the site due to soil movement operations.
- Equipment factors. The types of equipment available, their operating characteristics, rolling resistance, cost of mobilization, and cost of operation.
- Environmental factors. Legal, contractual, or environmental limitations on the method and type of equipment that can be used.

Wheel mounted and heavy tracked construction equipment (e.g., bulldozers) can be used where ground conditions permit, but in low ground pressure conditions the venerable marsh buggy (Figure 35) is the primary construction platform. Operational standards have been compiled to provide marsh buggy and other vehicle operators, and those who hire them, guidance in how to avoid and reduce these impacts (LDNR 2000).

Figure 35. Marsh buggy working at end of pipe.

Depending on project objectives and site specific conditions, floatation channels (channels where the dredge excavates material to provide floatation as it advances (floatation dredging)) may, or may not, be approved in the contract specifications. Pipeline corridors can include canals that, given sufficient dimensions for navigation, improve efficiency (and reduced costs) in pipeline mobilization, operation, and demobilization. Improved accessibility for floating construction equipment can allow transport of pipe sections by water to the site and its subsequent assembly, maintenance, disassembly, and transport from the site.

Prime movers for dredging booster pumps can be driven by either diesel or electric driven with electronic data telemetry/control instrumentation potentially solar powered with battery backup. If diesel engines are used as prime movers for the booster pumps, transport of diesel fuel to the booster station can be more efficient if accomplished by fuel barge. As a general example, if a 1,490 kW (2,000 hp) diesel engine burned 90 gal fuel/hr, the daily fuel consumption rate would be 2,160 gal/day. Optimization of peak performance-energy required to accomplish objectives is a very important design element. Certain booster pumps will require cooling water to maintain correct operating temperatures as described in the “Interstate 10 Construction Between Baton Rouge and New Orleans Project” section.

Feasibility of using abandoned pipelines for moving dredged material in coastal Louisiana

The following is excerpted from Hales et al. (2003) summary of a presentation by Mr. Van Cook, LDNR, Baton Rouge, LA.

> “In 1992, Louisiana Senate Resolution No. 164 was passed which directed the Louisiana Department of Natural Resources (LDNR) to develop and implement a pilot project to determine the feasibility of using abandoned pipelines for sediment diversion in the coastal restoration program. The resolution stated that many such abandoned pipelines existed, and that the pipeline owners were willing to work with the state to allow use of pipelines for sediment diversions. The consulting firm of Pyburn & Odom, Inc. was retained to provide engineering services for the study (Pyburn & Odom, Inc. 1993). Task 1 of the study was to determine the potential feasibility of using abandoned oil and gas pipelines for sediment diversion to marshes. If Task 1 were found to be feasible, then Task 2 would be to prepare a conceptual design and an estimated cost for a pilot project to demonstrate practical feasibility. Canvassing the oil and gas companies for location of abandoned pipelines was not a task for this study.

Pipeline capacities were evaluated as to (a) lengths (5, 14, and 30 miles), (b) diameters (8, 12, 16, and 24 in.), (c) slurry concentrations (10, 20, 30, and 40 percent solids), (d) slurry composition (lower Mississippi River sand with median grain size of 0.18 mm), (e) pumping capacity (operating velocities at least 10 percent above minimum velocity to establish flow with a heterogeneous mixture; booster pumps placed at 1-mile intervals), (f) allowable pressure (design operating pressure of 165 psi (310 ft of pressure head), and project pipe erosion rates (highest on pipe bottom at 1/8 in. of wear per 500,000-2,000,000 cu yd of dredged material pumped. The sediment source was assumed to be the lower Mississippi River. It was also assumed that sediment would be placed in the marsh to 9 ft of height (including compaction, settlement, and sediment loss) in 3 ft of water depth.

Three pipeline system scenarios were considered: (a) direct connection where the dredge discharge pipe could be connected directly to an abandoned pipeline, (b) indirect connection where an intermediate pipeline would be necessary to connect the dredge discharge pipe to an abandoned pipeline, and (c) band storage and barge or truck transport from the dredge to an abandoned pipeline. All systems considered involved many other factors such as: (a) legal (servitude, ownership, liability), (b) environmental (contaminants), and (c) regulatory (permits).

The study determined that the use of abandoned pipelines to transport sediment to create or restore marshes in coastal Louisiana is potentially feasible. A pilot study was undertaken to determine practical feasibility. A conceptual design was considered at Tiger Pass near the Tidewater facility using abandoned Exxon 8-in.-diam pipeline. Dewatering and re-slurrying of the dredged material was required. The estimated cost was found to be $ 1 million to restore 10 acres of marsh. While abandoned pipelines do exist, no pipelines were found to be unconditionally available. Furthermore, the pipelines that were found to be even conditionally available were of less than optimal size. Most were in the 8 to 12-in.-diam size, far less than an optimal diameter for transporting large quantities of dredged material. The use of abandoned pipelines was found to be potentially feasible, but practical feasibility was not proven. Cost per acre was exceedingly high, and abandoned pipelines of an appropriate size and in the appropriate location are believed to be essentially non-existent.”

5 End-of-Pipe Sediment Management

End-of-pipe sediment management methods used to place slurry (ultimately sediment after dewatering) primarily depend on the restoration project's objectives, site specific conditions, and slurry characteristics (i.e., type of sediment) being placed. Rosati and Mendelssohn (in preparation) reviewed end-of-pipe sediment management methods that have been used to restore coastal wetland functions and values that included traditional hydraulic pipeline placement, thin layer placement, slurry placement, and scrape-down placement.

Traditional hydraulic pipeline placement

In the traditional hydraulic pipeline placement method, dredged material is pumped directly on site with the goal generally being to create marsh from open water at the lowest cost possible by maximizing the concentration of sediment in the slurry (Figure 36). The relative amounts of sediment required to be transported and placed depends on the placement site-specific conditions (e.g., more sediment would be required to restore open water sites compared to material being placed within a confined disposal facilities) and sediment characteristics.

Figure 36. Traditional hydraulic pipeline placement.

Coarse-grained (sand) material will fall out of suspension quickly and can (given the appropriate grain size distribution) be used to construct dikes or other structural elements (e.g., ridges and terraces). To achieve project goals with fine-grained materials, it may be necessary to construct some form of lateral confinement. Wetland design placement alternatives for traditional hydraulic placement include confined, semi-confined, or unconfined (open water). Confined placement or a confined disposal facility (CDF) is a diked area constructed to contain dredged material to retain the sediment within the diked perimeter while effluent is discharged by a control structure such as a weir. The lateral confinement elements may consist of either dikes placed hydraulically, sediment dug from immediately adjacent area and piled, rock enclosures, sediment-filled geotextile bags, or emergent land features or bathymetry.

Thin-layer placement

One method of potentially slowing wetland loss is to artificially supply sediments to subsiding marshes. Techniques normally employed to move and distribute sediments are impractical in the unstable soils of wetlands, so new methods have been developed. The primary method is to deposit thin layers of sediment, usually by spraying a sediment slurry under high pressure over the marsh surface. The technique is essentially a modification of existing hydraulic dredging methods in which sediments are hydraulically dredged, liquefied, and then pumped through a high-pressure spray nozzle (Figure 37). Developed in Louisiana, it has since been performed on the Gulf and Atlantic coasts and shows promise for general application (Ray 2008a).

Slurry placement

Slurry placement is a relatively new approach to nourishing wetlands with hydraulic pipeline placement where sediment is allowed to flow onto existing marsh with a high fluid to sediment ratio (e.g., 75 to 85 percent liquid and 15 to 25 percent solids by volume), which facilitates the sediments flowing over long distances (Mendelssohn and Kuhn 2003).

Scrape-down placement

The scrape-down placement method involves placing material from a previously stock-piled land-based operation into the nearshore. Dredged sediments that have been stockpiled onshore, or created adjacent to a navigation channel in dredged material “islands” are sometimes moved to create wetlands using a backhoe, or “scrape down” methods. The material is then reworked in the nearshore to obtain the elevation and aerial extent required for a functional wetland (Rosati and Mendelssohn, in preparation).

Figure 37. Spray disposal of dredged material (photograph courtesy of Bob Blama, USACE Baltimore District).

6 Potential Environmental Impacts

Despite the potential advantages of LDC, there are several concerns related to environmental damage incurred as part of LDC operations that must be taken into account. These concerns should not be viewed as obstacles to restoration, but merely as operational costs for which appropriate mitigation is required. As previously described, the pumping system consists of the dredge, dredge pump, booster pumps, the pipeline itself, and the end-of-pipe delivery system. Although the precise method for laying the pipe is uncertain, it is assumed it will either be buried, laid directly over the surface of the marsh, placed along nearby waterways, or some combination of these methods. Each of these methods has potential short- and long-term negative environmental impacts which will be briefly discussed and a method for calculating the additional amount of created marsh required compensation for LDC-related damage presented.

Extensive queries of computer-based search engines including Cambridge Scientific Abstracts, Google Scholar, and associated databases were made for information on pipelines and environmental impacts (Table 3). During these queries no references dealing with placement of pipelines directly on the marsh surfaces were encountered.

Table 3. List of literature databases searched.

Aquatic Sciences and Fisheries Abstracts
Conference Papers Index
Digests of Environmental Impact Statements
Environmental Impact Statements: Full-Text & Digests
Environmental Sciences and Pollution Management
GeoRef
GeoRef In Process
Oceanic Abstracts
TOXLINE

Most studies encountered referred to buried pipelines associated with the petrochemical industry (e.g., Van Dyke et al. 1994) or backfilled canals dredged as part of the pipeline installation (e.g., Knott et al. 1997). As a result, the effect of placing the pipeline directly on the marsh is evaluated based on reports describing the effects of dredged material placement, wrack, and vehicular traffic, all impacts which could result in smothering of the vegetation or compression of the soil. Shading impacts are estimated from studies of dock and bridge shading and the effects of obstructing sheet flow are inferred from studies describing alterations of water levels and marsh topography.

Although this report focuses primarily upon the potential environmental LDC-related impacts of pipeline and dredged material placement activities, subaqueous borrow area impact concerns are also considered.

Borrow Area Impacts

Dredging of subaqueous sediments for wetland creation can create depressions in the underwater landscape, called borrow pits or dredged holes. These depressions differ in volume, size, shape, and depth depending on the extent of the dredging operation and can result in both short- and long-term environmental impacts. Short-term impacts are generally limited to temporary increases in turbidity and sedimentation and decreased dissolved oxygen (DO) concentrations. Since most materials being dredged are sandy or coarse, remobilization of contaminants and nutrients is usually not a serious problem. Long-term impacts can result from altered bathymetry and may include loss of benthic habitat, altered habitat, and degraded water and sediment quality. Impacts resulting from changes in bathymetry are frequently the result of altered current flow. For instance, Wong and Wilson (1979) demonstrated from modeling that current flow over borrow pits decelerated over the center, but accelerated on the periphery of the pit. Both the velocity and direction of currents in the immediate vicinity of large pits could be altered, while small holes were more effective at decelerating flows within the depression. Pit morphology can also have a strong influence on current flows. Polis (1974) showed that pits with high width to depth ratios were more likely to be well flushed than ones with low ratios. Koo (1973) also observed that pits with relatively gentle side slopes are more likely to be well flushed than pits with steep banks. Swartz and Brinkhuis (1978) have reported that local conditions can have profound effects on the flushing rates: pits in areas of strong currents are generally better flushed than those in areas of relatively slow current flow. Likewise, Murawski (1969) has shown that pits with connections to nearby channels tend to be better flushed than isolated pits. This result is analogous to that of dead-end dredged canals where low flushing rates can result in low dissolved oxygen concentrations (e.g., Taylor and Saloman, 1968; Lindall et al., 1973 and 1975). Low DO conditions result when flow decelerates to the point that microbes can deplete the oxygen from the water and are often exacerbated by the development of thermoclines or pyncnoclines. Chronic or persistent stratification of the water column can result in hypoxia (low DO levels) or anoxia (no DO) can produce impacts ranging from physiological stress on individual organisms to the death of entire assemblages (Diaz and Rosenberg 1995). In a study of a Danish fjord with seasonal hypoxia, Jorgensen (1980) reported periodic mass mortality of benthic invertebrates.

Decelerated current flow can also result in increased sedimentation. Under decelerated flow the probability of sediments dropping out of suspension increases and if flows are sufficiently slow particles finer than the original substrate settle out. The result can be a change in the nature of sediment present in the basin of the pit. Infilling of sandy dredged sites by fine materials has been reported by Jones and Candy (1981), Van Dolah et al. (1994), Schaffner et al. (1996), Jutta and Van Dolah (1999), and Jutta et al. (1999a). Where borrow areas are located in areas of high sediment transport, infilling can be rapid as was the case in Panama City, Florida (Saloman et al. (1982). Pits dredged to depths of 3-5m filled to within 1m of their original elevation within 1 year. Jutta et al. (1999b) found that a borrow pit offshore of Garden City Beach, South Carolina completely filled within two years of dredging and second site was nearly a fifth filled within the same time period (Jutta et al. 1999c). Van deVeer et al. (1985) reported infilling rates in the Dutch Wadden Sea finding that dredged tidal channel sites with high transport rates filled within three years, although tidal flats where transport rates were low were still not completely filled after 13-16 years.

Properties of the materials filling borrow pits can also have profound consequences for the benthic invertebrates that inhabit them. The structure of benthic assemblages is determined by the type of sediment present such that assemblages of sandy sediments are quite different from those of mud both in terms of species composition and trophic structure (Lenihan and Micheli 2001). Muddy substrates are generally dominated by burrowing and surface-feeding detritus feeders while those of sands tend to be dominated by filter-feeders (Gray 1974; Diaz and Schaffner 1990; Snelgrove and Butman 1994). Sediment type also influences benthic colonization rates (Newell et al. 1998). For instance, muddy sediments in areas of relatively low salinity (oligohaline) tend to colonize rapidly (weeks to months) because the natural community is dominated by opportunistic species which are capable of quickly producing large populations. Fewer opportunistic species are typical of sandy marine sediment assemblages and colonization can take several years. Where fine sediments are deposited in a sandy dredged pit the benthic assemblage that colonizes it may not provide sufficient or appropriate food for predators. In addition, muddy sediments have the capacity to retain far greater levels of contaminants than sand and thereby increasing the potential for bioaccumulation and trophic transfer of contaminants. Where the pits are shallow or sediment movement quickly refills the depression with appropriate materials colonization can be rapid and complete (e.g., Saloman et al. 1982; Bowman and Marsh 1988; Schaffner et al. 1996; Scott and Kelley 1998).

Impacts common to all placement methods

Construction and maintenance Impacts

Construction and maintenance activities associated with pipelines will inevitably result in damage to the marsh surface. Wheeled and tracked vehicles can crush or kill vegetation and create ruts which become waterlogged and result in erosion. Off-road vehicles impact marshes by compression of the soil and particularly by production of ruts. Godfrey et al. (1978) found that as little as one pass by a jeep through peaty low marsh (*Spartina alterniflora*) soils resulted in destruction of plants apparently through water-logging in the ruts created by the vehicle. The impacted areas recolonized slowly and still had not returned to normal densities at the end of 3 years. Impacts to high marsh (*Spartina patens*) were less severe with vegetative cover complete within 3 years although ruts created by vehicle passage along the border between high and low marsh induced some erosion. Hannaford and Resh (1999) studied the effects of all-terrain vehicles on a California wetland dominated by *Salicornia virginica*. Vehicles were tested for light use (two passes over an area) and heavy use (20 passes). Even light use created a swath of broken stems, however stem biomass was comparable to natural stands within a year; heavy use impacts were still evident after a year. Wilshire et al. (1978) examined coastal dune, grass, and chaparral habitats in the Sand Francisco area for impacts of off-road vehicles on vegetation and soils. They reported clear evidence of loss of vegetation and highly compressed soils in all cases. Compression resulted in increased surface strength, bulk density and erosion, and decreased infiltration rate. The authors hypothesize that these changes in soil properties make it more difficult for new growth to occur in impacted areas due to the difficulty encountered by new roots in penetrating the compacted soils.

Similar results were reported by Hosier and Eaton (1980) for coastal dune and grassland vegetation on a North Carolina barrier beach island. Duever et al. (1986) studied the impacts of light, medium, and heavy use of wheeled, all terrain, and tracked vehicles as well as airboats on various habitats in the Big Cypress National Preserve. Wheeled and tracked vehicles had the most profound impacts in all tests of the degrees of use with revegetation not complete in many cases 7 years after impact. Airboats had few and generally short-lived impacts.

Specially modified vehicles called “marsh buggies” (see Figure 38) have been developed to reduce these impacts by reducing the weight per unit area to less than 2 lb/sq ft. The effect of these vehicles appears to vary depending on the degree of use. Wilson et al. (1999) has reported that only short-term (1 year or less) impacts were found after equipment associated with three-dimensional seismic surveys. Bass (2004) found that long-term impacts are possible, particularly if the same areas are repeatedly traversed. Mendelssohn et al. (1993) suggest that heavy equipment employed during an oil spill cleanup operation not only destroyed vegetation but compressed soils to the extent that flooding levels were increased. Impacted marshes required 5 years to recover. Curole and Huval (2005) report that 9.5 acres of wetlands were severely or moderately impacted by improper use of marsh buggies during a restoration project at the West Belle Pass Headland. The State of Louisiana has issued specific guidelines for use of these vehicles which includes limitations on the numbers of vehicles used, the area over which they may travel, detailed operational recommendations, and a requirement for restoration of damaged marsh (LDNR 2000).

Placement of booster pumps will also result in damage to the marsh both from transport of the equipment to the site and the placement of material to provide solid footings well above the range of tidal inundation. Such footings are generally created by placement of sand or other sediments thus destroying the underlying marsh. Accommodation will also have to be made for storage and potential spillage of fuels and other petrochemicals from the booster pumps. Construction of necessary safety precautions such as spill containment pits will also result in destruction of small amounts of marsh in the vicinity of the booster pumps and must be taken into consideration. Carbon emissions and noise produced by the pumps may also affect local wildlife populations.

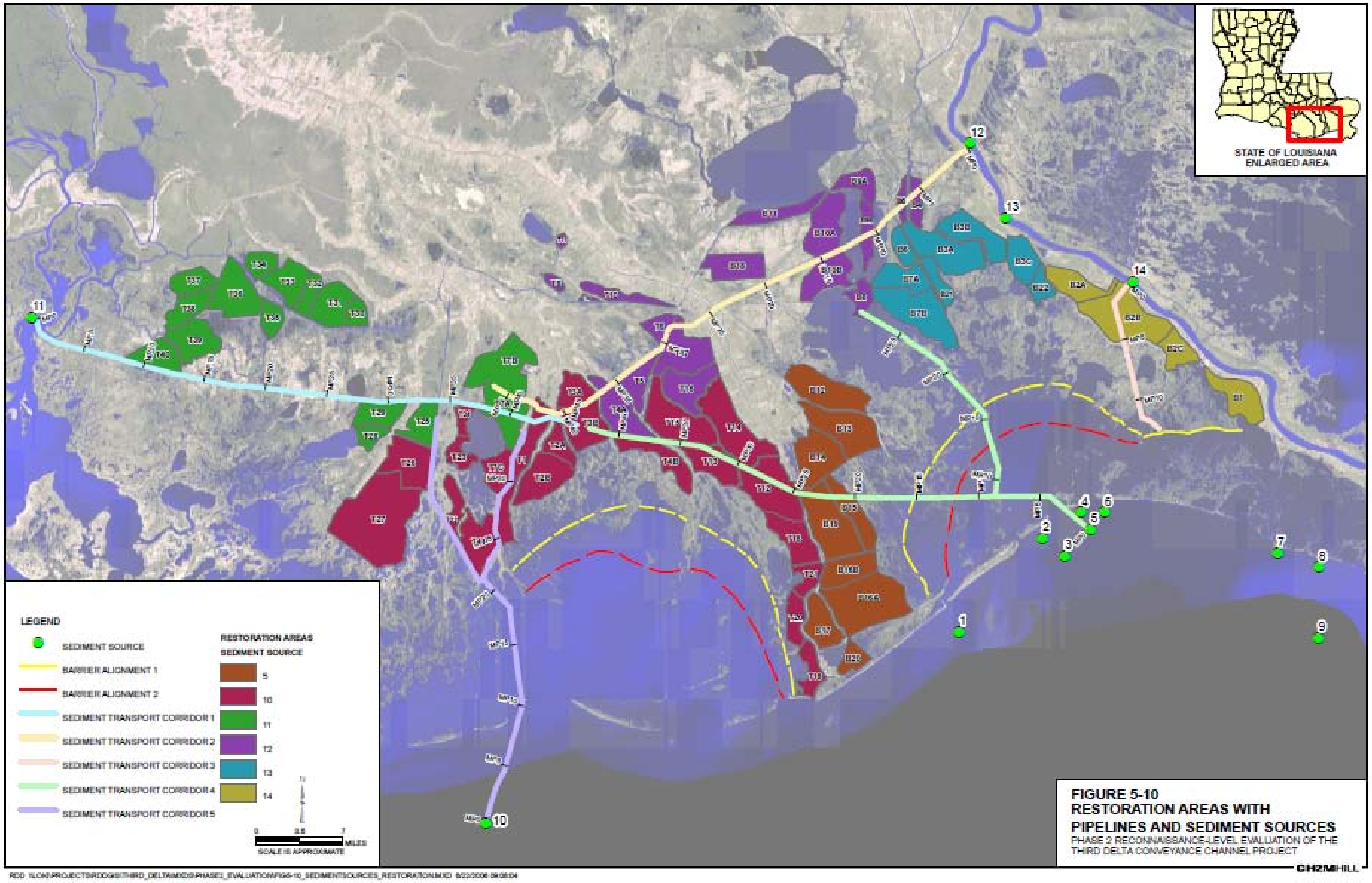


Figure 38. Phase 2 Reconnaissance-level evaluation of TDCC project report's pipeline conveyance alternative areas with pipelines and sediment sources (source: CH2M HILL 2006).

