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16. Abstract

A two-year project, Alternative Dredging and Disposal Methods for the Texas Gulf Intracoastal Waterway, investigates the cost and engineering of long distance pumping, beneficial uses of GIWW-dredged material for the Texas coastal zone, separation techniques for GIWW-dredged material, optimum slurry flow, and alternatives for analyzing dredged material disposal. A cost-estimating program incorporates fuel costs, dredge crew labor costs, routine maintenance and repairs, major repairs, overhead costs, depreciation, profit, mobilization and demobilization, and capital investment cost for a cutter suction dredge. The Cutter Suction Dredge Cost Estimation Program (CSDCEP) estimates the production rate and cost of dredging projects. Comparisons with actual production rate and costs show CSDCEP is accurate. An attractive beneficial use of dredged material from the GIWW is manufactured soil, which can be manufactured using dredged material, recyclable organic waste materials (sewage sludge), and bio-mass (cellulose or saw dust). Researchers estimate the manufacturing and transportation costs at \$13 to \$20 per cubic yard depending on the blending method, mode of transportation, and ease of excavation. Another beneficial use is thin-layer disposal, spraying dredged material on adjacent wetlands. A geotube filled with dredged material placed along the Texas GIWW could provide a beneficial use while preventing further inundation of wetlands due to erosion. Dewatering wheels and hydrocyclones have been identified as two potential separation techniques. Results from the CD-CORMIX software show that the reduced flow from smaller dredges can reduce turbidity during the dredging process.

17. Key Words Beneficial Uses of GIWW-Dredged Material, Cost Estimating, Manufactured Soil, Geotube, Thin-Layer Placement, Separation Techniques, Dewatering Wheel, Hydrocyclone, Cutter Suction Dredge, Turbidity Reduction	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

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TEXAS GULF INTRACOASTAL WATERWAY (GIWW) DREDGED MATERIAL: BENEFICIAL USES, ESTIMATING COSTS, DISPOSAL ANALYSIS ALTERNATIVES, AND SEPARATION TECHNIQUES

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The United States Government and the state of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation/Symbol	Definition
AASHTO	American Association of State Highway and Transportation Officials
ADDAMS	Automated Dredging Disposal Alternatives Management System
AOS	Apparent size opening
ASTM	American Society for Testing and Materials
B	Buoyancy flux
B	$[(\gamma_s / \gamma - 1)\ g\ d^3_{50} / \nu^2]$
B	Horizontal width
b	Geotube flat base length
b_4	Empirical constant = 9.1
BHP	Brake horsepower
BM	Bio-mass
BS	Bio-solids
b_v	Value of x at which V reduces to some specified fraction of V_m
C	Tracer concentration
C	Sediment concentration by volume
C	Sediment concentration by weight
C'_T	Suspended solids concentration at the surface
C_d	Drag coefficient
CDF	Confined disposal facility
CDF	Cumulative distribution function
CDFATE (CD-CORMIX	Model for predicting the dilution and mixing zone of a typical continuous dredge discharge operation
C_m	Tracer concentration on the jet axis (centerline)
CPAR	Construction productivity advancement research program
CRDA	Cooperative research and development agreement
CSDCEP	Cutter suction dredge cost estimating program
C_T	Suspended solids concentration
C_v	Concentration of solids by volume
CZMP	Coastal zone management program
d	Median particle diameter
D	Pipe inside diameter
D	Pump impeller diameter
D	Diameter of a round discharge pipe
D	Pipe diameter
D	Depth from water surface
D	Distance
d_{50}	Grain diameter in mm
DE	Dredge efficiency
Dim	Indicates dimensionless quantity
DM	Dredged material
E	Excavation costs
EPA	Environmental Protection Agency
η	Pump efficiency
f	Friction factor
F_{excav}	Excavation factor
F_L	Coefficient based on the grain size and sediment concentration
$F_{s\text{-}bd}$	Factor of safety for biological degradation
$F_{s\text{-}cd}$	Factor of safety for chemical degradation
$F_{s\text{-}cr}$	Factor of safety for creep