Salinity differences

A critical factor identified in previous reviews of LDC is the potential impact resulting from differences in salinity between the waters used for transport (source waters) and those of the receiving area (e.g., Reed 2004). Salinity is a “master” or controlling factor that affects not just marsh vegetation but also the animal species that utilize it. The most acute impacts will occur where the difference between source waters and receiving waters are the greatest. For instance, McKee and Mendelssohn (1989) found that freshwater marsh plants were killed by a sudden exposure to salinities of 15. Freshwater species such as *Panicum hemitomon* and *Leersia oryzoides* were tolerant of salinities as high as 9.4 while others such as *Sagittaria lancifola* experienced tissue damage in salinities as low as 4.8. In subsequent research with several of these same species, Howard and Mendelssohn (1999a) report that increased salinity results in decreased growth. The most salt tolerant was *P. hemitoman* followed (in order) by *S. lancifola, Eleocharis alustris* and *Schoenoplectus (*formerly *Scirpus*) *americanus*. These same authors (Howard and Mendelssohn (1999b) also report that exposure to pulses of high salinity affected growth. This is an important issue since pumping will depend on dredging schedules and thus be periodic rather than continuous. In their study Howard and Mendelssohn (1999b) found that *S. americanus* was the most tolerant of the four species to salt pulses while the remaining species experienced reduced growth. Recovery of these species was negatively affected by both the increased salinity and the length of exposure. Gough and Grace (1998) examined the impact of altered salinity regime on both freshwater and brackish water marsh communities by reciprocal transplantation experiments. Sods of freshwater marshes transplanted into brackish water lost both species and biomass especially if herbivores were present. Sods of brackish water plants transplanted into freshwater conditions were not selectively favored by herbivores but community structure changed over time as brackish water plants were progressively replaced by freshwater species. Alexander and Dunton (2002) followed changes in Texas hypersaline marshes after a freshwater diversion and reported changes in plant community structure. Total annual cover of the halophyte *Salicornia bigelowi* increased with increases in freshwater inflow while that of *Batis maritima* generally decreased. Zedler (1983) has also reported increased cover by a *Salicornia* species in California marshes after a period of heavy rainfall.

The distributions of fish and invertebrate species are also controlled by the salinity gradient (Day et al. 1989; Little 2003). Determined by their ability to regulate or adapt to varying salinity levels, different species assemblages are associated with fresh, brackish, estuarine, and marine waters (e.g., Boesch 1977; Bulger et al. 1993; Wagner 1999; Martino and Able 2003). For example, Tenore (1982) and Hyland et al. (2004) have demonstrated the presence of relatively distinct benthic assemblages associated with oligohaline, mesohaline, and polyhaline salinities in North Carolina estuaries. Along the east and gulf coasts tidal freshwaters are often dominated by insect larvae, oligochaetes, gammarid amphipods, and the clam *Corbicula fluminea* while oligohaline assemblages are dominated by chironomid fly larvae, oligochaetes, and the clam *Rangia cuneata*. Mesohaline assemblages are dominated by polychaetes including *Nereis succinea* and *Heteromastus filiformis* and the clam *Macoma balthica*. Polyhaline assemblages are dominated by stenohaline species such as *Paranois fulgens* and *Glycera* spp. Normal seasonal fluctuations in salinity result in redistribution of these assemblages as the isohalines move up or down the estuary (e.g., Tenore 1982). These fluctuations are more pronounced when salinity changes are large and abrupt as occurs after large storms. For instance, abnormally low salinities in lower Chesapeake Bay following Tropical Storm Agnes in 1972 resulted in declines or temporary elimination of many benthic species (Orth 1976). Relatively stenohaline taxa such as *Ampelisca sp.* and *Podarke obscura* were completely absent after this storm, while more euryhaline species including *Crepidula convexa* and *Mogula manhattensis* suffered initial mortality but quickly became more numerous after the storm than before it. Larsen (1976), studying the impact of the same storm on infauna of oyster beds in the James River (Chesapeake Bay) found similar results. Forbes and Cyrus (1993) have described similar changes in the macroflora and benthic fauna of St. Lucia Lake, an estuarine lake in South Africa that undergoes radical changes in salinity due to variations in freshwater inflow and evaporation. The lake varies from hypersaline conditions to freshwater resulting in cycles of periodic appearance and disappearance of populations as conditions change.

Although the physical and temporal scale of such effects will differ for LDC operations, periodic alterations in the salinity gradient associated with initiation and cessation of pumping can be assumed to have similar, if more localized, effects.

Eutrophication

While not directly related to salinity differences between pumped and receiving waters, there is also a question whether or not eutrophication may result from pumping of nutrient rich river water. These concerns are based on the role of Mississippi River water in creating a hypoxic zone in coastal Louisiana (Rabalais et al. 1996; Dortch et al. 1999) and the production of extensive blooms of blue green algae and fish kills (Dortch et al. 1998; Poirrier and King 1998) following the 1997 diversion of Mississippi River water into Lake Pontchartrain. In contrast, results from freshwater diversions projects at Davis Pond and Caernarvon (Louisiana) indicate that existing marsh complexes may be able to process the excess nutrients (Delaune et al. 2003; 2005).

Burial impacts

As previously described, there are two basic methods for burial of pipelines associated with the gas and oil industry: “push” and “flotation” (Tabberer et al. 1985). In each case, a trench is dug into which is the pipe is laid and then covered over with the soil removed from the trench. The “flotation” method also requires dredging of a canal to permit access for the heavy equipment necessary for laying the pipe. The access canal is left intact to allow for later maintenance or repair activities.

A key issue with regard to both methods of pipeline burial is the potential for altering the elevation of the marsh in the area of backfill. Elevation is a critical factor controlling both the composition and productivity of southeastern marshes with higher elevation sites dominated by *Juncus roemerianus*, *Distichlis spicata*, and *Spartina patens* while lower elevations are dominated by *Spartina alterniflora* (Stout 1984). If the area of backfill is too high it could revert to upland vegetation while decreased elevation may result in increased submergence significantly decreasing the survival of some species (Mendelssohn and McKee 1988; Reed and Cahoon 1992).

Another issue common to both methods is the rate of recovery of backfilled sites. Revegetation will occur either by dispersal of seeds or spreading of rhizomes from nearby plants (Redfield 1972; Hartman 1988). The primary mechanism for colonization by *S. alterniflora* in low marsh will most likely be by spreading of rhizomes; in the high marsh *S. patens* and *D. spicata* will colonize by seeds and rhizome growth, respectively (Hartman 1988). The rate of vegetative recolonization will vary: some marshes may achieve pre-disturbance levels of cover within 2-3 growing seasons while others will take much longer (Table 4). Warren et al. (2002) examined natural reestablishment of *S. alterniflora* marshes in Connecticut after years of impoundment and colonization by *Phragmites australis* and *Typha* spp. Their estimates range from 5 to 21 years, with the actual rate dependent upon primarily on the degree of tidal flooding. Sites with relatively low elevation, greater hydroperiod and high soil water tables tended to develop the most rapidly. Hinkle and Mitsch (2005) measured recolonization rates of 5 years in previously impounded Delaware Bay marshes.

Table 4. Estimated recolonization time for salt marsh vegetation.

Source	Rate	Reference
Species: *Spartina alterniflora*		
Dredged material	2 years	Reimold et al. (1978)
Dredged material	3 years	Cahoon and Cowan (1987, 1988)
Physical disturbance (hurricane)	1-2 years	Guntenspergen et al. (1995)
Physical Disturbance	2 years	Hartman (1984)
Vehicular traffic	3 years	Godfrey et al (1978)
Impoundment	5-21 years	Warren et al. (2002)
Impoundment	4 years	Hinkle and Mitsch (2005)
Oil spill	5 years	Mendelssohn et al. (1995)
Species: Spartina patens		
Wrack	1 year	Tolley and Christian (1999)
Goose feeding	6 years	Miller et al. (2005)
Oil cleanup	1.4 years	Pahl et al. (2003)
Oil spill	5 years	Mendelssohn et al. (1995)

Recolonization rates will also be determined by the absolute size and shape of the impacted surface. Since *S. alterniflora* spreads primarily by rhizome growth, the rate at which an unvegetated patch will recover will depend on the proximity of plants to the patch. Redfield (1972) has estimated the rate of *S. alterniflora* expansion (i.e., rhizome growth) to be 20 cm/year, thus a 1-m-wide patch would require 2-3 years to cover the bare sediments assuming growth from both sides of the patch.

The colonization rate of marshes where sediments have been placed as a beneficial use of dredged material has been studied several times and the results can be applied to both estimates of recolonization rates and the impact of spilled sediments along the pipeline. Most studies have been performed in low (*S. alterniflora*) marsh and generally report that as long as the overburden does not exceed 25-30 cm, smothered vegetation achieves pre-disturbance levels of vegetative cover in 3 to 5 years (Reimold et al. 1978; Cahoon and Cowen 1987, 1988; Burger and Shisler 1983; Ray 2008a, Table 2). This rate is due to the ability of the plants to penetrate the overburden or to colonize it by penetration of rhizomes from the periphery of the deposit. Overburdens greater than 25-30 cm can result in a shift to high marsh or upland species due to the altered elevation of the soil.

Neill and Turner (1987) have examined a number of backfilling operations and concluded that restoration success is a function of marsh type, canal location, age, and structure, and dredge operator performance. Complete replacement of the fill material was a critical factor since that ensured a return to appropriate marsh elevation. Reexamination of the same sites 20 years later Baustian and Turner (2006) also concluded that success was determined by the extent to which the dredged material was returned to the canal. The position of the canal with the marsh was also critical factor: restoration of backfilled canals in intact marshes were more successful than in deteriorating marshes.

A critical issue specific to the floatation method of pipeline burial is the creation of a canal to facilitate access and later maintenance operations. Canals associated with the petrochemical industry have been linked to land loss in Louisiana (Scaife et al. 1983; Bass and Turner 1997) therefore, while dredging of a temporary access canal may be permitted, there will almost certainly be a requirement for backfilling.

Impacts from placement on marsh surface

Laying the pipe directly on the marsh will smother vegetation underneath and compress the soil. The movement of construction vehicles and personnel on the marsh during installation, maintenance and removal will have similar impacts. Sediments may also leak from the pipeline near joints and at the end of the pipe. Coarse materials may accumulate at these points, resulting in pockets of higher elevation. The pipeline can also be expected to shade plants on either side of the pipe and block sheet flow over the marsh. While the total area of impacted marsh is relatively small for short distance pumping, long distance pumping projects will inevitably impact larger areas and to a far greater extent and thus not be effective for restoration of relatively small plots. Otherwise, the damage incurred could offset the amount of habitat being restored. In addition, the time frame during which habitat is impacted differs between short- and long-distance operations. Short-distance pumping projects seldom last more than a few months, thus smothering of the underlying vegetation may not kill the plants and there is the potential for rapid revegetation of the site. During long-distance pumping operations, some portions of the pipeline will remain in place several years, killing the underlying vegetation and requiring far longer periods of time for the plant community to reclaim the site.

Blockage of sheetflow

Perhaps the most insidious impact related to pipeline placement is the potential for blockage of sheet flow over the marsh. Sheet flow, the movement of water over the marsh surface, is essential to marsh ecosystem functioning. It affects both import and export of nutrients and organic materials across the marsh and controls marsh utilization by economically and ecologically important fisheries species (Rozas 1995; Mitsch and Gosselink 2000). Obstruction of sheet flow by pipelines may alter the degree to which an area is inundated and therefore affect composition of the vegetative community. Increased inundation in lower elevation sites may result in undesirable effects since increased submergence appears to significantly decrease survival of *S. alterniflora* (Mendelssohn and McKee 1988; Reed and Cahoon 1992). The pipeline's orientation to the predominate direction of sheet flow and its position in the drainage pattern of the marsh will be of critical relevance to the degree of impact. Even in cases where water can flow around the pipeline (e.g., near creek crossings or where rivulets pass underneath the pipe) sheet flow will be impeded on both incoming and outgoing tides, altering the hydroperiod of the marsh in the immediate vicinity of the pipe. Such an alteration is especially important for fisheries species which rely on the marsh as both a source of food and a refuge from predation.

Both resident fisheries species such as mummichog (*Fundulus heteroclitus*) and grass shrimp (*Palaemonetes* spp.) and nonresident species, especially the juvenile forms of many fishes, crabs, and penaeid shrimps, utilize the marsh surface for feeding and as a refuge from predation (Kneib 1987). Important nonresident fish species include spot *(Leiostomus xanthurus*), Atlantic menhaden (*Brevoortia tyrannus*), Atlantic croaker (*Micropogonias undulatus*), southern flounder (*Paralichthys lethostigmata*), red drum (*Sciaenops ocellatus*), and spotted seatrout (*Cynoscion nebulosus*) (Rozas and Hackney 1984). Other abundant species include Gulf killifish (*Fundulus grandis*) and diamond killifish (*Adinia xenica*) in high marsh, penaeid shrimp (*Penaeus spp.*) in hummocky low marsh, and grass shrimp (*Palaemonetes spp.*), blue crabs (*Callinectes sapidus*), striped mullet (*Mugil cephalus*) and sheepshead minnows (*Cyprinodon variegatus*) in both habitats (Rozas and Reed 1993). Resident species are most abundant in the interior of marshes and nonresidents most abundant near the marsh edge (Peterson and Turner 1994). Both resident and nonresident species tend to move on to the marsh surface as the tide inundates the area and retreat to marsh creeks on the outgoing tide (Kneib 1984; Kneib and Wagner 1994). Even partial obstruction of sheet flow will decrease the amount of time that fisheries species have to utilize the marsh surface, resulting in less feeding time and more exposure to predators. Both of these impacts will lower the amount of fisheries production. Complete obstruction will have even greater impact by eliminating access to some areas of the affected marsh.

Smothering of vegetation and compression of soils

Placing pipelines directly on the marsh surface for a period of several years will also compress the soil. The actual extent of impact will depend on the diameter of the pipe, the combined weight of the pipe and its contents at peak flow, and the compressibility of the soils. Large diameter pipes will obviously cover a larger amount of marsh surface and their additional weight will most likely result in increased soil compression. Likewise, the greater the weight of materials passing through the pipe, the greater the total pressure exerted on the soils and the higher the amount of compression. Determination of the precise extent to which compression will occur at different points along the route of the pipeline will require not only an estimate of the total force applied by the pipeline (e.g., lbs/sq ft) but also direct measures of soil compressibility. The highly organic and mud-rich soils typical of low marshes are more easily compressed than the relatively inorganic soils of high marshes (Knott et al. 1987; Bradley and Morris 1990). Precise information on pipe size, weight, and weight with contents will have to be estimated prior to implementation of pumping operations. Likewise, there is limited information on soil compressibility and direct measurements will be necessary over the projected length of the pipeline.

The presence of the pipe directly on the marsh surface for several years will undoubtedly kill all underlying vegetation and revegetation of affected sites can not begin before the pipe is removed at the end of the project. Presumably, revegetation will proceed at rates similar to those previously discussed . Recolonization rates may also resemble those of naturally occurring disturbances such as the deposition of wrack. Wrack is floating mats of dead or decaying vegetation placed on marsh surfaces during high tides or by storm driven waves. Although wrack mats do not compress the soils they smother the underlying vegetation and are thought to be responsible for development of unvegetated salt pans under some conditions (Frey and Basan 1982). Salt pans may develop after the wrack material decays and the newly barren soils are flooded by high tides. When the flood waters evaporate they leave an elevated soil salinity which is inimical to most plant growth. The recolonization of high marsh after wrack burial varies with species and site-specific parameters (Brewer et al. 1998; Tolley and Christian 1999). Tolley and Christian (1999) report that while *S. patens* and *D. spicata* covered by wrack achieved pre-disturbance levels of cover after one growing season, *Juncus roemerianus* had still not recovered 2 years after burial. Pahl et al. (2003) followed recolonization of a mixed *S. patens* and *D. spicata* marsh that had suffered an oil spill, comparing it with nearby sites that had been experimentally burned to remove the oil and reference (neither oiled nor burned) sites. The oiled-burned site was initially colonized by a sedge (*Schoenoplectus robustus*), but *S. patens* became the dominant cover type within 1 year. Vegetative cover by *S. patens* at oiled and burned sites was equivalent to reference sites within 16 months.

In addition to directly killing the underlying plants and compressing the soils, pipelines may leave long, linear depressions or ruts in the soil. Because of their low relief and low tidal range, marshes of the Gulf coast are especially sensitive to even minor changes in elevation (Gosselink 1984; Reed and Cahoon 1992; Rozas and Reed 1993) and depressions could potentially have impacts that exceed their apparent size. If the ruts are isolated from the nearby creeks they may fill with water during high or storm driven tides resulting in water-logging of the soils. Water-logging in low marsh has an inhibitory effect on *S. alterniflora* due to the accumulation of sulphides in the soil (Mendelssohn and McKee 1988) and can be expected to have effects similar to those reported by Godfrey et al. (1978) for vehicle ruts. Reed and Cahoon (1992) suggest that increased inundation can result in increased resuspension of surface sediments and decreased deposition of organic matter ultimately leading to plant death and erosion of marsh sediments. Since retention of soil particles is directly related to stem density, any disturbance that reduces stem density is also likely to reduce sedimentation and delay refilling of the depression (Gleason et al. 1977). Long linear depressions connected to tidal flow at any point may, in effect, create tidal creeks that may erode, deepen and expand over time due to loss of vegetation.

Water-logging in high marsh can be expected to exacerbate elevated high soil salinities as the water evaporates resulting in formation of salt pans. If the ruts are connected to adjacent water bodies they may promote salt water intrusion and alteration of the drainage pattern. Such impacts are unlikely to be on the same physical scale as those described for ditching for mosquito control but may still contribute to lowered water-tables and increased drainage of the marsh. Numerous authors have noted the association of *S. alterniflora* with mosquito ditches or other areas where creek-side levees are penetrated even in high marsh locations (e.g., Miller and Egler 1950; Redfield 1972; Stout 1984).

Finally, sediments may spill from leaky joints, pipeline breakages or near the discharge points. It can be assumed that these will have similar impacts to those of dredged material placement with the degree of impact being a function of the nature and the depth of the spilled sediments (see previous section).

Shading

Depending on the size and orientation, areas on either side of the pipeline may be shaded potentially resulting in decreased plant growth. Although there do not appear to be any studies specific to shading impacts to marsh vegetation resulting from pipelines, there are several related to dock shading. However, key differences between shading impacts resulting from docks or bridges and those expected from pipelines is the lack of a solid structure elevated above the marsh surface and the relative size of the structure. As a result, a significant proportion of the area under a dock or bridge can be expected to be continuously shaded, while shading from a pipeline will cover a relatively small area and will be intermittent with one side of the pipe shaded in the morning but not the afternoon and the opposite on the remaining side. As a result shading from pipelines is unlikely to result in the same degree of impact as docks or bridges.

Alexander and Robinson (2004) found that stem densities of *S. alterniflora* were 56 percent lower in areas under docks in Georgia salt marshes; a subsequent study reported 21-37 percent reductions in biomass and carbon production in shaded areas (Alexander and Robinson 2006). Individual stems where taller in shaded than natural areas but the difference in size did not offset the decrease in biomass. Sanger et al. (2004) also reported decreased stem densities of *S. alterniflora* in shaded areas under docks in South Carolina. Shading not only affects plant growth but can also impact marsh fauna. Struck et al. (2004) found that when light attenuation under bridges was greater than 85-90 percent densities and diversity of benthic fauna associated with *Spartina* and *Juncus* marshes were 25-52 percent less than unshaded areas.

Placement in waterways

The primary concern with placing the pipeline in marsh waterways is the potential for blocking water movement onto and off of the marsh. Just as placing the pipeline directly on the marsh surface will block sheet flow, blockage of marsh creeks and rivulets would interfere with movement of both materials and organisms between the marsh and adjacent waters. For instance, both resident and nonresident fisheries species move on to the marsh surface on the incoming tide and retreat to marsh creeks on the outgoing tide (Kneib 1984; Kneib and Wagner 1994). Obstruction of these waterways would decrease the amount of time for fisheries species to utilize the marsh surface and increase their exposure to predators. Placing the pipeline on floats might minimize such impacts but could also interfere with boating or shipping activities.

Governmental and environmental organizations with an interest in long distance conveyance issues

As with any project concerned with dredging, wetland, or restoration issues, a wide range of governmental agencies and non-governmental organizations (NGOs) will be concerned with operations involving LDC of dredged material. These include all levels of organization within the U.S. Army Corps of Engineers (e.g., Planning, Operations, Real Estate, Legal) both on the district and divisional levels as well as National Marine Fisheries Service (National Oceanographic and Atmospheric Administration, Department of Commerce), National Resources Conservation Service (Department of Agriculture), U.S. Environmental Protection Agency (including the Gulf of Mexico Program), U.S. Fish and

Wildlife Service, U.S. Geological Survey, and U.S. Minerals Management Service (Department of the Interior). The state of Louisiana agencies concerned with LDC include the Louisiana Department of Wildlife and Fisheries (LDWF), Department of Environmental Quality (DEQ), and LDNR. Within LDNR at least separate divisions are specifically involved: Coastal Restoration, Coastal Engineering, and Lands. In Mississippi the Department of Marine Resources, Department of Wildlife Fisheries and Parks, and Department of Environmental Quality would all be involved to some greater or lesser degrees in any LDC project. Interested parties on the level of local government will vary depending on the precise location of the dredging site, restoration project, and those lands that the pipeline traverses. Parish, county, and city governments would all be participants in project planning. Both national and local NGOs would also take part in project planning, but it is impossible to predict which are most likely to participate without knowing the precise location of the restoration project and path of the pipeline.

Marsh creation issues.

There are two major issues common to all marsh creation projects including those created by LDC of dredged material. The first is how the “success’ or “failure” of the created marsh is defined and whether or not lesson’s learned from previous marsh construction projects are integrated into project design. The second is the likelihood of an “unexpected outcome.”

Streever (2000) has reviewed the relative “success” and “failure” of previous efforts to create salt marshes using dredged material concluding that success in the sense of recreating all the functions of a natural marsh is unlikely due primarily to differences in sediments, elevation, and marsh physiography. Overall, created marshes tend to have lower belowground plant biomass, lower soil organic content, fewer benthic invertebrates (especially polychaetes and crustaceans), and fewer nektonic crustaceans (e.g., grass shrimp) than natural marshes. Comparing the physical characteristics of created and natural marshes in Galveston Bay, TX, Delaney et al. (2000) found that created marshes had higher elevations, more linear edge, and less variable physiography than natural marshes. Also examining created and natural marshes in Galveston Bay, Shafer and Streever (2000) reported no difference in elevation or soils but less unconnected edge, i.e., fewer ponds and flooded depressions in created marshes. Darnell and Smith (2001) came to a similar conclusion about created marshes in the Aransas National Wildlife Refuge. These differences can clearly restrict long-term prospects for a created marsh ever achieving full ecological functioning (Streever 2000), nonetheless recreation of significant elements of marsh function is still possible. Above ground biomass and plant stem densities of created marshes are often not only equal but sometimes greater than natural marshes (e.g., Minello and Zimmerman 1992). Thus created marshes can be expected to provide much of the wave dampening and sedimentation functions critical to adsorbing storm driven wave energies.

Construction of wetlands using LDC will not differ from those created using conventional methods, however, it will still be important for the eventual “success” of LDC marshes to clearly define project goals and the limitations of what can actually be constructed. Design of the wetlands must include careful consideration of the proper elevation, soils and habitat structure (e.g., presence and density of ponds and creeks) to maximize those functions that can be achieved (Streever 2000; Shafer and Streever 2000; Darnell and Smith 2001; Turner and Streever 2002). As previously mentioned, elevation and soils are critical features in the development of marsh vegetative communities. Marshes along the Gulf coast typically have low relief, which when combined with the relatively low tidal range make even minor changes in elevation important in controlling vegetative communities (Gosselink 1984; Reed and Cahoon 1992; Rozas and Reed 1993). The presence and density of creeks and ponds are essential to utilization of the marsh by consumer groups such as fishes and decapod crustaceans as evidenced by incorporation of habitat edge by tidal channels as a component in modern wetland assessment techniques (e.g., Shafer et al. 2002, 2007, Minello et al. 1994; Minello and Rozas 2002).

Darnell and Smith (2001) closely examined shorebird usage of created marshes at Aransas National Wildlife Refuge (Texas) and found that different construction techniques and sediment types resulted in substantially different created habitats. Sites where sediments were predominately sand required periodic movement of the discharge pipe to prevent mounding however even when moved the resulting marsh had a relatively uneven surface. Sites where the sediments contained a lower sand content and the discharge pipe was stationary, marsh surfaces tended to be more topographically uniform. The slopes of constructed sites were steeper than those of natural marshes resulting in altered vegetation and reduced shorebird utilization. Conversely, Brusati et al. (2001), also working in Texas, failed to find significant differences in hydrology, circulation, shorebird utilization or macroinvertebrate densities between created and natural marshes. Clearly differences in construction techniques can have profound effects on the functioning of created marshes.

Turner and Streever (2002, Chapter 7) have summarized many of the problems encountered in previous attempts at marsh creation and place great emphasis on issues related to recreating the appropriate elevation, topography, and site geomorphology. They specifically recommend that future marsh creation projects consider:

1. Suitability of the sediment.
2. Absence of high wave energy conditions or if unavoidable the use of appropriately scaled protective structures.
3. Avoidance of sensitive habitats (e.g. submerged aquatic vegetation or shellfish beds).
4. Avoidance of altering either water flow or sediment transport regimes.
5. Protection of natural shorelines.
6. The quality of the underlying sediments and the likelihood of soil compaction.
7. Availability of plant propagules.
8. Recreation of natural geomorphology.
9. Accessibility of the restoration site to construction equipment (e.g., graders).
10. Incorporation of natural features such as creeks and ponds.

Unexpected outcomes.

“Unexpected outcomes” are also a concern in the creation of coastal wetlands. An excellent example is the case of Elkhorn Slough in California (Van Dyke and Wasson 2005). Elkhorn Slough is a tidal estuary along the Central California coast that has been highly modified by diking of wetlands and modification of the estuarine inlet. When circulation was restored to previously diked wetlands the tidal prism was changed and the environment changed from depositional to erosional. As sediments were eroded, the fauna of the slough changed from a mud-based assemblage to a sand-based assemblage. As a result, a well-meaning effort to restore wetlands actually damaged the habitat rather than repair it. Before restoration is implemented by LDC of dredged material or any other technique it is essential that the ultimate effect of physical alteration of the area be carefully analyzed.

A second "unexpected" outcome is the probability of invasive or non-target species becoming established either at the restoration site or on marsh damaged by pipeline operations. The two species of most concern to salt marsh restoration in Louisiana are introduced strains of the common reed *Phragmites australis* and the semi-aquatic rodent *Myocaster coypus*, better known as nutria. While *Phragmites* occurs naturally in this area, invasive strains are also present which can quickly colonize a site and may crowd out preferred species (Saltonstall 2002; Howard et al. 2008). Nutria, introduced to Louisiana in the 1930s, can heavily impact marshes during feeding virtually denuding some areas. Kinler et al. (1998) report that nearly 24,000 acres of Louisiana marsh was damaged in 1998 alone. The LDWF estimates in excess of 21,000 acres were damaged each year between 1999 and 2003, although by 2007 this value was down to approximately 9,000 acres (LDWF 2008). Close monitoring and preventive measures were necessary to minimize or eliminate these types of "unwanted" outcomes.

Damage calculations

Construction of new marshes utilizing LDC will unavoidably create some degree of damage to the natural marshes over which the pipeline is laid and construction equipment must be moved. Careful planning and care in performing the construction can minimize such damage; however, it is important that it also be counterbalanced by creation of a sufficient amount of new marsh in addition to that planned for the creation project in order to completely replace any lost marsh functions.

A number of rapid assessment methods are available for assessing damage to wetlands of which the two best known are the Hydrogeomorphic Approach (HGM) and Wetland Value Assessment Methodology (WVA). HGM is founded on a classification of wetland types developed by Brinson (1993) and assesses wetland functions based on a series of hydrologic, geomorphic, and other structural indicators. Indicators related to different ecological functions are combined to form functional capacity indices. HGM guidebooks describing assessment of most Gulf coast tidal wetlands have already been developed (Shafer et al. 2002, 2007) (http://el.erdc.usace.army.mil/wetlands/guidebooks.html).

WVA was developed specifically for use in Louisiana under the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA). It employs a habitat suitability index approach to assess habitat support of fish and wildlife and has been widely applied within the state. An example of the Swamp Community (WVA) Model can be found at http://ees.uno.edu/restoration/Benefits%20Workshop%20Sept%2004%20Final%20Report.pdf.

Another potentially useful tool is Habitat Equivalency Analysis (HEA). HEA is not a functional assessment method, but a technique for estimating the amount of constructed or restored habitat necessary to counterbalance damages supported by the National Oceanic and Atmospheric Administration (NOAA 1977), HEA has already been used for freshwater streams, seagrass beds, and coral reefs (Chapman et al. 1998, Fonseca et al. 2000, Milton and Dodge 2001) and has been accepted as a basis for settlement in Federal court (USA vs. Melvin A. Fisher et al. 1997).

HEA calculations require estimates of the total area of lost habitat, the total loss in services supplied by the damaged habitat, and the rate at which created habitat will develop (Ray 2008b). Total lost services are estimated from the extent of damage to the resource and the loss in service that occurs between the initial damage and when the restored or replaced habitat becomes fully functional. Calculations incorporate the concept of discounting from economic theory, which assumes that a greater value is An example where HEA was used to scale salt marsh restoration can be found in Penn and Tomasi (2002). In this case, an oil pipeline at Lake Barre, LA, spilled more than 6,500 barrels of crude oil over 1,700 ha of marsh. Most of the area was only lightly oiled and was expected to rapidly recover. Damage assessment determined that blue crabs, shrimp, and squid were impacted while waterbirds and shorebirds birds either experienced direct mortality or toxicity due to oiling. Models from French et al. (1996) were used to estimate losses in aquatic and avian fauna and the amount of salt marsh necessary to replace these losses was estimated from known levels of production and trophic level transfer. It was determined that a total of 1.5 ha of marsh was required to offset faunal losses and an additional 6 ha to replace the damaged marsh.

A more in depth listing and description of wetland assessment techniques can be found in Bartoldus (1999). Likewise, the Ecosystem Management and Restoration Information System (EMRIP) offers a comparison of wetland techniques online at http://el.erdc.usace.army.mil/emrrp/emris.

7 LDC Project Design (Borrow Area/Pipeline Corridor/Placement Site)

The design of an LDC project will be influenced by all system components illustrated in Figure 1:

- Strategic objectives
- Governing laws, regulations, and policies
- Dredging equipment
- LDC equipment
- End-of-pipe- handling
- Potential environmental impacts
- Economics

and their respective interactions relative to the borrow site, pipeline corridor, and placement site conditions. The experiences gained from past, current, and near-future wetlands restoration projects by the various agencies (e.g., USACE, LDNR, NRCS, NOAA, and NMFS) using pumped dredged material in restoration programs (CWPPRA, BUDMAT, Dedicated Dredging Program, etc.) provides very valuable information and knowledge applicable to the design, construction, and maintenance of LDC projects.

The major differences between these conventional types of wetland restoration projects (ones that involve pumping less than 16 km (10 miles) and future LDC projects are implications imposed by the longer pumping distances and the significantly larger volumes of sediment that would have to be transported and placed to make LDC feasible. As per Khalil and Finkl (2009), there is a need for very large quantities (hundreds of millions of cubic meters) of sediments for coastal and wetland restoration in Louisiana. Suhayda et al. (1991) presented a 20 year scenario as an example of how funding might be used to stabilize Louisiana's wetland loss by pumping 80 ,000,000 cu m/year (104,000,000 million cu yd/year) sediment through a pipeline-based infrastructure; and predicted that after 16 years, no-net-loss of wetlands could be achieved. In the reconnaissance-level study by CH2M HILL (2006), three pipeline alternatives were evaluated with sediment delivery rates that ranged from approximately 13,700,000 to 36,700,000 cu m/year (18,000,000 to 48,000,000 cu yd/year) over a project life span of 50 years.

These types of sediment volume magnitudes have never been dredged and transported before for coastal wetlands restoration (over the spatial and temporal scales necessary to significantly impact the loss rate in Louisiana) anywhere in the world.

The following summary update on dredging to construct coastal wetlands in Louisiana under the Breaux Act and other programs was presented by Mr. Gregory Miller (USACE Memphis District) at the Long-Distance Pipeline Transport of Dredged Material to Restore Coastal Wetlands of Louisiana Workshop (Hales et al. 2003).

> “To date, 142 projects have been authorized to restore 130,000 acres at a total cost of $1.3 billion. Techniques and project types undertaken include: (a) confined cell wetland creation, (b) unconfined deposition for wetland creation, (c) barrier island restoration, and (d) diversion channel construction.
>
> The Breaux Act has constructed 15 projects utilizing hydraulic dredging for habitat restoration. Twenty-three million cu yd have been hydraulically dredged, and 3,100 acres have been created or benefited at a cost of $100 million. These projects include (a) Bayou LaBranche wetland creation (1994, 2.5 million cu yd, 203 acres, 70 percent land and 30 percent water), (b) Atchafalaya sediment delivery (1998, 720,000 cu yd, 185 acres, marsh created during construction as part of larger plan to reopen two river passes), (c) Big Island mining (1998, 3.4 million cu yd, 922 acres, marsh created during construction as part of larger plan to redirect river flow), (d) Barataria Bay Waterway wetland restoration (1999, 75,000 cu yd, 9 acres, resulted in shallow open water not marsh in cell but overflow material enhanced adjacent wetlands), (e) Lake Chapeau project (1999, 500,00 cu yd, 260 acres, problems with dikes, borrow material, and access corridor, positive end result), (f) West Belle Pass headland restoration (1998, 1.75 million cu yd, 184 acres, problems with containment dikes and access corridor damage), (g) dustpan dredge demonstration project (2002, 220,000 cu yd, 20 acres, operational experiment rather than marsh creation project), (h) Holly Beach sand management project (2002, 1.75 million cu yd, 300 acres of beach and dune habitat restored, only pure beach nourishment project built by CWPPA), (i) Sabine Refuge marsh creation (2002, 1 million cu yd, 200 acres, post-construction dike degradation, plantings, and trenasse cutting), and (j) West Bay

> sediment diversion (under construction, 1.6 million cu yd, 100 acres to be created during construction of river diversion channel)."

Coastal wetlands restoration projects conducted under CWPPRA are specifically required to be evaluated as to how well it achieves long-term solutions to arresting coastal wetlands loss. This requirement necessitated the development of a monitoring program to adequately assess the effectiveness of coastal restoration projects as described by Steyer et al. (1995):

> "Monitoring is more critical to the success of CWPPRA than to traditional mitigation programs because large spatial scales and uncertainty regarding the status of the wetlands at any given time preclude the use of repeated trial and error, which is allowed in the Clean Water Act, Section 404, process. Instead, monitoring plans prepared by this Monitoring Program will be designed with the expectation that some projects will be less effective than others to facilitate learning from all projects, regardless of their success. This monitoring philosophy is a departure from traditional monitoring programs in which documenting effectiveness of a project is the goal of monitoring, and understanding why and how a project was effective (or not) is of minor importance. Thus, the monitoring philosophy behind the CWPPRA Monitoring Program is based on adaptive management (Boesch et al. 1994) and feedback monitoring (Gray and Jensen 1993). Consequently, the Monitoring Program not only detects unsuccessful projects, but also provides other CWPPRA working groups with a basis for improved project designs and operation.
>
> Determining the effectiveness of CWPPRA projects in creating, restoring, protecting, and enhancing coastal wetlands in Louisiana is a daunting task because spatial and temporal variability cause differences between reference and project areas that hinder traditional experimental design and statistical techniques (Underwood 1994). The temporal variability and large spatial variability across the Louisiana coastal zone in wetland loss rates not only reduce the value of traditional experimental design and statistical techniques but also require a monitoring approach with a high degree of flexibility if the effectiveness of management actions under different environmental conditions are to be detected (Boesch et al. 1994). Thus, the Monitoring Program is designed not only to detect unsuccessful projects, but also

> to provide a basis for improved project designs and operation. The data generated from the Monitoring Program will be used to refine decision criteria and improve the level of accepted decision error. This will improve the quality of results and confidence in management decisions."

Results of these monitoring programs and adaptive management reviews (including lessons learned and recommendations) for CWPPRA projects is available at http://www.lacoast.gov/projects/list.asp. As presented by Mr. Gregory Miller (USACE New Orleans District) at the Long-Distance Pipeline Transport of Dredged Material to Restore Coastal Wetlands of Louisiana Workshop (Hales et al. 2003), lessons learned include the following:

- Clear project goals must be formulated, and design efforts should be goal-oriented.
- Containment versus confined disposal should be determined based on whether it is desired to have the material flow to other areas or be restrained from entering other habitats.
- Sediment characteristics must be compatible between the borrow area and the disposal region.
- Wetland creation site characteristics must be ascertained for the present and for many years into the future.
- It is critical to manage the construction properly, and to enforce all contract specifications.

Borrow site/pipeline corridor/placement site

These three components (borrow site, pipeline corridor, and placement site) establish the physical environment in which the LDC project must be designed, constructed, and maintained relative to the other components (in Figure 1) previously discussed. While optimization of future LDC projects will depend upon the integration and interaction between the wide variety of these system components, one of the critical aspects will involve, given project goals, how well the dredging components mesh with respective pipeline transport and placement components with regard to maximizing production rates, while minimizing costs and environmental impacts. In Chapters 3, 4, and 5 of this report, fundamental descriptions were presented on:

- Different dredge types to identity general production characteristics in the context of their subsequent influences on subsequent LDC and placement operations.
- Long distance hydraulic transport and LDC design considerations and equipment.
- End-of-pipe sediment management methods and equipment used to place slurry.

The next section, these three components and their respective interactions between each other will be discussed relative to overall LDC design.

Borrow site

Borrow site (or source of the sediment) aspects that must be considered in the design of an LDC project include:

- Volume of sediment available.
- Temporal availability of sediment.
- Spatial availability of sediment.
- Sediment physical characteristics.
- Sediment chemical characteristics.

Various locations have been suggested by various authors for sediment sources including several locations on the Mississippi River (e.g., Pass au Loutre), Horseshoe Bend on the Atchafalaya River, Ship Shoal, ebb shoal deltas offshore of Barataria Bay, Houma Navigation Canal, and former distributaries of the Mississippi River (alluvial deposits such as Bayous Delarge, Grand Caillou, Terrebonne, and Pointe au Chien) (Coastal Planning & Engineering, Inc. 2004) (CH2M HILL 2006; Khalil and Finkl 2009; Pyburn & Odom, Inc. 1993; Woodward-Clyde Consultants 1991; Suhayda et al.1991; etc.) The availability of sediment is considered to be a limiting factor in the design of large scale coastal restoration programs in Louisiana (CH2M HILL 2006). While determination of sediment volumes and respective physical and chemical characteristics of sediment sources are becoming more complete as the number of geotechnical surveys and studies (e.g., for CWPPRA, USACE, and CIAP projects) increase, uncertainty about its availability still exists.

Regarding uses of the sediment form these potential sediment sources, CH2M HILL (2006) states that “Restoration of barrier islands will require a certain size range of sediments, whereas marsh restoration can use a wider size range of sediments. Silt-sized particles, while not useful for barrier island restoration projects, may be used for marsh creation projects. A sediment budget that quantifies prospective sources (both riverine and offshore) needs to be developed, so that realistic restoration goals can be made that account for the limited availability of sediment.”

Khalil and Finkl (2009) describe the long history of exploration that Louisiana has for offshore sand resources, but, because present day exploration for sand and mixed-sediments is guided by project-specific protocols, write that:

> “The most important intent of this paper is to inculcate an attitudinal change in the perception of approaches to build wetlands and barrier islands. The general practice is to propose and plan restoration projects and then start looking for sand resources. Given the paucity of sand resources due to the deltaic sedimentological and geomorphological setting, there is a need to change this decades-long practice. Instead of looking at project specific needs, it is posited that a programmatic approach be adopted to effectively manage the demand for large sediment volumes needed to restore sustainability in the Louisiana coastal zone. This approach should be followed by assigning priorities to ensure proper and justified (scientifically and economically) distribution of sediment resources to different projects. An essential component of this proposed protocol is the implementation of a plan for sharing sand resources, part of a rational management scheme for utilizing sand resources, to avoid conflicts of interest (e.g., sand wars) and a procedure to arbitrate conflicts (e.g., Finkl and Kreumpel 2005). A better and effective regional sediment management plan has the potential to significantly reduce the cost. Under the overall aegis of Regional Sediment Management (RSM), a Louisiana Sand Management Plan (LASAMP) would aid in a systematic approach to restoration in Louisiana.
>
> Broadly speaking, RSM refers to the optimum utilization of various sediment resources (littoral, estuarine, and riverine) in an environmentally effective and economical feasible manner. RSM changes the complexion of engineering activities within the systems from the local or project-specific scale to a broader regional scale which is defined by the natural sediment processes. By managing the sediment on regional scale, RSM aids in making the best local project decisions within the

context of a regional plan that maximizes overall benefits and/or reduces total cost. Basically, RSM in a geological regime comprises sediment deposits and its inventory on regional scales, encompasses understanding of regional sediment budgets of the system along with records of dredging activities in the region. In Louisiana, the RSM effort is being conducted through the following initiatives:

- Evaluation and inventory of various types of sediment\sand resources
- Development of a regional sediment budget
- Development of a Dredged Material Placement Policy (DMPP) or Beneficial Use of Dredged Material Program (BUDMAP) to maximize nearshore benefits from sediment placement and a monitoring program to supply scientific reasoning for the selection of the dredged material placement, and
- Include all the above data into a GIS database."

The LASAMP, as proposed by Khalil and Finkl (2009), would better coordinate various coastal restoration projects and would address the following aspects:

- "Provide a broader perspective to best manage sand resources by viewing the projects regionally than treating projects individually and taking advantage of previously unidentified synergistic effects.
- Cater to the demand for large volumes of sand needed for numerous proposed projects to restore sustainability in the Louisiana coastal zone.
- Address key resource issues in terms of the volume of sand that might realistically be available, how to allocate access to the available sand, and what are the environmental tradeoffs with large-scale dredging of the sand resources. (Total Projects vs. Total Sand Requirement).
- Set up priorities to ensure proper and justified (scientifically and economically) distribution of sedimentary resources to different projects.
- A rational management scheme for optimum utilization and sharing of sand resources should be introduce by adopting Borrow Area Management (BAM).
- Avoid any conflict of interest among various interested parties and arbitrate conflicts of interest.
- Ensure proper environmental safeguards or trade offs.

- Minimize costs by providing organized resource information on an engineering scale in a GIS database (LASARD) for planners/ engineers.
- Delineate sand deposits that should be off limits, restricted or reserved so that no oil and gas pipelines and infrastructures should be laid.”

While design optimization of an LDC system will require a thorough understanding of sediment supply physical characteristics and quantity, the efficient operation of this system will require a guaranteed sediment supply, but the ability to predict “renewable” sediment sources’ replenishment capacities is not yet well understood. Besides USACE experiences with using sediment from the Mississippi River for wetlands restoration, and preliminary work being conducted for the CIAP Mississippi River Long Distance Sediment Pipeline Project, a current CWPPRA project is designed specifically for dredging sediment from the river for wetlands restoration as well as increasing understanding of the river’s ability to replenish its sediment supply. This project, the Mississippi River Sediment Delivery System Bayou Dupont (BA-39), described in Louisiana Coastal Wetlands Conservation and Restoration Task Force (2009a):

> “involves dredging sediment from the Mississippi River for marsh creation and pumping it via pipeline into an area of open water and broken marsh west of the flood protection levee.
>
> The proximity of the project to the Mississippi River presents a prime opportunity to employ a pipeline delivery system that will utilize the renewable sediment resources from the river to restore and create wetlands. Unlike most marsh creation projects that involve borrowing fill material from adjacent shallow water areas within the landscape, this project will utilize river sediment, thus minimizing disruption of the adjacent water and marsh platform. The Bayou Dupont project represents the first example of pipeline transport of sediment from the river to build marsh as a CWPPRA project. Limited, but successful, experience has been gained by USACE through beneficial use of dredged materials. Results from this project should serve to demonstrate the value and efficacy of greater use of pipeline-conveyed river sediments for coastal restoration.
>
> The U.S. Environmental Protection Agency, working through the Louisiana Department of Natural Resources, is coordinating engineering and design of the project. While this work is ongoing,

> related technical workshops are being conducted to refine sediment transport and placement issues."

To date, one of the most recent, comprehensive, and published. investigations on LDC relative to sediment sources is the "Phase 2 Reconnaissance-level evaluation of the Third Delta Conveyance Channel Project" by CH2M HILL (2006). The Third Delta Conveyance Channel (TDCC) concept involves creating a new delta between the Atchafalaya River and Mississippi River deltas by sediment carried through a constructed conveyance channel that would follow the eastern slope of the natural Bayou Lafourche levee system and split into two channels near Raceland. In a Phase 1 workshop, one of the primary conclusions "was that a major component of any alternative to the TDCC would include pipeline conveyance of dredged materials from the Mississippi or Atchafalaya rivers or from offshore sources in the Gulf of Mexico coast" CH2M HILL (2006). One of the Phase 2 report's primary objectives was to develop project alternatives that could accomplish the same basic ecosystem restoration goals as the TDCC: the creation and maintenance of land and a sustainable diverse ecosystem in the Barataria and Terrebonne Estuaries. After TDCC performance and land building capacity were determined (based on results of analysis of performance measures and evaluation criteria), three pipeline conveyance alternatives were developed in this study with respective land-building goals of 5, 10, or 15 square miles/year for a 50-year project life. The sediment sources and transport corridors to achieve these objectives are shown in Figure 38. The distance from the centroid of each restoration area identified in report to (generally) two sediment sources was calculated to facilitate the screening of these respective restoration areas and to develop costs CH2M HILL (2006).