$F_{s\text{-}id}$	Factor of safety for installation damage (1.3)
$F_{s\text{-}ss}$	Factor of safety for seam strength
g	Acceleration due to gravity (32.2 ft/s^2 or 9.81 m/s^2)
gpm, GPM	Gallons per minute
γ	Specific weight of fluid, specific weight of the slurry
γ_s	Specific gravity of the solid
GIWW	Gulf Intracoastal Waterway
H	Total pump head
H	Ambient water depth
h	Height of geotube
H_d	Discharge head
h_m	Minor head losses in pipe
h_o	Depth of discharge pipe below the water surface
H_s	Suction head
Hs	Significant wave height
i	Hydraulic gradient of water
i	Number of times each material is transported
i_f	Hydraulic gradient of the fluid
i_m	Hydraulic gradient of mixture (meters of water per unit of length)
K	Minor loss coefficient
L	Inlet/outlet spacing
L	Geotube circumference
LTFATE	Long-term fate
M	Momentum flux
MS	Manufactured soil
μ	Dynamic viscosity of fluid
ν	Fluid kinematic viscosity
NWR	National Wildlife Refuge
ω	Pump speed (radians/s)
P	Pressure
P	Horsepower
P	Dredge production (cy/hr)
p(x)	Hydrostatic pressure at x
PF	Production factor
p_o	Pumping pressure
Q	Volumetric flowrate, discharge, flow rate of slurry
R	Transportation cost in dollars per m^3-km
r(x)	Radius of curvature at x
R_{excav}	Unit excavation cost
ρ_f	Density of fluid
ρ	Density of water
ρ_o	Clear water density
ρ_s	Density of solids
SETTLE	Computer program for design and operation of confined disposal facility
SG_f	Specific gravity of fluid
SG_s	Specific gravity of sediment particle
S_m	Specific gravity of mixture
S_s	Specific gravity of solids
T	Time since disposal in days
T	Total transportation cost
T	Tensile force
θ	Angle of discharge pipe with respect to the vertical
TNRCC	Texas Natural Resources and Conservation Commission

T_{ult}	Geotube ultimate tensile strength
TxDOT	Texas Department of Transportation
U, V	Tide velocity
U_a	Uniform ambient current
USACE	U.S. Army Corps of Engineers
UV	Ultraviolet rays
V	Average velocity, mean velocity
V	Volume of material
V_{50}	Mean mixture velocity at which half of the mass of the solids is suspended by the fluid and half by contact with other particles
V_c	Transition velocity
V_f	Fall velocity of soil sediments
V_i	Volume of material
V_m	Mean velocity on the jet centerline
V_{sm}	Maximum velocity at limit of stationary deposition
V_t	Particle settling velocity, terminal velocity
V_{th}	Transition velocity
WES	Waterways Experiment Station
x	Transverse (radial) distance from jet centerline
Y	Mass flux of sediment
z	Elevation
z	Vertical distance along the jet centerline

IMPLEMENTATION RECOMMENDATIONS

1. The newly developed Cutter Suction Dredge Cost Estimating Program (CSDCEP) estimates the dredge production rate and subsequently uses the estimated production rate to evaluate the dredging cost. CSDCEP is capable of determining when booster pumps are needed for long distance pumping and includes the associated costs in its final cost estimate. The CSDCEP is a generalized program that gives an accurate cost estimate as demonstrated by comparison to actual project costs along the GIWW.

2. Converting dredged material to a manufactured soil is technically feasible. Researchers need to perform individual feasibility studies for each site to determine if the dredged material has the properties necessary for producing a high quality manufactured soil. Site selection is paramount in selecting a disposal area where excavation equipment can work. Many disposal areas are located along the coastline, and the Texas Gulf Intracoastal Waterway in particular. Most sites are remote with limited land access.