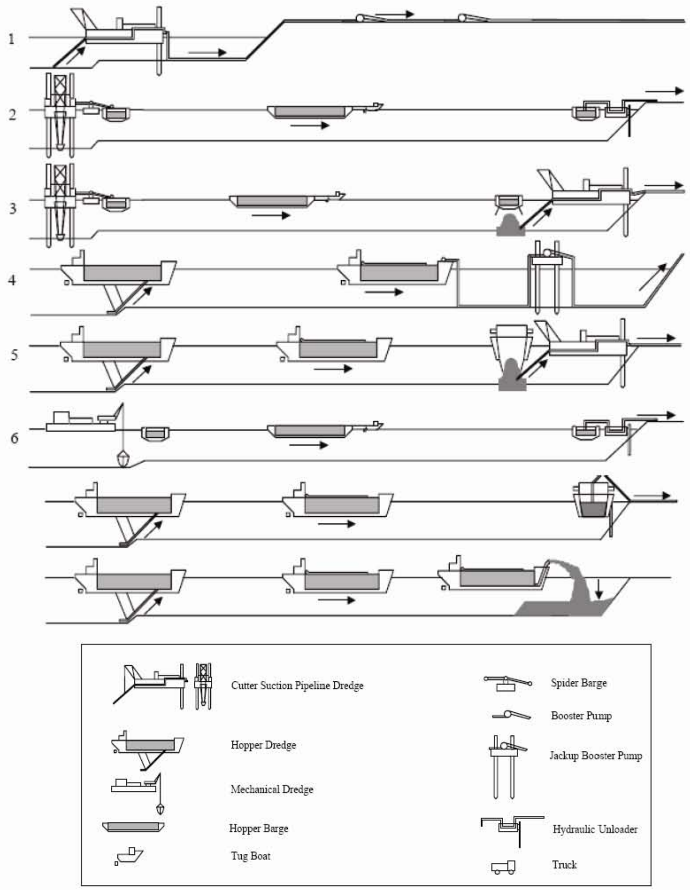
The following factors can influence the selection and operation of specific dredging, LDC, and placement equipment and method(s) used to perform an LDC project in relation to the other system components (strategic objectives, economics, environmental impacts, etc):

- Location of both the borrow (dredging) and placement sites and distance between them.
- Physical environment of and between the borrow and placement areas.
- Quantities and physical layout of material to be dredged.
- Physical characteristics of material to be dredged.
- Dredging depth.

- Type of dredges available.
- Type of LDC equipment available.
- Method of placement.
- Production required.
- Environmental requirements.
- Type of contract(s) used.

From an LDC system conceptual design standpoint, the dredged sediment can either be single-handled or re-handled. A “single-handled” LDC project transport methodology would involve a “singular” excavate, transport, and placement process such as dredging with a cutterhead pipeline dredge with booster pumps where energy is applied to the sediment in a relatively continuous manner as shown in Figure 39-1 (modified from Randall and Koo 2003). Re-handling methodologies involve the additional, discrete, application (or applications) of energy to the sediment to complete the entire transport circuit (as illustrated by the remaining examples in Figure 39). While all the re-handling examples in Figure 39 involve the use of pumps, additional forms of transport energy could be applied in other forms such as transport by clamshell bucket (e.g., unloading a barge with a clamshell bucket on a crane, etc.). Chisholm and Clausner (1991), Pyburn & Odom, Inc. (1993), and CH2M HILL (2006) evaluated several of the transport scenarios in Figure 39 involving single and re-handling transport components. All of the transport scenarios presented by Woodward Clyde Consultants (1991) involved some barge transport and hydraulic unloading (hydraulic unloading process in Figure 39-2) that was called a Mobile Marsh Base Station (MMBS).

Borrow site location relative to the beginning of the LDC pipeline, and the physical environment between them, will influence the selection of dredging equipment and its respective operations. As previously described, different types of dredges can safely operate in different types of site-specific conditions (sheltered or exposed waters, high passing traffic volume, dredging depths, etc.) and are efficient within a given set of parameters (sediment type, transport distance, etc.). The size of the borrow area itself (length, width), in conjunction with sediment quantities and its physical layout (e.g., sediment thickness) can also impact dredge type(s) and size(s) selection, and respective dredging production rates and composition of sediment transported.



1. Cutterhead dredge excavates sediment at the source location and pumps the sediment through a pipeline with the aid of booster pumps to the placement area.

2. Cutterhead dredge excavates sediment at the source location and loads the sediment into barges via a spider barge. Barges are towed to the location of a hydraulic unloader. The hydraulic unloader reslurries the sediment and pumps the sediment through a pipeline directly to the placement area.

3. Cutterhead dredge excavates sediment at the source location and loads the sediment into barges via a spider barge. The barges sail under their own power or are towed to the nearshore location and place the sediment in a rehandling location. A second cutterhead dredge re-excavates the sediment and pumps it to the placement area through the pipeline.

4. Hopper dredge removes sediment at the source location and sails to location of floating pipeline. Hopper dredge connects to floating pipeline and pumps sediment through pipeline directly to placement area with aid of booster pump.

5. Hopper dredge removes sediment from source location and sails to rehandling location where it places the sediment on the water bottom. A cutterhead dredge re-excavates the sediment at the rehandling location. The cutterhead dredge pumps the sediment to the placement area through a pipeline.

6. Mechanical dredge excavates sediment at the source location and places sediment in barges. Barges are towed to the location of a hydraulic unloader. The hydraulic unloader reslurries the sediment and pumps it through a pipeline to the placement area.

7. Hopper dredge excavates sediment from source location and sails to the location of the pipeline pickup. The hopper dredge then connects to the pipeline and pumps the sediment through a pipeline to the beach without a booster pump.

8. Hopper dredge excavates the sediment from the source location, sails to a rehandling location, and pumps the sediment through a nozzle (rainbowing) onto the rehandling station.

Figure 39. Illustrations of sediment handling and re-handling scenarios using different dredging equipment combinations (modified after Randall and Koo 2003).

Riverine operations

A variety of different dredges and support equipment configurations have been proposed to dredge sediment from the rivers (Mississippi, Atchafalaya, etc.) and introduce into the LDC system. As per the Pyburn & Odom, Inc. (1993) report, cutterhead dredges would be used to provide the major supply of sediment, hopper dredges (even though they do not provide a relatively continuous supply of sediment like a pipeline dredge) would be used in high energy waters and places where pipeline dredges pose a navigation hazard, and mechanical dredges utilized mainly as auxiliary plant to construct dikes provide precision of sediment placement, or rehandle sediment on large scale dredging projects. An example of a hopper dredge in riverine operations is The Pilottown Anchorage Project conducted in 2006 where a hopper dredge was used for wetland restoration in coastal Louisiana.

In addition to transport by barges, conveyor belts, and trucks at various transfer points, this report also analyzed other dredge unloading configurations illustrated in Figure 39 (including the barge and hydraulic hydraulic unloader) to tie into and utilize abandoned oil and gas pipelines as trunk (or main) lines.

In CH2M HILL (2006), the riverine operations would involve the use of sediment traps, that would be mined by cutterhead, hopper, or dustpan dredges. As per CH2M HILL (2006):

> “The construction of sediment traps on the Mississippi River is considered an integral part of the pipeline conveyance alternative. Considering both the finite quantity of sediment available for coastal restoration and the fact that most (approximately 90 percent) of the annual sediment transport in the Mississippi River is carried as suspended load, sediment traps should increase the total annual amount of sediment available for dredging from the river by promoting settling of suspended sediments. Hydraulic and sediment transport modeling will have to be conducted to optimize the design and placement of the sediment traps.”

A sediment trap is described in the CWPPRA project entitled “Mississippi River Sediment Trap (MR-12)” currently in the engineering and design status (Louisiana Coastal Wetlands Conservation and Restoration Task

Force 2009b). A sediment trap is basically a large pit dug into the river bottom designed to capture sediment transported along the bottom by the river's current. This sediment would be subsequently mined with hydraulic dredges and pumped into the wetlands for restoration purposes. Hydraulic modeling (USACE New Orleans District 2001) suggests that a trap 6.4-km (4-miles) long, 457-m (1,500-ft) wide, and 20-m (65-ft) deep would optimize sediment deposition (Louisiana Coastal Wetlands Conservation and Restoration Task Force 2009b). It is currently envisioned that sediment mined from the trap would be used to restore wetlands immediately adjacent to the river, but this approach could potentially supply LDC projects with the prerequisite large volumes of sediment on the temporal basis that they require, and the "stationary" aspect of the traps would better facilitate "less temporary" LDC infrastructure.

Depending on a sediment trap's position relative to the navigation channel and if a cutterhead dredge or dustpan dredge was used to mine it, a pipeline may be required to transport sediment across the navigation channel. If so, navigation interests (i.e., river pilots) may raise serious concerns about this pipeline crossing the navigation channel and/or having a hydraulic pipeline dredge working in the channel compared to a relatively more mobile hopper dredge.

If a submerged line was used to cross the channel, a very robust anchoring system would be required to ensure that the pipeline would remain in place. Another option would be to install a "permanent" pipeline crossing similar to the ones regularly used by the oil and gas companies that would be buried underneath the river bottom to ensure stability, but an uncertainty concerning this configuration would be that, in the possible event of plugging the pipeline with sediment (e.g., incase of an emergency shut down), what technologies could be used and procedures be conducted (e.g., backflushing) to unplug the line? Another option to address both the submerged line and the dredge mobility concerns would be to dredge with a modified dustpan dredge using a flexible floating discharge line.

Modified dustpan dredge

This concept was successfully demonstrated in the CWPPRA project entitled "Dustpan Maintenance Dredging Operations for Marsh Creation in the Mississippi River Delta Demonstration (MR-10)" as reported in Welp et al. (2004). This report presents the demonstration results of the dustpan dredge *Beachbuilder* (Figure 40) using a flexible discharge at the

Head of Passes/Southwest Pass on the Mississippi River in June 2002. Though non-self propelled and operated by (anchor) wire ropes, the Beachbuilder's propulsion/advance capabilities were augmented for the demonstration by the addition of a tug boat. Dustpan dredges equipped with sufficient propulsion, a flexible-discharge floating hose connected to a hard point, and sufficient pumping capacity potentially have the mobility required for safe passage of vessel traffic and can economically pump dredged material outside the channel for wetlands restoration purposes.

Figure 40. Dustpan dredge Beachbuilder and flexible floating line (insert) used to effectively dredge entire width of Mississippi River navigation channel.

CH2M HILL (2006) describes a standard riverine dredging operation that would mine sediment and deliver it via LDC to wetland restoration sites basin wide that would include:

- "Sediment traps constructed in the rivers to promote settling of suspended material and increase the amount of material available for coastal restoration projects.
- Dredges and support equipment, including cutter-head, hopper, or dustpan dredges.
- Riverside fixed connection facilities for dredge off-load and a pipeline conveyance system, constructed in existing pipeline ROWs that intersect the Mississippi or Atchafalaya Rivers.

- Booster pumps, the number of which will be determined by the distance between the hard point and the restoration site.
- Construction equipment at the restoration area to handle and advance the pipeline and earth-working equipment to assist in achieving design elevations at the restoration site."

The "fixed" connection facilities would be used for offloading with dredges that would use a flexible pipeline connected to a hardpoint to pump sediment into the LDC system (as a pumping out connection the hopper dredges, and as a connection point for the pipeline dredges.

Pyburn & Odom, Inc. (1993) describe how the Mississippi River typically experiences stages of low-water for 6 to 8 months a year, and that this is when the USACE usually conducts its navigation dredging in areas such as Southwest Pass, along with the commercial dredges that mine point bars for sand. Because the hydraulic dredges do not work during higher river stages due to higher velocities and depths that exceed normal dredging depths, the authors suggest that a rehandling basin be set up to stockpile sediment during the dredging season to maintain a "continuity of sediment supply" during times with no dredging. The rehandling basin could be set up in a suitable location such as the water or land side of the levee, and the sediment dewatered and stockpiled in diked containment areas (confined disposal facilities) that, if properly designed, would provide protection from high water.

A rehandling concept was also utilized in the USACE Philadelphia District's (1969) Long Range Spoil Disposal Study, but the primary project objective was to empty CDFs instead of restoring wetlands. This concept consisted of using a semi-portable rehandling unit (an endless chain bucket dredge) that would be moved from CDF to CDF as required. "Its purpose would be to empty out available disposal areas and inject the dredged material into a long pipe line. The material would then be pumped to a distant repository through the line with successive booster stations. The rehandling installlation would be sized to accommodate the amount of material removed from the Delaware annually. It would pump 24 hr/day at the lowest velocity which would keep the required amount of material in suspension, in order to keep power requirements and wear at a minimum" (USACE Philadelphia District 1969).

The use of rehandling basins could also increase the flexibility of materials handling in different dredging operations where sediment could be stockpiled prior to final deposition. Advantages of rehandling basins include (Pyburn & Odom, Inc. 1993):

- Segregation of materials.
- Centralized disposal.
- Temporary storage for various concurrent dredging projects.
- Allow sediment from deeper draft hopper dredges to be rehandled for transfer to shallower draft barges or to a pipeline.

The segregation of materials could be accomplished by several possible methods. By constructing the rehandling basin as a multi-celled CDF, different types of sediment could be placed in different confinement cells as it is delivered to the rehandling basin. Another method would consist of using the phenomena of differential settling (coarser grained sediment like sand falls faster in the water column than finer grained sediment such as silts and clays) where the coarser grained material would deposit closer to the pipeline discharge, and finer grained sediment deposit father away. The ability to selectivity transport and deposit different sediment types (that will of course depend on the range of sediment types available for stockpiling) at different times may facilitate sediment placement strategy and operations optimization by matching up (as described by Pyburn & Odom, Inc. 1993) the desirability of select sediments for select applications as following:

> "For the purpose of marsh creation, sediment consisting primarily of silts and sands may allow areas of marsh to be constructed without confinement dikes required for sediment composed of finer grained materials containing relatively greater amounts of silts and clays. Some clays and organic materials probably will be needed to enhance vegetative growth. Elimination of confinement dikes would assist in reducing costs. Therefore, for marsh creation, silty sand would be the most suitable material to use. For restoration of existing deteriorating marsh, finer grained sediments and some organic materials would be preferable."

A potentially major advantage of a rehandling basin would be the improved ability to control slurry solid's concentration consistency. As previously described, solids concentration in the discharge directly from hydraulic dredges can vary widely. By using technology (like that utilized at the Bayou Bonfouca Superfund site (Taylor 1995) and in conventional mineral processing) to control the slurry solids concentration, optimization of LDC design and operation may be enhanced. As per Wilson et al. (2006):

> "For the operator of a slurry system, it is important to understand how the system will respond to variations in the properties of the slurry fed to it. It is also important for the designer to appreciate fully the implications of variations in particle size, concentration and throughput. As for all handling and processing operations, design must reflect the range of variability which must be anticipated. For slurry system, this implies finding the economic balance between controlling slurry consistency on the one hand, and on the other operating the pipeline under conditions which are not optimal but which can accommodate variations. For long-distance freight pipelines, the dominant capital and operating costs are usually associated with conveying. Therefore much effort is devoted to preparing and controlling slurry properties. At the other extreme, short in-plant conveyors and dredging systems may have to be designed for wide and sometimes uncontrollable variations in solids size and throughput. Nevertheless, in our experience some industries using hydraulic transport can make significant savings by recognizing that the stability and efficiency of conveying operations – particularly the energy efficiency, can be improved by limiting operating variability."

The evaluation of innovations (equipment, methodologies, contracts, etc.) and subsequent use of the well performing ones, should, wherever and whenever possible, be embraced by those who are involved in planning, designing, constructing, and monitoring projects in order to optimize LDC for wetlands restoration on a scale that has never been conducted anywhere in the world before. Other innovative extraction/transport technologies (besides just dredges) exist that may merit consideration in the quest to more efficiently remove sediment from the water body or function as rehandling equipment. These technologies include, but are not limited to, eductor (jet) pumps, submersible pumps, and technologies such as Streamside System® Collectors™. For example, hopper dredges could be used to dredge sediment from the Mississippi River and instead of reducing their production from the additional time that would be required to pump out their loads for subsequent LDC, they could dump their loads in a specially designated (and perhaps constructed) area, and one or more these alternative innovative technologies be used to rehandle the sediment for subsequent LDC (basically a variation of Figure 39-5 without the hydraulic pipeline dredge). Another example would be to gradually collect the river's bedload as it is naturally transported downstream, and pump this material to shore. The "track records" of these technologies range from proven performance in numerous projects to preliminary results from limited, small scale field trials.

Eductors (jet) pumps

Eductors (jet pumps) are hydraulic pumps with no moving parts, relying instead on an exchange of momentum to entrain the slurry (Richardson and McNair 1981). They have been used for sand bypassing at inlets as an alternative to conventional dredging for reducing channel shoaling and to reduce beach erosion since the early 1970s, and have been used with varying degrees of success (Clausner 1990). They operate by using a supply (motive) water pump to provide high pressure flow at the eductor nozzle. As the jet contacts the surrounding fluid, momentum is exchanged in the mixer as the jet slows while it accelerates the surrounding fluid, entraining additional fluid into the jet. As the surrounding fluid is entrained by the jet, it pulls in additional fluid from outside the eductor (Figure 41).

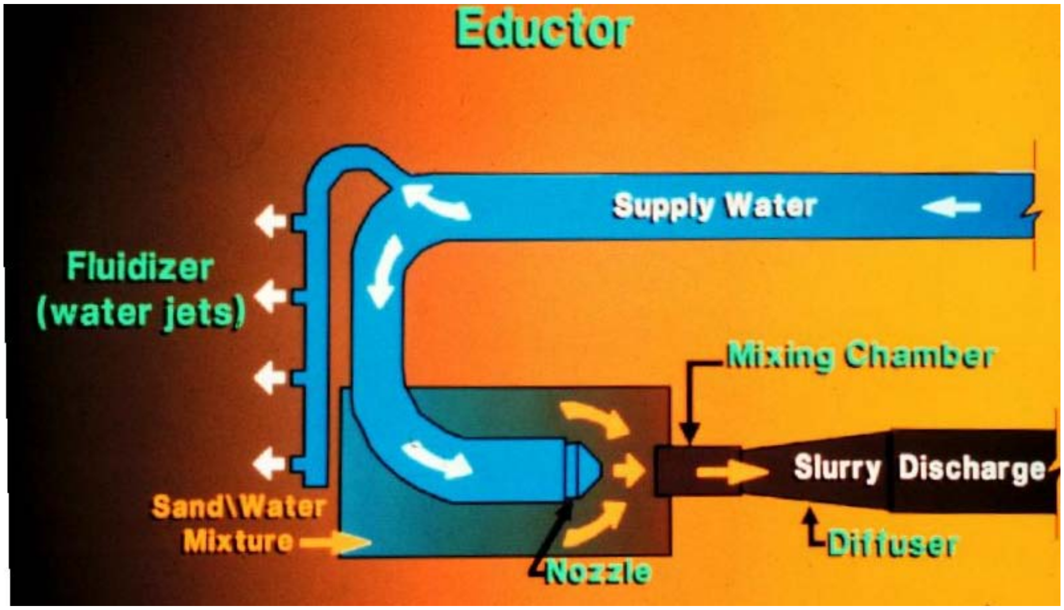


Figure 41. Eductor (jet) pump hydraulic operating principal.

Placing an operating eductor in saturated sand allows it to bypass a sand/water slurry (eductors do not perform well in consistent fine-grained materials, i.e., compacted clays). A booster pump maybe required in the discharge line to increase hydraulic head to efficiently pump the required distance. A conceptual illustration of a simple eductor bypass system is shown Figure 42. One advantage of eductors over conventional centrifugal pumps is that they are essentially immune from blockages in the discharge line. A brief explanation is that as the discharge line starts to clog, the pressure against which the eductor is working increases. This reduces the amount of material the eductor is entraining, thus reducing the potential for clogging the pipe. This reduces the amount of material the eductor is entraining, this reducing the potential for clogging the pipe. Eductors can also be buried in sand and, with rigid supply and discharge pipeline,, are able to excavate a crater above it by excavating sand beneath it (variation of Figure 42) (Richardson and McNair 1981. Disadvantages of the eductor are that it requires a separate motive water pump and water supply, and that the eductor can be susceptible to debris, particularly sticks and logs (Clausner et al. 1992).

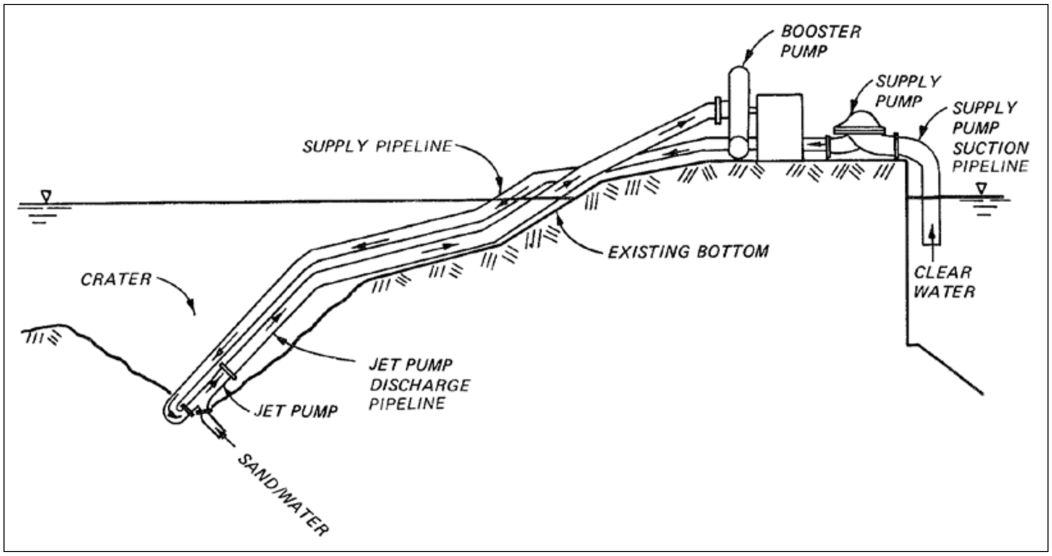


Figure 42. Side-view of simple eductor (jet) pump bypass system (source: Richardson and McNair 1981).

Figure 43 shows an eductor (with and without shroud) installed at Indian River Inlet, DE, sand bypassing plant in 1990. This bypassing plant uses a single eductor deployed from a 135-ton crawler crane with a 37-m (120-ft) boom to mine the up-drift fillet in the surf zone (Figure 44). Between February 1990 and August 1991, this plant bypassed over 153,000 cu m (200,000 cu yd) of sand and successfully performed its mission. The supply (motive) water was fed by a 340 hp pump providing 126 m (415 ft) of head rated at 158 liters/sec (2,500 gpm). This eductor has a 6.3 cm (2.5 in.) nozzle with 15 cm (6 in.) mixing chamber and averaged 153 cu m/hr (200 cu yd/hr) discharged through an 280 mm (11 in.) pipe (Clausner et al. 1992).

Fluidization systems

In the past, research on fluidization of sand at tidal inlets and harbor mouths has been undertaken to use fluidization for maintenance of channels (where fluidized shoaling sand is directed out of the channel) and for use in sand bypassing where fluidized shoaling sand is directed toward the jet or submersible pump (Weisman et al. 1996). These efforts have only consisted of laboratory and limited field trial demonstrations. The fluidization process consists of water being injected into a granular medium to cause the grains to lift and separate, then (gravity) flow down an elevation gradient (Figure 45a). The design objective for a fluidization system is to create a trench of a given cross-section and length (Figure 45b) that removes the shoaling sand from the channel, or extends the range of a fixed bypassing plant as illustrated in Figure 46. A significant problem experienced with this technology in the field demonstrations was that when the fluidizing system was not active, sand would enter inside the fluidizing pipes and subsequently clog up the line.

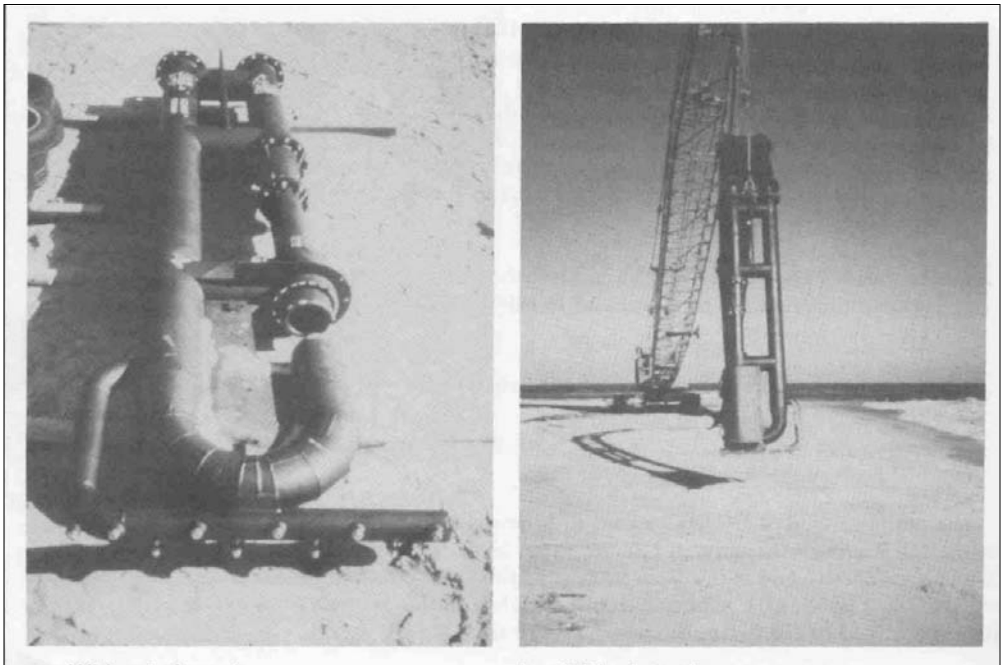

a. Without shroud b. With shroud

Figure 43. Indian River, DE, eductor.

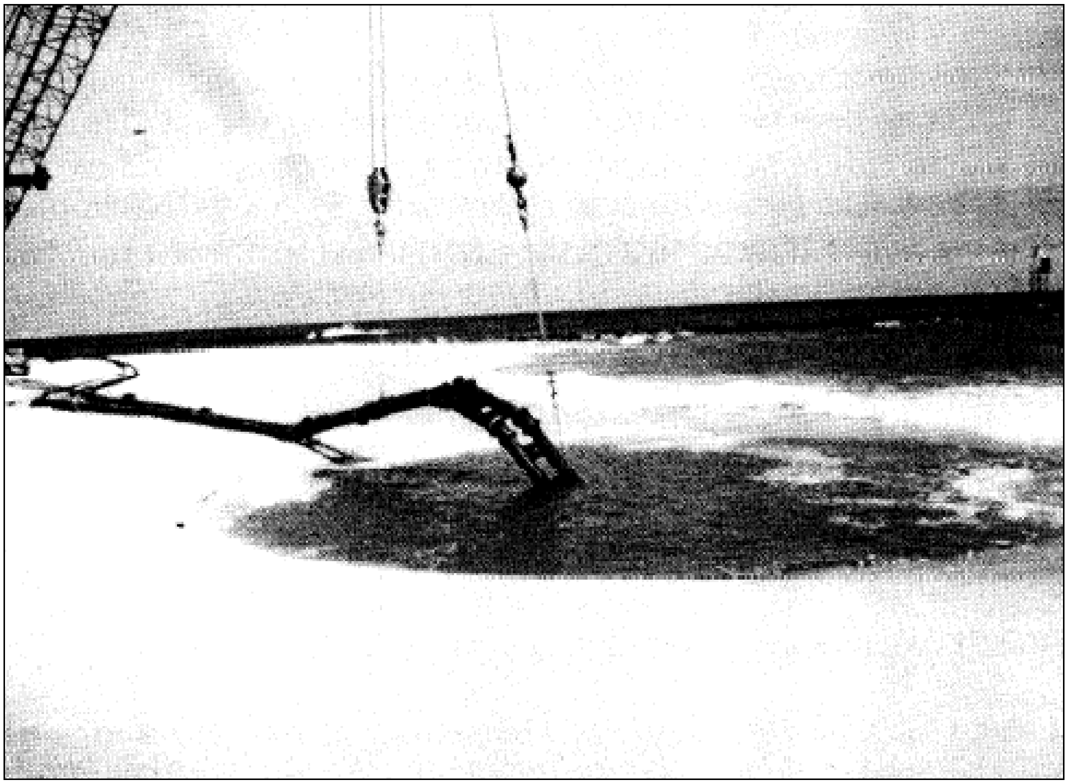
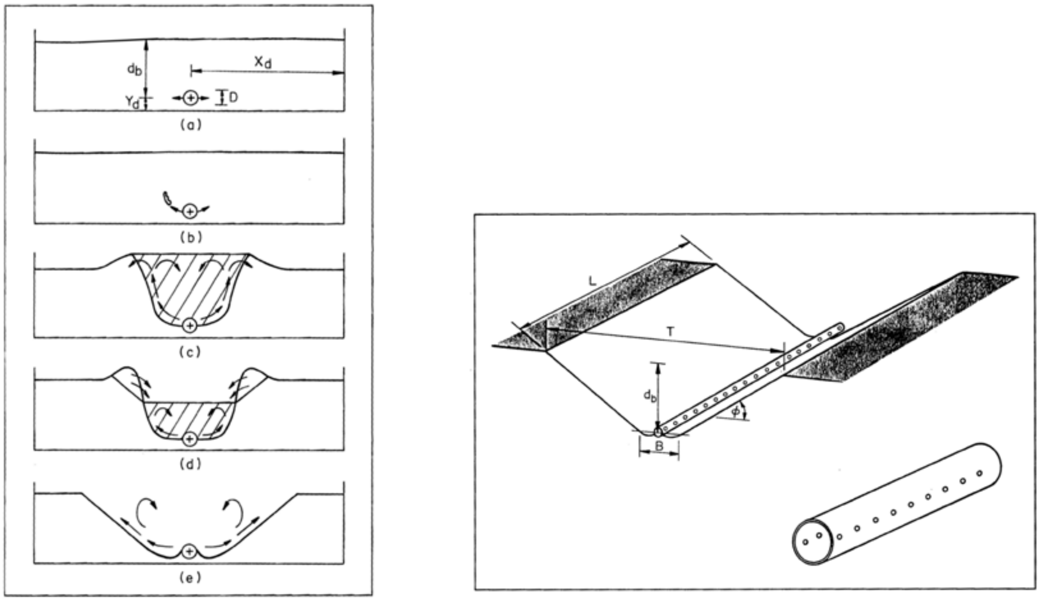


Figure 44. Indian River, DE, eductor in operation.



(A) (B)

Figure 45. (A) Five stages of fluidization: (a) free fluidization, (b) immediately prior to incipient fluidization, (c) full fluidization, (d) summary removal during full fluidization causing side slumping, and (e) jet erosion following complete slurry removal. Hatched area shows a fluidized zone, (B) fluidized trench (source: Weisman et al. 1996).

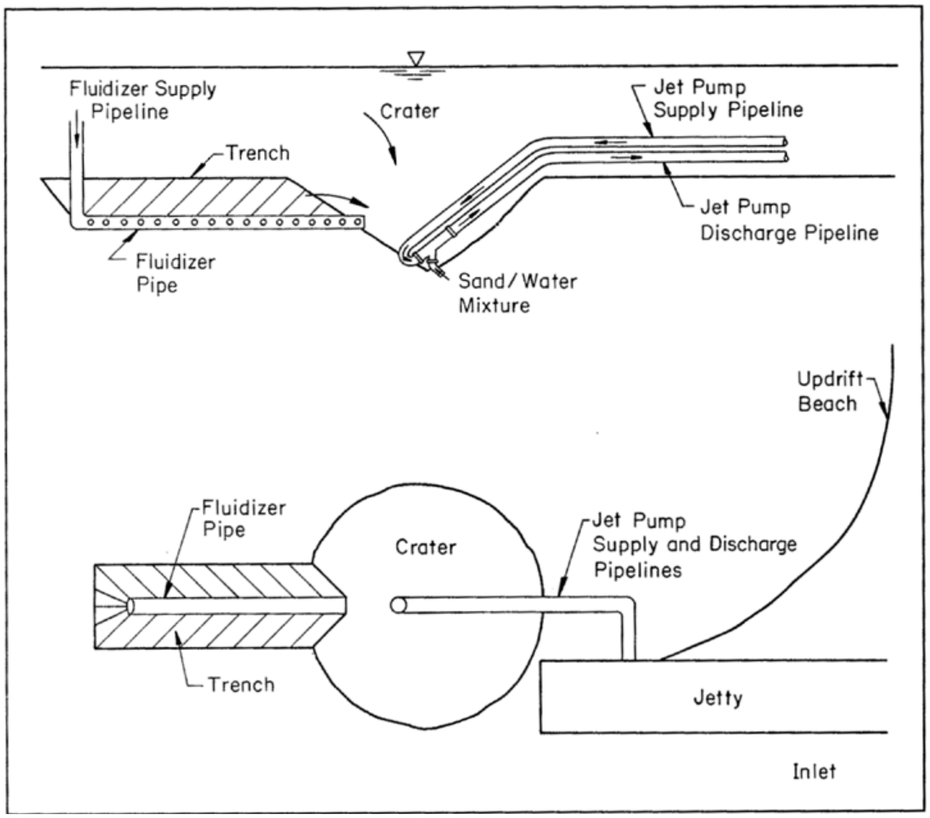


Figure 46. Fluidizer pipe used in conjunction with a fixed slurry pump; hatched area indicates fluidized zone (source: Weisman et al. 1996).

Submersible pumps

Submersible centrifugal pumps are typically single-stage vertical pumps with discharge diameters that range from 100 to 300 mm (4 to 12 in.) (Figure 47). Pump sizes are usually based on discharge-line diameters. Submersible pumps differ from conventional dredges in that the submersible pump is placed directly in the material to be removed. Submersible pumps are powered by hydraulic or electrical motors, usually requiring a diesel power source for the hydraulic pump or a generator. The power requirements for most of the submersible pumps used in dredging applications are in the 50- to 190-kw (70- to 250-hp) range. Some submersible pumps have an external agitator on the end of the impeller shaft that assists the material flow into the pump. In addition, an option to add a jetting ring or small cutterhead to improve material flow to the impeller is available on a number of submersible pumps.

Figure 47. Submersible pump operating without discharge hose connected (source: Javeler Construction).

The pumps range from approximately 1 m (3 ft) up to 2.5 m (8 ft) in height and weigh from under 500 lb to over 4 tons. They can be deployed from various platforms such as at the end of a crane or the boom of a backhoe. Submersible pumps (depending on the deployment method) can be easily maneuvered into areas of limited access such as when dredging locks in navigation structures.

In a Louisiana project involving the removal of a buried pipeline and returning the marsh back to its natural condition, a submersible pump was used as a re-handling technology. The pump was inserted into a transfer hopper that was being fed with “dry” sediment by a backhoe via a conveyor belt (Figure 48). Water was added to the transfer hopper to refluidize sediment in order for the submersible pump, in addition to four booster stations, to transport the sediment a maximum distance of 5.5 miles to the far end of the trench. Sediment was pumped into the trench as the old pipeline was removed (working from the far end back toward the re-handling station). The final step of the operation was to plant grass (personnel communication, Richard Binning, Javeler Construction).

Figure 48. Submersible pump immersed in a transfer hopper that's being loaded with sediment via a conveyor belt operating with water jets (source: Javeler Construction).

A primary advantage of submersible pumps over eductors is that they do not require a clean water source. In coastal inlet sand-bypassing operations, eductors are often combined with booster pumps to optimize production and efficiency and to allow the discharge to be pumped from one to several thousands of feet down drift. Submersible pumps typically used for bypassing operations often have higher discharge pressures than eductors and therefore may not require booster pumps, depending on the distance the material must be pumped. One disadvantage of submersible pumps is that they tend to dig vertical-sided holes. This operating characteristic can be a particular problem in cohesive material because it makes the pump susceptible to collapse of the hole, which can bury and choke the pump and may result in the loss of the unit. Most submersible pumps are not designed for burial and self-starting unlike an eductor, where the water supplied under pressure provides sufficient energy and dilution water to the eductor. Clean fine sand is the optimum material that submersible pumps can transport.

Tests were conducted by the U.S. Army Engineer Research and Development Center (ERDC) with different types of submersible pumps to investigate production in various types of debris (Clausner et al. 1992). One of the pumps with a 255 mm (10 in.) discharge achieved average production rates of 335 cu m/hr (440 cu yd/hr) in clean sand, and 215 cu m/hr (285 cu yd/hr) in sand with wood debris.

Streamside System® Collectors™

Streamside Systems® has developed innovative environmental restoration technologies that include sediment/bedload removal technologies (Collectors™) intended to remove bedload sediments for various applications. These applications include improving environmental conditions for habitat improvement for fish spawning or endangered mussels, reduction in pond and reservoir sedimentation by removal of bedload at the mouths of tributary streams, sediment bypass systems for coastal inlets, and maintenance of navigation channel depths.

In Figure 49, a Collector™ is shown installed in a stream, and Figure 50 shows an illustration of a 30 ft urethane-coated steel Collector™. This equipment was installed on the streambed and anchored. As bedload sediments move downstream over the Collector™, it drops through the screen into a hopper and the system can be passive siphon cleared, or actively pumped. A laboratory flume study was conducted by Lipscomb et al. (2005) to evaluate the efficiency of one of these bedload Collectors™ by determining the percentage of total sediment load and bedload it could remove from sediment-laden flow under various hydraulic conditions. Results from this Collector™ installed in a flume using different flows and median sediment grain sizes ranging from 0.5 to 1.3 mm, indicated capture efficiencies ranging from 99 to 54 percent. As per the manufacturer (personnel communication with Mr. John McArthur, President, Streamside Systems), the sizing of the grate/hopper assembly (both dimensionally and grate screen sizing) is scalable and must be designed for any specific application (e.g., the illustration of the 30 ft urethane coated steel collector that is currently scheduled to be installed in the Fountain Creek Project in Pueblo, CO). Subsequent field deployments have been, and are currently being, conducted for verification of results and visual validation of the Colorado State University controlled flume test facility results such as the Fountain Creek Project in Pueblo, CO (EPA 2009).

Figure 49. A bedload Collector™ installed in a stream (courtesy of Streamside System®).

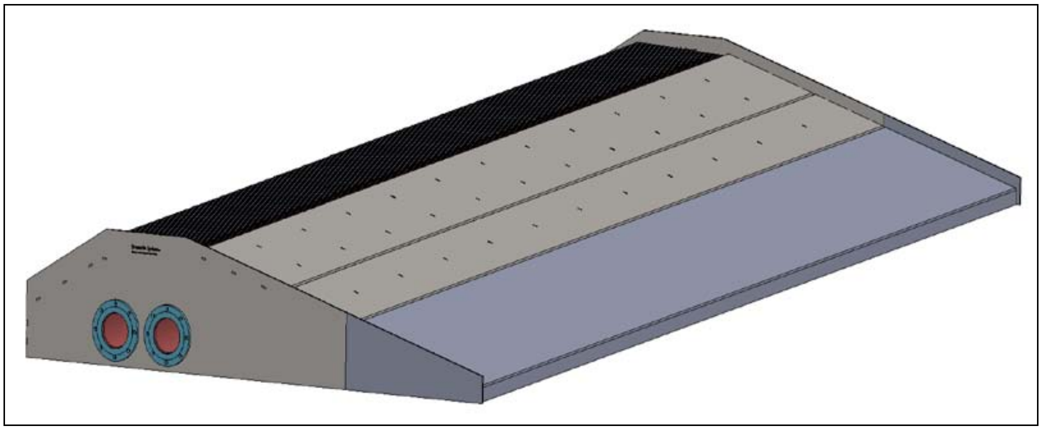


Figure 50. Illustration of a 30-ft-long erethane-coated steel bedload Collector™ (courtesy of Streamside System®).

Offshore operations

Offshore operations would include similar considerations as riverine operations, but there are significantly different considerations and limitations posed by the more energetic hydrodynamic environment and bathymetry. There is also concern (as described in the environmental effects section) regarding the environmental impacts of using offshore sediments (containing pore water with salt contents) for fresh water wetlands restoration (CH2M HILL 2006; Khalil and Finkl 2009; Hales et al. 2003; Pyburn & Odom, Inc. 1993; Woodward-Clyde Consultants 1991).

Chisholm and Clausner (1991) discuss various aspects of offshore operations in their evaluation of U.S. dredging equipment for its ability to effectively mine Ship Shoal, a large sediment body lying south of the Louisiana coast in water depths of 10 to 30 ft. Shallow depths, both in the borrow area and transport path, and the perspective long pumping distance between borrow area and placement site, posed some of the major limitations. Sand mining with (existing) different types of equipment used in different manners that were analyzed (Chisholm and Clausner 1991):

- "Hopper dredge transporting material to a single point mooring. The dredge then pumps the material through the single point mooring buoy and submerged line to shore.
- Hopper dredge bottom dumping material in shallow water as its draft allows. A pipeline dredge can then pump the material ashore.
- Pipeline dredge pumping material directly ashore. Boosters may be required.
- Pipeline dredge attached to a spider barge filling scows. Scows are towed to shore where they may be unloaded with a barge unloader or dumped.
- Bucket dredge filling scows which are towed to shore.
- Sidecasting dredge filling scows which are towed to shore."

Chisholm and Clausner concluded that existing dredging equipment (at that time) was not ideally suited for this project and it appeared that the most suitable piece of equipment would be a large hopper barge with a superior long-distance pumping ability. The authors also concluded that, while small hopper dredges that could bottom dump their loads for subsequent re-handling by pipeline dredges was also a viable alternative, "if the scope of the project were sufficiently large and of long duration, more suitable, innovative dredges could be tailored to support this use at a potentially lower unit cost."

CH2M HILL (2006) report that that all three major dredge types (cutterhead, hopper, and dustpan) could be used in offshore operations conducted outside the barrier island chains in Terrebonne and Barataria, but because these operations would be more susceptible to inclement weather, the dredges annual number of operating days would be reduced. Due to Ship Shoal's difficult operating environment for spud-mounted, or jackup mounted dredges attempting to load moored barges, Woodward-Clyde Consultants (1991) estimate that weather-related downtime could be as much as 20 percent of the time and in the context of the project proposed, would result in "unpredictable interruptions that would magnify costs throughout the system." Chisholm and Clausner (1991) estimated that large cutterhead dredges (discharge pipe diameters of 685 mm (27 in.) and greater) strongly constructed, in good repair, and operating on a anchor/cable (Christmas tree) positioning system could operate in seas of up to 5 ft, and based on wave hindcasting, that the dredge would experience 17 percent down time due to weather while hopper dredges would only experience 4 percent reduction.

Pipeline corridor

Pipeline corridor aspects that must be considered include:

- Location(s) of sediment source(s).
- Location(s) of dredged material placement area(s).
- Lands, easements, and ROWs.
- Oyster leases.
- Environmental resources (e.g., wildlife habitats).
- Topography and bathymetry.
- Presence of access channels.
- Presence of oil and gas pipelines.
- Physical obstructions (levee protection, railroads, etc.).
- Duration of pipeline life.
- Use of existing infrastructure.
- Synergy with other wetlands restoration projects.

These aspects relate to the design, construction, and maintenance of the slurry pump/pipeline system (as previously discussed), and, in turn, will impact the environment (as previously discussed).

The CH2M HILL (2006) report assumed that all the pipeline corridors (Figure 38) would be installed on existing ROWs. To determine these corridors, the study conducted a reconnaissance-level analysis of performance measures and evaluation criteria based on a majority of aspects listed above for three pipeline conveyance alternatives that were developed with respective land-building goals of 5, 10, or 15 square miles/year for a 50 year project life.

Coastal Planning & Engineering (2004) presented pipeline corridor aspects regarding advantages and disadvantages of long- and short-term pipeline installation and operation, and safety and operational concerns involving potential pipeline crossings in the Mississippi River (discussed later in Chapter 8).

Placement site

Aspects of dredging and transportation of slurry have been discussed in preceding chapters. This section will present information on aspects related to placement of the dredged sediment at the end of the pipeline. Dredged material placement must be able to create and nourish wetlands (that includes land-bridge restoration), expand chenier ridges, augment existing "spoil" banks and other features with higher elevations to be used as a structural element to create specific features (e.g., wooded habitat), fill/plug/isolate canals, and create shoreline protection features (e.g., offset, segmented, foreshore dikes). Large-scale concept restoration proposals for: (1) the creation and maintenance of land and a diverse, sustainable ecosystem in Barataria and Terrebonne estuaries are discussed in CH2M HILL (2006), (2) four severely degraded areas of the Louisiana coast are presented in Reed (2004), and (3) across the entire Louisiana State in Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority (1998). In order to achieve restoration objectives on the scale of these concepts, spatial and temporal coordination for the dredging, transportation, and placement of millions of cubic yards of sediment over decades will be required.

A general description of sediment placement in wetlands was presented by Pyburn & Odom, Inc. (1993) as follows:

> "Potential projects can consist of creation of new marsh in shallow open water or restoration of existing deteriorating broken marsh. Deposition of sediment to create new marsh differs from that required to introduce sediment into existing deteriorating marsh. For

> deteriorating marsh, sediment needs to be distributed in a manner that is more similar to sheet flow from floodwaters that distribute sediment over broader areas and in thinner layers. In comparison, sediment to create new marsh needs to be distributed in a manner that is more similar to a crevasse or break in the natural levee of a river whereby channelized flood waters distribute sediment over smaller and more concentrated areas and in greater thicknesses to build new marshland in shallow open water where waves and currents also contribute to the distribution of sediment. Marsh vegetation grows within the intertidal zone, to which initial deposition of sediment must settle. In general, coarser sediments are more suitable for marsh creation, whereas finer sediments are more suitable for marsh restoration.

The area of sediment deposition must be examined as to its suitability to receive sediment. Environmental considerations need to be taken into account such as impact on fish and wildlife and the existence of commercial shell fishing such as oyster leases. Physical characteristics need to be considered such as bottom soil composition, consolidation rates of dredged material, depth of water, tidal range, patterns of water flow, nutrient availability, and the proximity of any area available for marsh creation or restoration in relation to the discharge point from the (abandoned) pipeline."

Two fundamental placement approaches exist relative to end of pipeline: (1) placement of sediment and advance (add pipe), and (2) placement of sediment and retreat (remove pipe). These approaches can involve the use of a singular trunkline (main pipeline of the slurry transport system), or branchlines stemming out from the trunkline.

An aspect that should be considered in any of these placement configurations is the potential detrimental effects on nesting birds, waterfowl, etc., during placement, as illustrated by the experiences gained during the "Dustpan Maintenance Dredging Operations for Marsh Creation in the Mississippi River Delta Demonstration (MR-10)" (Welp et al. 2004). After approximately 7 days of pumping sediment to restore wetlands at the Head-of-Passes, several least tern and American avocet nests containing eggs were discovered on the placement site. The nests had been constructed some distance from the active placement point and were not being disturbed, but the USACE New Orleans District decided to terminate the grading operations, along with the dredging operations to preclude any damage to the nests. Although imposing environmental windows is one potential solution to the problem, use of bird startling measures, as presently incorporated in many dredging operations in Louisiana, may represent a more practical approach. In either case, this rapid colonization by the least terns and American avocets, as well as other species, is an aspect that needs to be considered for future dredging projects of a similar nature (Welp et al. 2004).

As described in Chapter 5, there are primarily four placement techniques: traditional hydraulic pipeline placement, thin-layer placement, slurry placement, and scrape-down placement. For some traditional hydraulic pipeline placement techniques that require containment structures, dike design is necessary for construction of reliable confining structures where existing (competent) lateral containment structure features such as "spoil" banks, natural ridges, barrier islands, etc., do not exist. These fundamental placement techniques, or variations of them, will be used to deposit sediment in areas with different site-specific conditions that will impact placement operations.

Woodward-Clyde Consultants (1991) describe examples of the trunkline and branching configurations used in conjunction with a barge pumpout methodology (called a Mobile Marsh Base Station) similar to that illustrated in Figure 39-2 and 39-5.

> "The two pipeline network configurations considered are: (1) a straight 5,000-ft-long pipe with the last 1,000 ft equipped with opposed nozzles spaced every 120 ft, and (2) a branched pipeline network in which a 5,000-ft mainline branches into telescoping laterals (number to be determined) which conduct water to the discharge points at least 5,000 ft downstream from the pump station. The branching network would provide for coverage of a larger area without moving the network. Design calculations were carried out assuming that a 2,500 cu yd barge would need to offload in a 4-hr period. Assuming a 30 percent porosity (conservative range of uncompacted soils) in the dredged materials, this represents a solids volume of 1,750 cu yd. At a design volumetric solids concentration of 15 percent, this represents a slurry flow rate of 21.9 cu ft/sec.
>
> For the purposes of this preliminary design, it is assumed that 600,000 cu yd of material will be delivered to the base station

> (5,000 cu yd per day on two 2,500 cu yd barges, for 120 days). At a design application of sediment equal to 2 ft, the marsh area to be rebuilt in the 4-month period will be 600,000 cu yd x 27 cu ft/cu yd + 2 ft = 8.1 million sq ft, or about 186 acres. With the constraint of offloading two barges per day, of primary concern, apart from the hydraulics of the system and costs, will be the speed with which any portable system can be relocated for the next "set".

Woodward-Clyde Consultants (1991) describe the selection of pipeline used in these configurations as follows:

> “The pipe materials considered were: steel, high-density polyethylene (HDPE), PVC, and fiberglass. PVC and fiberglass were eliminated from consideration due to their thrustblocking and anchoring requirements under the range of conditions considered. The marsh offers insufficient strength for anchoring PVC or fiberglass, hence they could be subject to excessive bending stresses resulting from pipe motion. HDPE (16-in. SDR 7.3) is both heavier and more expensive than 16-in. O.D., 0.188-in. wall thickness API 5L Prime Line Steel Pipe (rated at 840 psi). The HDPE weighs 41.34 lb/ft and costs approximately $25 /ft, while the steel weights 31.75 lb/ft and costs approximately $12/ft. However, installation costs for fused HDPE are much less than for welding steel ($25/ft quoted for 16-in. steel, compared to an estimated $6.25/ft for 16-in. HDPE). The speed with which HDPE can be fused (1 joint per hour) compared with steel (1 joint per 5 hours) suggests also that HDPE could be more suitable for this application.”

These two configurations (straight pipe and branched pipe network) are described by Woodward-Clyde Consultants (1991) as follows:

> “Configuration 1: Straight Pipe
>
> The configuration of a straight pipe system would be as shown in Figure 51. With a nozzled section 1,000 ft long (ten opposed nozzle pairs, 100 ft apart; shown schematically in Figures 52 and 53), and the nozzles throwing the sediments laterally 125 ft on either side of the pipe, an area 1,000 x 250 ft or 250,000 sq ft would be covered with one setting of the nozzles. To place an average 2-ft depth of sediment over this area would this require 500,000 cu ft of sediments, or 7.4 barge volumes. This would require moving the nozzles section every fourth

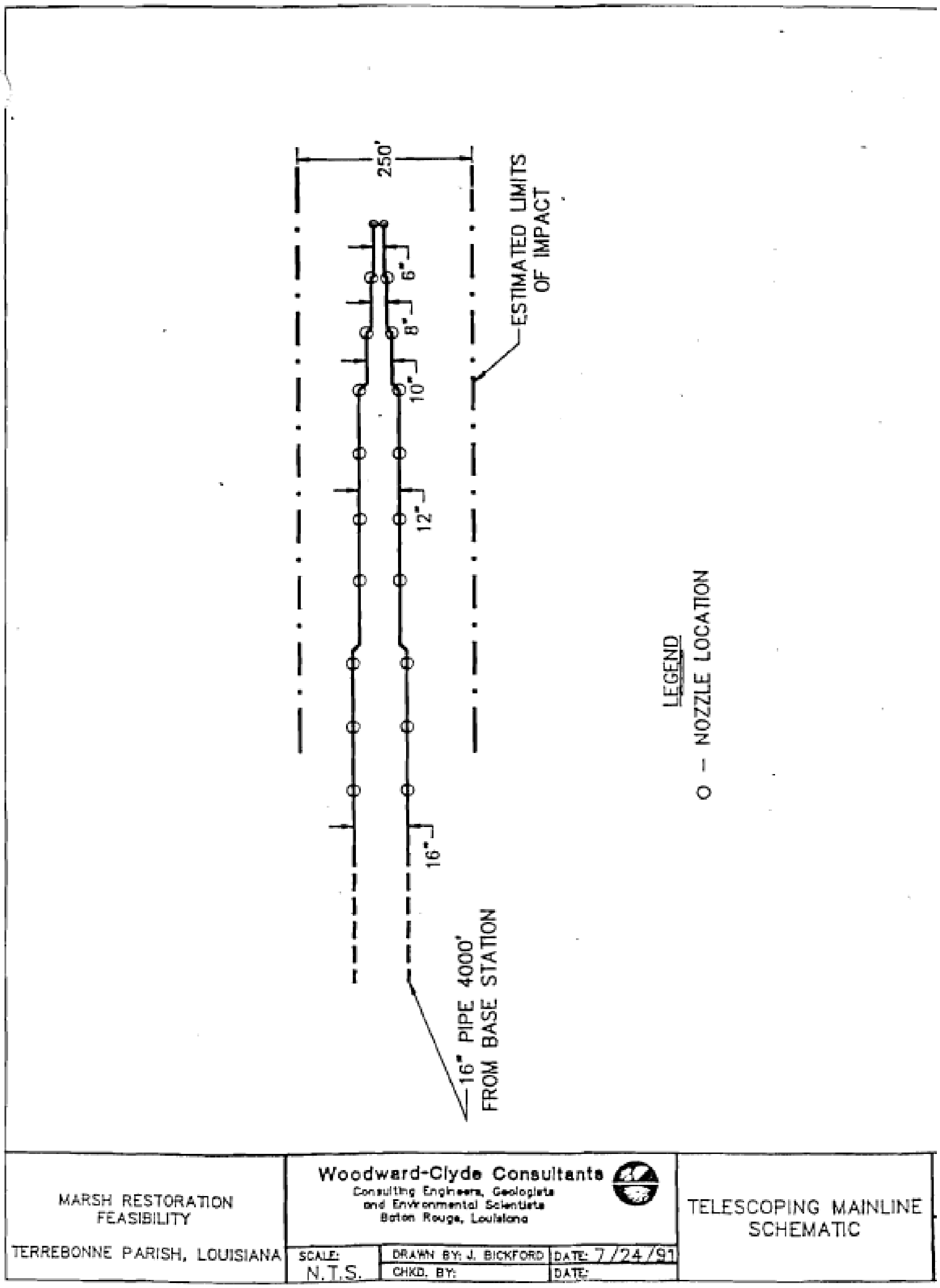


Figure 51. Configuration of straight pipe system (source: Woodward-Clyde Consultants 1993)

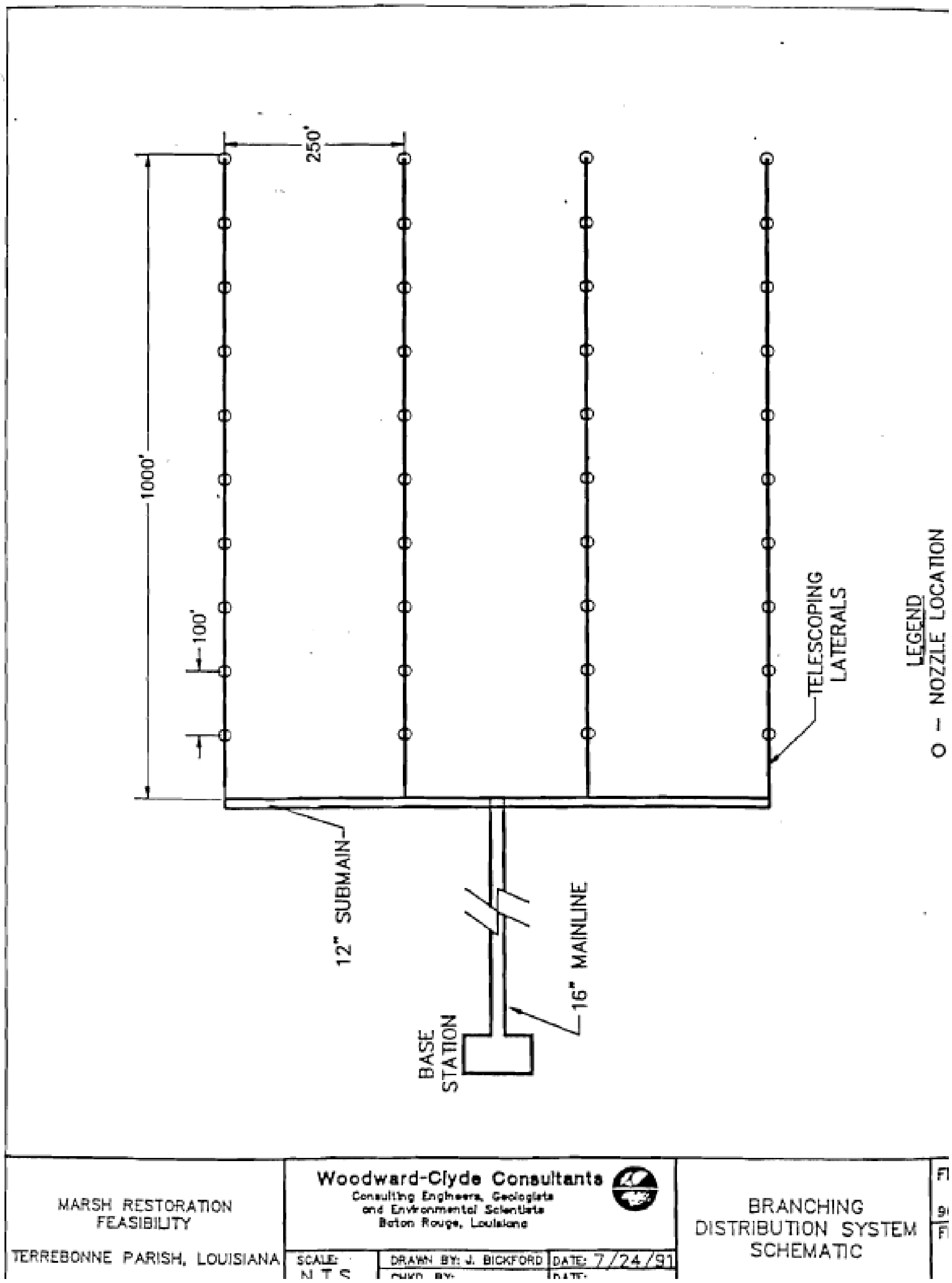


Figure 52. Configuration of branched pipe system (source: Woodward-Clyde Consultants 1993).

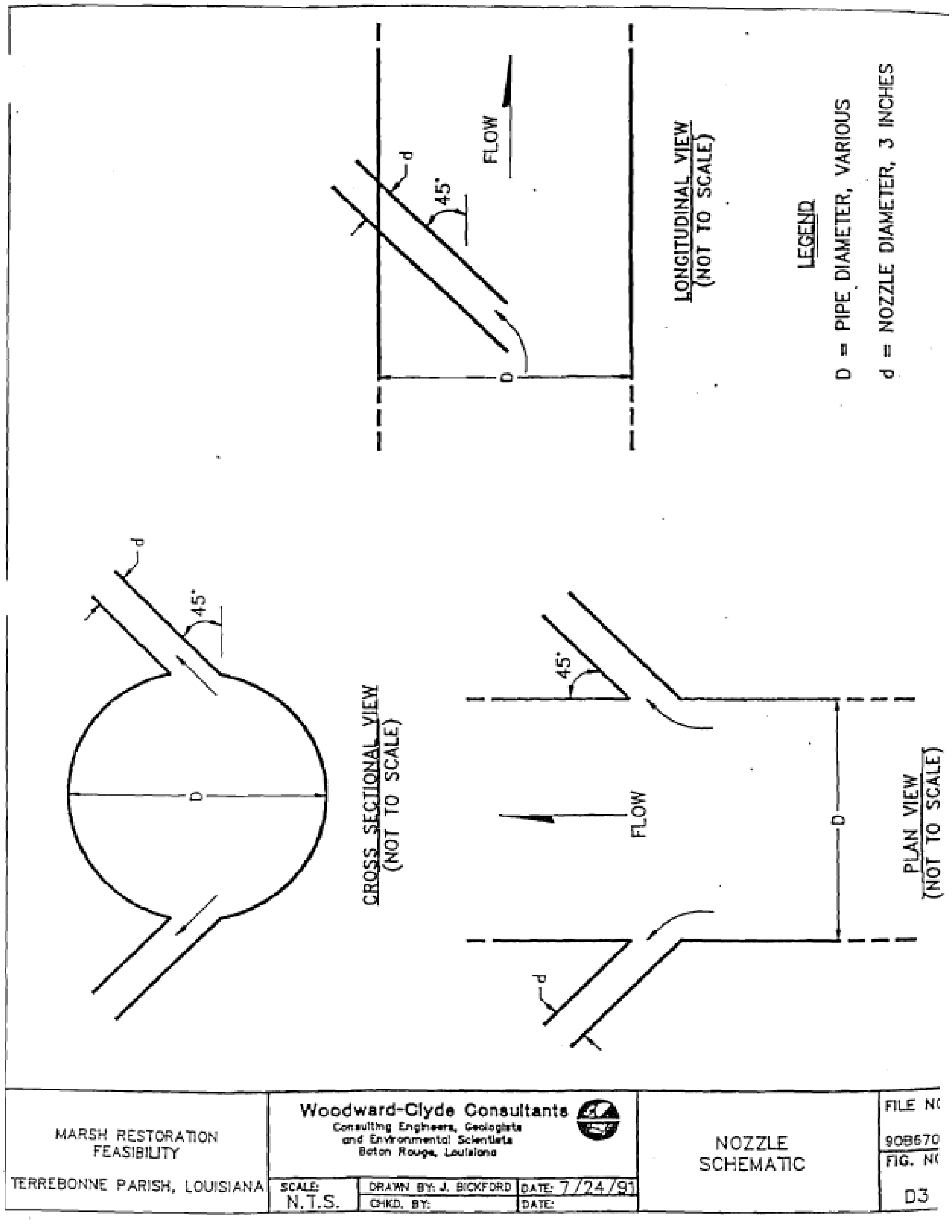


Figure 53. Configuration of pipe system nozzle (source: Woodward-Clyde Consultants 1993).

day, first by removing 1,000-ft sections of the mainline and moving the nozzles closer to the barge, and then, after three such moves, moving the entire mainline laterally 250 ft and repeating the process. Seven such lateral moves would be required to cover the 4,000 x 2,000 ft area (8 million sq ft) over which the sediment is to be distributed. For each of the linear moves (24 in all), the pipe would need only to be cut in and fused in one location.

The removed 1,000-ft section from each linear move would be cut into manageable lengths and moved laterally to the next mainline location. It is projected that each linear move would required two days effort. A second stand-by nozzle section would be used to reduce the down-time associated with both linear and lateral moves to a single day.

A schedule of operations under this configuration would then consist of four days of barge transport and off-loading followed by one day of down-time to reconfigure the system. It would thus require 5 months to distribute in the marsh the sediments dredged in 4 months. An additional month would be required for mob - demob.

Configuration 2:·Branched Pipe Network

The branched pipe network is shown in Figure 52. The advantage of this system over the straight pipe configuration is that the system can operate for a longer period of time without changing the nozzle locations. In the configuration shown, in which four 1,000-ft telescoping laterals come off a 12 in. submain, each setting will cover an area of 1,000 x 1,000 ft, or 1 million sq ft. It is apparent that only six linear moves and one lateral move would be necessary with this system to cover the entire 8 million sq ft area. The 2 million cu yd of material required for each setting would require 30 barge loads, or 15 days. The disadvantages of this configuration are the increased complexity of the system, the increased piping costs, and the greater time required to effect each move of the nozzle sections. Also, increased head losses in the smaller diameter laterals tend to decrease the uniformity of the sediment application. In the case of the four-lateral system shown, the laterals, in order to maintain required velocities, would have to telescope to 4 in. in diameter, and head losses over each lateral would be greater than 40 psi. To maintain uniformity of sediment distribution a maximum variation of 20 percent between the lowest and highest nozzle pressure is recommended (Jensen 1983). The 40 psi pressure loss would require that 200 psi be delivered to the bead of the laterals. By contrast, the straight pipe configuration requires 100 psi at the head of the nozzled section, since pressure losses along that section will be about 20 psi.”

Pyburn & Odom, Inc., (1993) describe some additional distribution mechanisms to enhance sediment placement as follows:

> "(1) Wave Joint. As shown in Figure 54, this mechanism allows for sediment to be discharged through either or both arms of a wye joint via valves, which can be operated in a manner consistent with a plan of sediment distribution. Flow through both arms can serve to increase the area over which sediment is discharged while reducing velocity. Flow through either single arm allows discharge to be redirected. Also, branching systems of smaller diameter pipeline to maintain adequate velocities can be employed using wye joints.

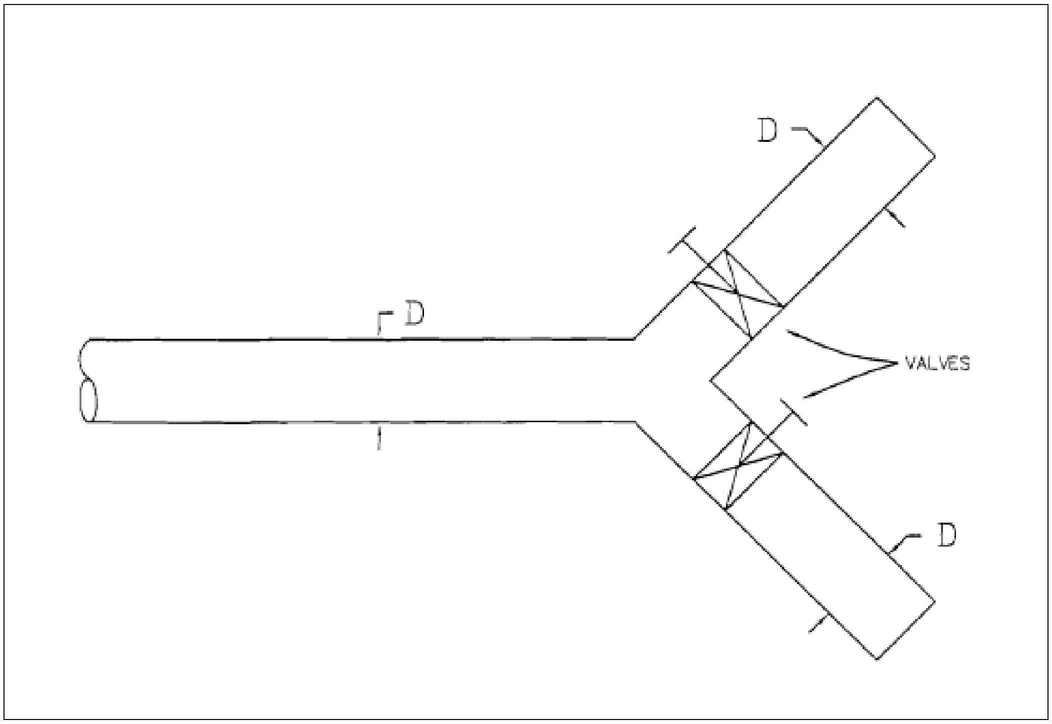


Figure 54. Wye joint (source: Pyburn & Odom, Inc. 1993).

> (2) Bleeder Pipe. A bleeder pipe contributes both to a sorting of material and a reduction of the discharge velocity. As shown in Figure 55, this mechanism involves the elevation of the end section(s) of the distribution pipeline on cribbing, piling, or pontoons. The bleeder pipe section has holes, varying in size from 2 to 6 by 6 in., cut in the underside of the pipe. Heavier sands and silts drop out at the holes, and the lighter silts and clays continue to flow until discharged at the end of the line. Placing the bleeder pipe on an incline assists the heavier particles in dropping through the holes. When the required

height is reached, the line is lengthened and the material placement continued in accordance with a plan of sediment distribution. The bleeder pipe can be equipped with movable gates over the holes to regulate the amount of flow.

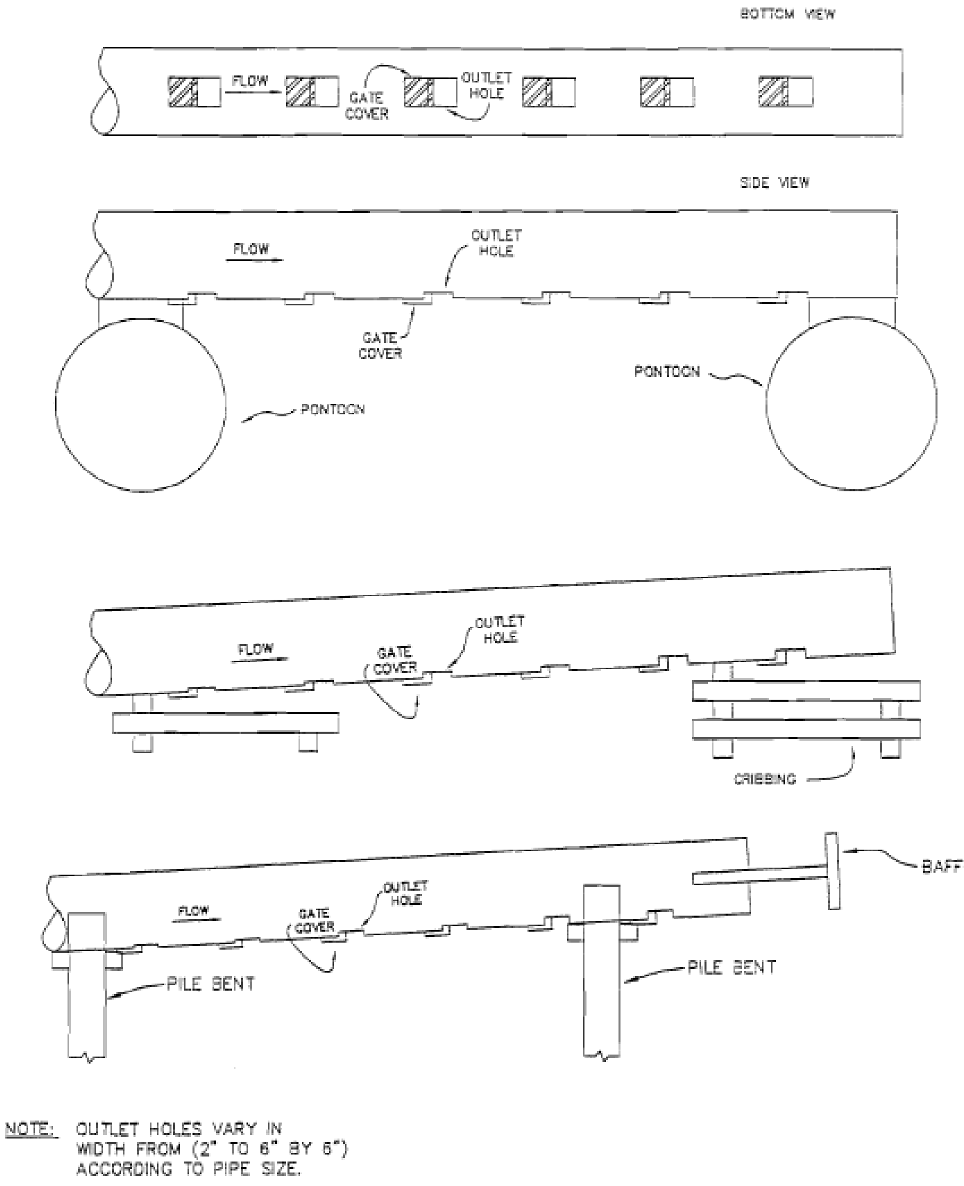


Figure 55. "Bleeder" pipe (source: Pyburn & Odom, Inc., 1993).

(3) Baffle. This mechanism consists of a plate located at the end of the pipeline and commonly mounted at an angle to the direction of flow. A baffle slows the discharge to reduce its erosive force, and it spreads the discharge over a wider area as it is deposited in accordance with a plan of sediment distribution. The force resulting from the slurry striking

> the baffle plate can be used to push the plate and floating pipeline forward. An example of a baffle, also known as a splash plate or discharge spreader, is shown in Figure 56. Another example of a baffle is shown on the end of the bleeder pipe in Figure 55."

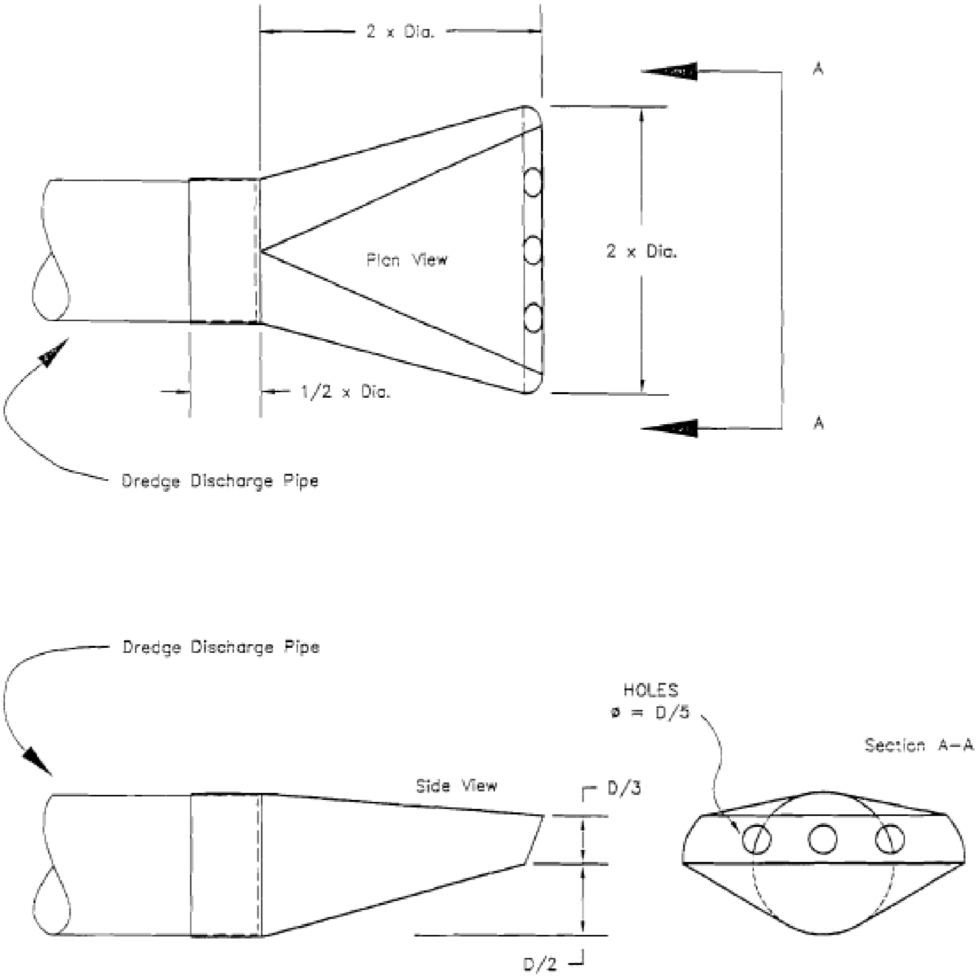


Figure 56. Discharge spreader (source: Pyburn & Odom, Inc., 1993).

Trafficability of the sediment handling equipment in both the pipeline corridor and placement site is a major factor in construction, operation, and maintenance efficiencies. As per Leach and Spigolon (1993):

> "Soils handling equipment must be capable of maneuvering on the ground surface environment at the project site. Ground surfaces may

> range from (1) fairly dry, firm upland areas, to (2) very soft surface soils in swampy areas where the free water surface is just above or just below the ground surface, to (3) extremely soft (fluid mud) to firm soils at substantial depths below water. It is expected that most wetlands earthwork will be conducted on the type (2), soft swampy soil surfaces, or with dredging equipment in an aqueous environment."

The interactions between types, sizes, and numbers of equipment used to dredge, transport, and place slurry, in conjunction with placement site specific conditions, will, of course impact operating efficiencies. An example of these types of interactions, and respective impacts, is illustrated by the following except from a narrative completion report (Louisiana Coastal Wetlands Conservation and Restoration Task Force 2002),

"Another problem was the pumping of the marsh creation site in Sabine National Refuge. At no time was the effluent or slurry to be allowed to go above +4.5 MLG. Due to the excessive amounts of water being pumped through a long pipeline to move the dredged material, breaches had to be made through the rear containment dikes in order to relieve the excessive amounts of clear water. Also in the marsh creation site, a cross dike oriented north/south was constructed where an over-flow was provided. This also had to be breached in order for the effluent to travel towards the southwestern end of the marsh creation site. Marsh Buggies were constantly tracking in the area; but did not have much impact on moving the effluent. The borrow material from the trenasse, also acted as a barrier which prevented the effluent from traveling into the intended direction. By breaching the rear containment dikes, it acted as a siphon, making the effluent follow the clear water out towards the rear dikes."

The project's design elevation (as previously described) can be a critical factor in achieving project goals. In the past, efforts to predict sediment elevations (after dewatering, consolidation, etc.) based on rules of thumb from experience have resulted in varying degrees of success. More recently, numerical models have been used to calculate estimated elevation changes of a created marsh (e.g., see Figure 57 of estimated elevation change of the Dedicated Dredging on the Barataria Basin Landbridge CWPPRA Priority Project List 11, State No. BA-36).

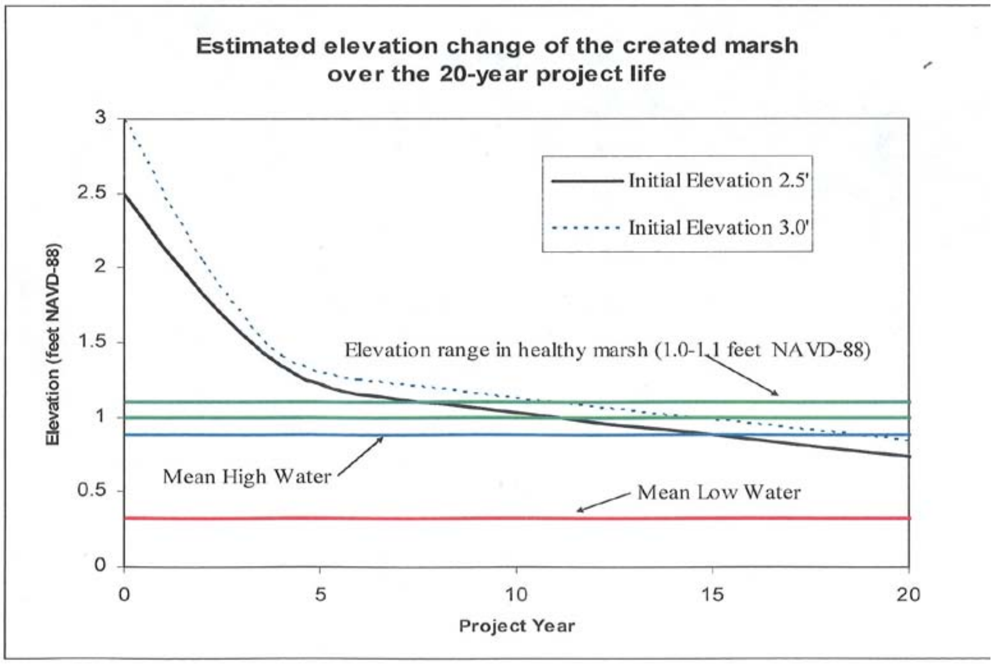


Figure 57. Estimated elevation change of the Dedicated Dredging on the Barataria Basin Landbridge CWPPRA (source: LDNR 2004).

Another application called Evaluation of Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill for Determining Long-Term Storage Requirements (PSDDF) is seeing increased application in predicting dredged material placement elevations as a function of time (Louisiana Coastal Wetlands Conservation and Restoration Task Force 2007).

This USACE application provides a mathematical model to estimate the storage volume occupied by a layer or layers of dredged material in a CDF as a function of time. The volume reduction and the resulting increase in storage capacity are obtained through both consolidation and desiccation (drying) of the dredged material. PSDDF can also simulate underwater placement of cohesive or noncohesive soil. PSDDF relies on the results of laboratory consolidation tests to estimate the magnitude and rate of consolidation and on climatic data for estimation of the rates of drying at a given site. PSDDF's major capabilities are that it determines: (1) the final or ultimate thickness and elevation of multiple lifts of dredged material placed at given time intervals, (2) determines the time rate of settlement for multiple lifts and therefore the surface elevation of the dredged material fill as a function of time, and (3) determines the water content, void ratio, total and effective stress, and pore pressure for multiple lifts as a function of time (http://el.erdc.usace.army.mil/products.cfm?Topic= model&Type=drgmat).

8 Economics

Introduction

Several feasibility studies and reconnaissance-level cost estimations have been conducted on LDC projects to date. Some ranges of costs from these efforts are provided here to simply illustrate potential magnitudes of future LDC projects. To not take these costs out of context, the reader is *strongly* advised to review the respective reports, presentations, etc., in their entirety to identify specific project objectives, assumptions, project-specific details, etc., to more fully understand what these estimates are based upon.

Woodward Clyde Consultants (1991) estimated project costs (in 1991 dollars) ranged from $4.3 million to $32.1 million. When examined on a unit cost basis to pump 30 miles for high density and low density slurry LDC systems, the price ranged from $15/cu yd to $27/cu yd.

Pyburn & Odom, Inc. (1993) estimated (using 1993 dollars) that by using an 8 in. abandoned pipeline to pump slurry a distance of 32 miles, the highest estimated total cost was approximately $58 million with a unit price of $80/cu yd. These costs are presented to illustrate a range of costs as they are not directly comparable to each other given the different project site-specific conditions and assumptions (dredging, re-handling, pipeline technology used, end-of-pipe re-handling etc.).

CH2M HILL (2006) calculated reconnaissance-level cost estimates (in fiscal year 2007 dollars) for three pipeline conveyance alternatives that were developed with respective land-building goals of 5, 10, or 15 square miles/year for a 50-year project life, with the main differences between the three alternatives being number and locations of areas to be restored. In the report it was expected that restoration areas closer to sediment sources would be rebuilt first, to both demonstrate the successful application of this technology and limit costs. Concerning estimated costs:

> "Unit costs for dredging and conveyance across varying distances were estimated from conversations with dredging industry contacts and include daily costs labor; supplies and equipment including dredges; booster pumps and fuel; pipeline construction and earthmoving

equipment; and operators. Costs for initial and replacement pipelines were taken into account. The costs assume that dredges do not operate during low-flow periods because of reduced sediment loads. Hence, construction companies would be required to mobilize and demobilize once per year per dredge location for the duration of the project, which is expected to be 50 years. The total number of mobilization / demobilization events equates to 50 times the number of active sediment borrow locations.

Ten percent of the construction costs were added to account for contingencies, such as relocation, easements, and compensations. The calculated amount might overestimate actual costs because pipelines require less space than a conveyance channel and can be routed around obstructions. A contingency of 30 percent was added to the total costs, to account for uncertainties in the estimates. The total construction costs differ greatly, from more than $9 billion for Alternative 1 to almost $32 billion for Alternative 3. These costs would be generated over a period of 50 years; yearly expenses would range from $190 million to $650 million" (CH2M HILL 2006).

As previously described in the Chapter 4 for the Mississippi River Long Distance Sediment Pipeline Project currently being conducted by CIAP, the preliminary total cost estimates range from $600,000,000 to $800,000,000 that would average approximately $20,000,000/year - $100,000,000/year with the following design assumptions: (1) 50,000,000cu yd to be transported (cut volume), (2) the project life varies from 8 to 30 years depending on operating months that could range from 3 to 10 months/year, and (3) the pipeline length varies from 15 to 30 miles. Conclusions regarding costs depending on a number of factors that have been reached at this project's current stage of implementation include:

- Physical Pipeline Factors: Size, Distance, Ground Conditions, access issues.
- Operating Costs in $/cubic yard go up with distance due to booster operational costs, pipeline wear and drop in dredge operating time with addition of boosters.
- Average operating $/cubic yard depends on distribution of quantity along length (i.e., pump west slowly or build pipe west faster and then pump).

- Capital cost of Installation are very large and many cubic yards are needed to spread those costs over time.
- Costs can be lowered in the short term by paying contractors to ob-demob their own pipeline and boosters but it is more cost effective in the long term (provided a sufficiently large volume of sediment will be delivered) to install the system once.
- Prudent decisions on how much pipe to install and how to contract it require an understanding of long term funding outlook.

Coastal Planning & Engineering Inc. (2004) calculated preliminary construction cost estimates (exclusive of mobilization and demobilization costs) that ranged from $6.06/cu yd to $12.04/cu yd for LDC pipeline lengths for the respective study's alternatives of pumping sediment approximately 10 to 19 miles. This report presented the following aspects of a permanent pipeline:

> "The permanent installation of a pipeline along the selected route was discussed with the dredging contractors. The consensus appears to be that the permanent installation of a pipeline along the Empire Waterway may not be desirable if a third party is used for the construction task. One of the contractors expressed a concern of relying on the quality of pipe and welds produced by a third party. The failure of a pipeline in a limited access region such as the Empire Waterway could delay the project significantly and be difficult to repair, service, and maintain. If it is desired to pump sand across the Mississippi River using a submerged pipeline, the installation of a permanent submerged pipeline could reduce the cost and risk that the dredgers will encounter in this type of operation. The permanent installation could be conducted to fasten and secure the pipe to permanent engineering standards, reducing the concerns for a lost or failed pipeline. The need for a permanent installation can be addressed by either assigning this responsibility to the initial contractor, or by using the regional multi-year contracting method."

Given that an LDC project to restore the Louisiana coast has not been conducted before, the ability to: (1) accurately estimate project and maintenance costs, and (2) appropriately select which contract type(s) that is (are) best to use, is unknown.

Although not classified as an LDC project, the Sabine Refuge Marsh Creation project contract that was awarded for $9 million to construct a 5.8 km- (3.6-mile-) long “permanent” pipeline (no booster pumps) to carry dredged sediment from the Calcasieu River Ship Channel to the marshes in Cameron and Calcasieu Parishes could be a significant step in improving the understanding of various LDC-related aspects. As previously described, the intent to install the “permanent” pipeline” along the same route that previous temporary lines have taken is to reduce the environmental impacts of the work along the permanent pipe, and by reducing mobilization and demobilization costs, the stakeholders hope to save approximately $2 million each dredging cycle time.

The type of funding and contract and supporting plans and specifications used will impact total LDC project costs. Bid competitiveness for an LDC project will be dependent on: (a) well-defined existing conditions, (b) long lead times and contract durations, and (c) clear measurements and payment criteria and industry interest will be a function of size and frequency of available work technology (Hales et al. 2003).

As per Coastal Planning & Engineering Inc. (2004):

> “The cost effectiveness of the long distance transport of sediments from the Mississippi River to the project sites can be improved by using special contracting methods. The type of contract that should be considered would be a regional, multi-year renewable dredging contract. This type of contract would reduce the risk to the bidding contractor, since they will know that their initial effort will be used in the following year. In addition, it will benefit the government since the mobilization/material costs can be spread out over many years and averaged over larger dredge quantities. The contractor would be more comfortable in acquiring the booster pumps, pipeline, and other equipment needed to perform the project efficiently. For example, if the contract is let for 1 year, the contractor may skimp on boosters and acquire substandard pipeline. This equipment would make productivity lower and increase the risk of pipeline failure. With a multi-year contract it would be more advantageous to acquire higher quality pipe and additional boosters. An additional booster may actually decrease the unit cost since an increased production rate can offset the expense of the additional booster. With the multi-year contract the dredger can emplace the pipeline once and leave some or

> all of it there for the duration of the project. This would eliminate the need for transport of the pipeline to the project site and assembling it each time dredging is required. A regional approach might also entail combining the Scofield Island complex with another project such as Shell Island."

These aspects illustrate that the configuration of risk allocation relative to contact specific deliverables (or in other words who will be responsible for what, when) affects contract costs. For example, if the re-handling basin concept (operating on a relatively permanent basis annually pumping millions of cubic yards of sediment) was to be implemented, options to be considered also include awarding two contracts, one for the dredging and delivery of sediment (long or short term), and the other for re-handling and placing it (long or short term), as opposed to say a dredging contractor being responsible for (in addition to doing the dredging) operating and maintaining a pipeline (owned by others) for a relatively short duration. Advantages and disadvantages of long and short duration contracts should be considered relative to risk allocation and bid competitiveness.

Given the scope and complexity of an LDC project, different contract types such as a Request-for-Proposal may be appropriate or contracting mechanisms similar to the Value Engineering (VE) methodology used by the USACE Value Engineering Program that's based on a partnering philosophy. As described at HQUSACE (2009), VE recognizes that the Contractor and USACE share common goals and that by working together in a spirit of cooperation that a quality product can be produced that saves taxpayer's dollars while offering the Contractor a unique experience to increase profits. The USACE formally defines VE as "the organized study of functions to satisfy user needs with a quality facility at the lowest life-cycle cost through applied creativity."

VE is not merely cost-cutting (reducing costs by simply eliminating features specified in the contract) or cutting corners (reducing costs by substituting inferior quality) or is a matter of accidentally stumbling on a way to reduce construction costs, rather it is a proven, systematic approach to problem-solving. The steps involved in this process include

- "Analyzing all phases of the construction project to identify current or potential areas of high cost and low value.

- Brainstorming to identify (1) high cost/low value items and (2) alternative ways of performing the same functions more efficiently and cost-effectively. (Think in terms of "what else will satisfy the required function?").
- Evaluating alternatives to select the best way to reduce the cost of performing the necessary functions while maintaining high quality and product integrity.
- presenting your ideas to the users by submitting a VE Change Proposal."

It may be possible under an innovative contract type, that the contractor is compensated using pay-for-performance mechanisms that use defined metrics for measuring the quality, quantity, and location of scalable coastal features constructed during contract execution. The contract would specify priorities for restoration of coastal features, which is tied to the metrics for measurement and payment. The more complete understanding of conditions that the dredging Contractors have thorough dredging contract documentation that include comprehensive documentation and specifications, the higher the probability to optimize risk allocation, and promote submittal of reasonable bids from qualified Contractors.

Summary

In many coastal Louisiana restoration projects, the distances that sediments need to be transported (10-30 miles or more) are greater than those typically conveyed by using conventional dredging technology (Hales et al. 2003). LDC is a mature technology for bulk transport that has been used efficiently from the economical and environmental perspectives of specific applications like coal and phosphate transport. At the workshop entitled "Long-Distance Pipeline Transport of Dredged Material to Restore Coastal Wetlands of Louisiana" the consensus of panelists and the audience (that consisted of national and international experts in the field of long-distance transport of dredged sediment and other materials by pipeline) was that there were no fundamental technological challenges to the delivery of sediment via LDC (Hales et al. 2003). LDC of the quantities of sediment that will be required to significantly impact Louisiana's wetlands loss rate, on the temporal and spatial scales necessary to achieve restoration goals, has never been conducted anywhere in the world before. The engineering challenges will be in the design, operation, and maintenance to achieve respective strategic goals in the most cost effective and environmentally acceptable manner.

A review of the scientific and technical literature and interviews with personnel involved in LDC-related projects were conducted in order to produce a summary of state-of-practice dredging project information and knowledge that was presented in the preceding sections described within the context of a framework constructed on a "systems approach" where an understanding of the system is framed by examining the linkages and interactions between the elements (or variables) that compose t he entirety of the system. The LDC system (and respective elements as shown in Figure 1) was defined as the evolution of a construction project using LDC by pumping slurry for wetland restoration.

These results were synthesized to identify scientific and engineering uncertainties (used in the context that uncertainty implies a lack of predictability, of structure, and of information, Rogers 1995) related to LDC of dredged material for wetlands restoration. The objective of this report is to identify these uncertainties to personnel involved in planning, designing, constructing, monitoring, and assessing future LDC demonstration projects.

The following scientific and engineering uncertainties were identified:

- Costs vs. benefits of large scale wetland restoration - can functioning ecosystems be created by LDC methods transporting very large volumes of sediment (as opposed to significantly smaller wetlands restoration projects)?
- Optimization of pipeline conveyance component design, construction, operation, and maintenance (e.g., centrifugal pumps and/or displacement pumps, controlled slurry solids concentration vs. direct linkage to dredge, etc.).
- The impact of the 'transport' water used to slurry sediments on placement site ecosystem (e.g., saline transport water in freshwater environment).
- Questions remain regarding the effects of massive sediment removal from the Mississippi River, what is the likely volume and renewable availability of sediment from the River?
- Effectiveness of structural components such as sediment traps that could potentially be used to facilitate sediment recovery for LDC optimization.
- Pipeline conveyance allows the import of sediment from outside the estuarine basins for use in ecosystem restoration. While this material

could be used directly for project construction, an alternative approach is to use local material for projects and refill the borrow areas with the pipeline. The economic and ecological costs and benefits associated with both alternatives should be explored to maximize efficiency of sediment pipelines.

- Dredged material placement projects that seek to achieve appropriate elevations for marsh vegetation and functioning channels for fisheries habitat, provide opportunities to explore the costs and ecological outcomes associated with the design features. Evaluations across a range of placement approaches would inform future marsh creation projects.
- Ability to understand the performance and costs of a range of alternatives conceptualized, formulated, evaluated, and compared through a systematic approach.
- Capacity to deal with the potential detrimental effects on nesting birds and waterfowl during placement (e.g., fill while advancing or retreating)?
- Capability to analyze slurry pipeline interactions with oil and gas pipelines regarding whether slurry pipelines can be laid over top of oil and gas infrastructure, and if so, how much cover (separation material), if any, would be required to avoid any damage to the underlying pipeline.
- Predict pipeline erosion and corrosion (optimum grade of steel, use of HDPE, coatings vs. cathodic protection).
- Predict LDC-placed sediment elevation over time.
- Ability to predict ecological impact of pipeline construction and maintenance activities.
- Ecological impact minimization (e.g., raised pipeline vs. shore line vs. submerged line vs. buried line).
- Ability to predict sediment placement characteristics as a function of physical sediment characteristics and slurry density. Designer slurry possible (vary water content to facilitate spreading of the material)?
- Technology concerning buried pipeline (e.g., Mississippi River crossing) that, in the possible event of plugging the pipeline with sediment (e.g., incase of an emergency shut down), what could be used to unplug the line?
- Potential impact of the generation of long density waves with high amplitudes on the efficiency and safety of the hydraulic system.
- Ability to predict formation of clay balls that reduce pumping efficiency.

- The ability to accurately estimate project and maintenance costs, and appropriately select which contract type(s) that is (are) best to use for LDC projects, is unknown.

If efforts are applied to reduce the levels of these uncertainties in future LDC demonstration projects by applying adaptive management and adaptable expectations approaches, then the increased predictability, structure, and information gained from these demonstrations may be used to optimize subsequent full-scale LDC Louisiana coastal restoration projects.

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Appendix A

Major restoration initiatives*

*Extracted from Lindquist and Martin (2007).

*The purpose of the Coastal Restoration Annual Project Review is to provide interested parties with easily accessible information about projects constructed to date and the current efforts to address Louisiana's coastal land loss problem. For more detailed information on these projects visit fttp://dnr.louisana.gov/crm, call 1-888-459-6107, or write to the Department of Natural Resources, Coastal Restoration Division, P.O. Box 44027, Capitol Station, Baton Rouge, LA, 70804-4027.

Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA)

In 1990, the U.S. Congress recognized the national significance of wetland loss in Louisiana and passed the Coastal Wetlands Planning, Protection and Restoration Act (Public Law 101-646, Title III; also known as the Breaux Act) to contribute Federal monies and build upon existing state restoration activities. In 2004, the U.S. Congress voted to extend CWPPRA for an additional 15 years, under the Consolidated Appropriations Act, 2005. Since passage, CWPPRA has dedicated approximately $60 million annually to wetland restoration projects in Louisiana and has authorized 166 projects, of which 81 have been constructed. CWPPRA also created a partnership between Louisiana and five Federal agencies: the U.S. Departments of the Army, Agriculture, Commerce, and the Interior; and the U.S. Environmental Protection Agency. Since 1991, the State of Louisiana and its Federal partners have annually selected restoration projects for implementation.

Coast 2050

In 1997, a significant planning effort called "Coast 2050" was initiated to combine all elements of Louisiana's previous coastal restoration efforts, as well as recommend new initiatives. This new approach included input from private citizens, local governments, state and Federal agency personnel, and the academic community. This comprehensive plan focused all efforts of the participating agencies on the common goal of restoring and protecting the coastal ecosystem in Louisiana.

The 1998 report entitled “Coast 2050: Towards a Sustainable Coastal Louisiana” subdivided the Louisiana coast into four planning regions based on hydrologic basins. In order to reestablish a sustainable, highly productive ecosystem, Coast 2050 identified the following three strategic goals as the essential natural processes required:

- Goal 1: Assure vertical accumulation to achieve sustainability.
- Goal 2: Maintain estuarine gradient to achieve diversity.
- Goal 3: Maintain exchange and interface to achieve system linkages.

The Louisiana Coastal Wetlands Conservation and Restoration Task Force (also known as the Breaux Act Task Force) and the State Wetlands Authority adopted the Coast 2050 effort as their official restoration plan. It also garnered the support of the 20 parish councils and police juries within the Louisiana coastal zone.

Louisiana Coastal Area (LCA) Ecosystem Restoration Program

The “Louisiana Coastal Area, LA - Ecosystem Restoration: Comprehensive Coastwide Ecosystem Restoration Study” was the initial effort of the State of Louisiana and the USACE to implement the restoration strategies outlined in the Coast 2050 report. Guidance from President Bush’s 2005 budget request resulted in a scaled-down version of the comprehensive study entitled “Louisiana Coastal Area, Louisiana Ecosystem Restoration Study” (hereafter, referred to as the Study). Although not a comprehensive plan, the LCA Study lays out a series of projects and programs as a first step toward achieving the restoration goals outlined in the Coast 2050 Plan. By focusing on critical projects, allowing for action on larger-scale restoration strategies, and supporting the program with science-based decision support systems, near-term projects can be implemented with low risk and uncertainty while the science and technology that will ultimately provide for sustainable restoration of Louisiana’s coastal ecosystem are developed.

The LCA Study contains seven recommended program features for implementation: (1) five projects for conditional authorization; (2) ten additional projects for implementation in the next 10 years under standard authorization processes; (3) six large-scale studies that will lay the groundwork for the systemic restoration of deltaic processes and natural system hydrology; (4) a Science and Technology Program that will implement the principles and practices of adaptive management; (5) a

Demonstration Project Program that will assist in resolving critical uncertainties; (6) a program to reevaluate existing water resources structures for their potential to contribute to ecosystem restoration; and (7) a new program for expanded beneficial use of dredged material. The LCA Study main report can be viewed at http://www.lca.gov/main_report.aspx.

Critical restoration projects

A total of 15 critical projects were identified through the study process that could be implemented in the first 10 years of the LCA Program. Five of these projects are recommended for conditional authorization, including three freshwater reintroduction projects, a barrier island project, and a project to implement environmental restoration features for the Mississippi River Gulf Outlet (MRGO). These five projects are based on proven science and technology, are in the engineering and design phase, and have had the National Environmental Policy Act (NEPA) compliance process initiated. Therefore, it is likely that they will be able to go to construction before the remaining ten projects. The requested construction authorization by Congress would be conditional upon the approval of a decision document by the Secretary of the Army. The remaining ten projects would be authorized through the standard process for implementation of USACE projects.

The first three freshwater reintroduction projects recommended in the LCA Study have been partially developed through CWPPRA. These are the River Reintroduction into Maurepas Swamp (PO-29), the Mississippi River Reintroduction into Bayou Lafourche (BA-25b), and the Delta Building Diversion at Myrtle Grove (SA-33) projects. The barrier island project, Barataria Basin Barrier Shoreline (BBBS) Restoration, is based on work that has undergone extensive analysis under a previous USACE/LDNR feasibility study. The goal of this project is to reestablish the geomorphic functions of the Caminada Headland and Shell Island. It is anticipated that the BBBS project draft feasibility study will be completed in early 2008. Pending closure to deep-draft navigation, the LCAM Project will focus on environmental restoration in the area.

Large-scale studies

As the near-term projects are implemented, research will continue on large-scale concepts that may provide more long-term solutions for sustaining our coastal wetlands. These concepts include initiating new delta-building in the central portions of the Barataria-Terrebonne

Estuarine System, optimizing water and sediment distribution at the Old River Control Complex and in the Chenier Plain, and "re-plumbing" the lower Mississippi River Delta to optimize ecosystem functions while maintaining the important navigation functions of the river. Although there is great promise in these concepts, there is also great uncertainty that requires time to investigate. While work has been initiated on some level on all six of the large-scale projects identified in the Study report, the Chenier Plain Freshwater and Sediment Management and Allocation Reassessment Study, the Mississippi River Hydrodynamic Study, and the Mississippi River Delta Management Study will undergo further development in 2008.

Science and Technology Program

It is essential to incorporate the best available science and technology into program implementation. The LCA Science and Technology (S&T) Program, jointly managed by LDNR and ERDC scientists, provides the scientific and technical underpinnings of the LCA Program. Significant progress has been made toward implementing the simple program structure presented in the LCA Study report; however, sufficient flexibility remains for the program to adapt its procedures based on evolving needs. For the past 2 years, the LCA S&T Program has commissioned research to resolve critical scientific uncertainties and develop data management, decision support and modeling tools that managers need to plan and assess program activities. Information on the projects that have been funded to date and their associated deliverables can be found at http://el.erdc.usace.army.mil/lcat.

In addition, the S&T Program has established the LCA Science Board to provide external peer advice to LCA programmatic efforts and the Science Coordination Team to leverage management and research activities with other state and Federal agencies.

Demonstration Project Program

Related to the S&T Program is a Demonstration Project Program that will enable the testing of new technology and restoration concepts in the field to minimize the risk associated with implementing similar projects throughout the coastal zone. The oversight provided by the S&T Program in executing the demonstration projects will ensure that these learning opportunities are fully exploited.

Beneficial Use Program

The potential exists to utilize existing federally-authorized projects in the coastal zone for increased benefit to the ecosystem. The USACE New Orleans District dredges an average of 70 million cu yd of material annually from Federal navigational channels. Of this amount, up to 30 cu m would be available to enhance coastal wetlands. The 10-year, $100 million LCA BUDMAT Program will provide funding to optimize the use of dredged material to achieve the LCA's hydrogeomorphic and ecosystem objectives. The goals of this program are to: (1) create, restore, and/or nourish coastal wetlands, (2) create or restore coastal landscape features, such as barrier islands and chenier ridges, and (3) provide protection to coastal wetlands or coastal landscape features. The costs associated with the program are those that are incurred above and beyond the ordinary costs associated with the USACE's dredging and disposal operations base plan. The completion of the draft feasibility report for the BUDMAT Program is scheduled for early 2008.

Next steps

The LCA Study was completed in December of 2004. The Chief of Engineers of the USACE signed his report (http://www.lca.gov/ chief_report.aspx) in January of 2005, providing the opportunity for Congress to authorize the LCA Program in a future Water Resources Development Act (WRDA). This WRDA was passed by Congress on 8 November 2007, over-riding a veto by President Bush. In the meantime, the state and USACE initiated activities related to the LCA Program under existing study authorities.

Coastal Impact Assistance Programs of 2001 and 2005

Congress authorized the CIAP to assist coastal oil and gas producing states in mitigating the impacts of production activities on coastal habitats, natural resources, and infrastructure. The 2001 CIA P was authorized under Section 903 of the Commerce, State, and Justice FY01 Appropriations Act. Louisiana received $26.4 million under this one-time authorization. These funds were expended according to legislation and guidelines developed by the National Oceanic and Atmospheric Administration (NOAA). The 2005 CIAP was authorized under Section 384 of the Energy Policy Act of 2005. Under this act, Louisiana is projected to receive up to $510 million over 4 years, beginning in 2007. Sixty-five percent ($331.5 million) of these funds will go to the state, and 35 percent ($178.5 million) will be provided to the 19 coastal parishes. These funds will be disbursed by the Minerals Management Service (MMS). To obtain CIAP funds, Louisiana was required to submit CIAP Plans, which described how the funds would be expended. The LDNR has led the formulation of these Plans, working closely with the coastal parishes and various state and Federal entities. The 2005 CIAP Plan was formulated with extensive public and technical input. The LDNR solicited input and proposals from the coastal parishes, state and Federal agencies, non-governmental organizations, landowners and the public, beginning at coast-wide public meetings in February 2006. A description of the program, guidelines for application, and project selection criteria were disseminated via meetings and mailings, and were posted for download from the LDNR-CIAP website.

The LDNR received 337 proposals from coastal parishes, municipalities, state and Federal agencies, non-governmental organizations, universities, corporations, landowners, and the general public by the 22 May 2006 deadline. The LDNR solicited public input on these proposals at regional open-house events in Baton Rouge and Lafayette, and the proposals were also available for review on the LDNR-CIAP website. Proposals were initially screened by the LDNR to determine if state CIAP funds were being requested, if the projects complied with the authorized uses of CIAP funds, and whether the proposals were focused on infrastructure or coastal restoration/conservation. Each conservation and restoration proposal involving state CIAP funding was reviewed to determine whether it had clear links to a regional strategy for maintaining critical landscape features. Key questions asked by LDNR staff were whether the proposal would produce regional benefits and whether the proposal's cost could be supported by CIAP. If the proposal met the above criteria and had a high degree of certainty of benefits, then it was selected for detailed technical analysis. Projects that were being developed using CWPPRA funds were generally excluded from further CIAP consideration.

An external technical review of the selected CIAP project proposals was then conducted. The review identified the strengths and weaknesses of individual proposals, and assessed their competitiveness as candidates for CIAP funding. A LDNR technical review panel then ranked the proposed projects using compiled information and the results of the external technical review, and generated a preliminary list of projects for the Draft CIAP Plan. This list was then presented to the CIAP selection committee, which included representatives from the Louisiana Departments of

Transportation and Development, Wildlife and Fisheries, Agriculture and Forestry, Environmental Quality, and GOCA. An external science advisor and members of the CPRA also participated. The project list adopted by the selection committee became the primary component of the 2005 CIAP Plan. The CIAP Plan drew heavily from recent collaborative coastal planning efforts (e.g., the Coast 2050 Plan, the LCA Plan, and the Governor's Advisory Panel and Science Working Group on Coastal Wetland Forest Conservation and Use). Care was also taken to ensure that the CIAP Plan was consistent with the state's Master Plan.

Governor Kathleen Blanco transmitted Louisiana's final CIAP Plan to the Secretary of the Interior and the MMS on 1 June 2007, following approval of the CIAP Plan by the CPRA. Louisiana's plan was the first submitted of any of the six eligible states. The 2005 CIAP Plan consists of 115 Tier One (or high priority) projects including: 10 projects to be supported by the state's share of the CIAP funds; 13 projects jointly funded by the state and parishes; and 92 projects involving parish-only CIAP funds.

The 2005 CIAP Plan was formally approved by the MMS on 29 November 2007. With this approval, the state and coastal parishes can apply for noncompetitive grants to fund their projects. The LDNR has started to implement many of the projects included in the CIAP Plan using money from the state's Coastal Protection and Restoration Trust Fund.

Appendix B

Interviewees:

Axtman, Timothy	U.S. Army Engineer District, New Orleans
Beldon, Laura	Louisiana Office of Coastal Protection and Restoration
Brodnax, Cheryl	National Oceanographic and Atmospheric Administration
Carroll, Jerry	Louisiana Department of Natural Resources
Clark, Karl	U.S. Army Engineer District, New Orleans
Clausner, James	U.S. Army Engineer Research and Development Center, Vicksburg, MS
Corbino, Jeff	U.S. Army Engineer District, New Orleans
Creef, Edward	U.S. Army Engineer District, New Orleans
Ethridge, Beverly	U.S. Environmental Protection Agency
Ettinger, John	U.S. Environmental Protection Agency
Hanson, Bill	Great Lakes Dredge and Dock
Joffrion, Russ	Louisiana Department of Natural Resources
Knotts, Christopher	Louisiana Department of Natural Resources
Lachney, Fay	U.S. Army Engineer District, New Orleans
LeBas, Luke	Louisiana Department of Natural Resources
Levron, Al	Terrebonne Parish Consolidated Government

Miller, Gregory	U.S. Army Engineer District, New Orleans
Randall, Robert	Texas A&M University, College Station, TX
Reed, Denise	University of New Orleans
Rozas, Lawrence	NOAA Fisheries, SEFC/Estuarine Habitats and Coastal Fisheries Center
Russo, Edmond	U.S. Army Engineer Research and Development Center, Vicksburg, MS
Salamone, Ben	U.S. Army Engineer District, New Orleans
Schorr, Henry	Manson Construction Company
Smith, Rick	Weeks Marine, Inc.
Sweeney, Rachel	NOAA Fisheries
Taylor, Ancil	CF Bean, LLC
Thomson, Gordon	Coastal Planning & Engineering, Inc.
Thompson, Whitney	Louisiana Department of Natural Resources
Winslow, Kyle	CH2M HILL
Whitlock, Lee	Georgia Iron Works (GIW)

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14. ABSTRACT

Restoration of Louisiana's marshes and other coastal habitats will, in many cases, require dredged sediments to provide suitable substrate. Potential restoration sites are often at great distances from the sediment source. It will require special efforts, commonly referred to as long distance conveyance (LDC), to pump sediment to the sites. For the purposes of this report, LDC projects are defined as those Louisiana coastal restoration projects that involve hydraulic transport of slurry (mixture of sediment and water) through pipeline distances of 16 km (10 miles) or greater. Pumping slurry through a long pipeline is a mature technology for bulk transport that has been used efficiently in specific applications like coal and iron ore transport. At the workshop entitled "Long-Distance Pipeline Transport of Dredged Material to Restore Coastal Wetlands of Louisiana," the consensus of panelists and the audience (that consisted of national and international experts in the field of long-distance transport of dredged sediment and other materials by pipeline) was that there were no fundamental technological challenges to the delivery of sediment via LDC (Hales et al. 2003). The engineering challenges will be to optimize LDC design, operation, and maintenance to achieve respective strategic restoration goals in the most efficient, cost-effective, and environmentally acceptable manner possible.

(continued)

15. SUBJECT TERMS

Coastal restoration
Dredging
Long distance hydraulic transport
Long distance pipeline
Louisiana wetlands restoration
Marsh creation
Pipeline environmental impacts
Slurry transport

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14. ABSTRACT (concluded)

Technical literature was reviewed and interviews with personnel involved in LDC-related projects conducted to summarize state-of-practice LDC dredging project information. Dredging and transport methodologies in relation to LDC state-of- practice are presented, and potential environmental impacts of long distance pipeline transport across wetlands are discussed. Scientific and engineering uncertainties related to LDC optimization of dredged sediment for coastal restoration are identified. Uncertainty, as used in this context, implies a lack of predictability, structure, and information (Rogers 1995). The report’s objective is to identify these uncertainties to personnel involved in planning, designing, constructing, monitoring, and assessing future LDC demonstration projects. If efforts are applied to reduce the levels of these uncertainties in future LDC demonstration projects by applying an adaptive management approach, then the increased predictability, structure, and information gained from these demonstrations may be used to optimize subsequent full-scale LDC Louisiana coastal restoration projects.