3. The main issues affecting the feasibility of manufacturing soil include finding a market or use for the converted topsoil, determining the optimum site for the project, deciding which bio-mass should be used and from where it will come, and acquiring the bio-solid or reconditioned sewage sludge. A methodology exists for determining the costs associated with converting dredged material to topsoil. The new methodology and cost analysis has been applied to two potential pilot sites along the Texas GIWW to demonstrate the methodology. The two sites, Matagorda Bay and the Bolivar Peninsula near Galveston Bay, show that manufactured soil for use in construction and landfill projects is feasible with prices ranging from \$17 to \$26 per m^3 (\$13 to \$19.9 per cy) of manufactured soil.

4. Manufactured soil cost of \$17 to \$26 per m^3 (\$13 to \$19.9 per cy) is a function of the blending method, mode of transportation, and ease of excavation. This price is also based on the bio-solid being reconditioned to a Class B level for restricted uses and donated by a sewage treatment facility. A higher cost of \$28 to \$32 per m^3 (\$21.4 to \$24.5 per cy) is necessary if the bio-solids are reconditioned to an unrestricted Class A level. Although manufactured soil is more expensive than typical landfill cover and construction materials, it must be emphasized that the purpose of converting dredged material to topsoil is to reduce the volume of dredged material placed into a disposal area. In addition, the use of dredged material from the disposal site will save costs associated with the purchase of land for new disposal areas.

5. It is recommended that plant-screening tests be performed on the dredged material to evaluate its suitability as a manufactured soil and potential growing capacity. These tests determine the percentages of each material, dredged material, bio-solid, and bio-mass, for optimal plant growth. In addition, the effects of salinity on selected plant types are also determined from the screening test. A small or medium size scale (800 to 8,000 m^3 or 1,046 to 10,464 cy of dredged material) pilot study is recommended to demonstrate viability of the concept.

6. There are several dredging sites along the Texas GIWW where the thin-layer disposal method can be applied. Initial reviews identified Galveston Causeway to Bastrop Bayou, Freeport Harbor to Caney Creek, and San Bernard River to Matagorda Bay as possible dredging locations for thin-layer disposal. For the specific dredging site, the thin-layer disposal width and thickness can be predicted by knowledge of the dredging volume, disposal thickness, and disposal width versus thickness curves.

7. When the thin-layer disposal thickness exceeds the desired thickness limit (currently 15 to 25 cm) for a specific dredging site, then increasing the dredging frequency and changing the dredging time schedule should be considered in order to apply the thin-layer disposal at this location. Current equipment can spray approximately 76.2 m (250 ft) inland and retractable reels and the associated pipe can be used to spray the dredged material further inland. Another possibility is to augment the thin layer disposal with excess dredged material being discharged into the current confined disposal facilities.

8. Experiences with thin-layer disposal have been documented at many sites outside of Texas. Many thin-layer beneficial use projects have been successful and it appears there are opportunities for this relatively new technique to be used for the benefit of the operation of the Texas GIWW. Additional physical and biological investigations are needed to further evaluate the acceptability of thin-layer disposal for the Texas GIWW.

9. It is recommended that researchers conduct pilot studies to determine the effectiveness of long-term dredge material management using geotubes that are filled with dredged material. These pilot studies should be conducted simultaneously with a dredging project and monitored to report the condition of the geotubes and their effectiveness in preventing further erosion along the GIWW. The geotubes for these studies are recommended to be approximately 9.14 m (30 ft) circumference, 152 to 305 m (500 to 1,000 ft) in length, filled directly from a small dredge or branch pipe, and have a minimum scour apron width of 9.14 m (30 ft). It is also recommended that further studies be conducted regarding scour and the width of the scour aprons to maximize the structure's effectiveness against erosion and undercutting.

10. The separation of sands and silts and the dewatering of dredged material can extend the life of a confined disposal facility (CDF) by reducing the volume of disposed material. In addition, separated material like sand can be used for beneficial purposes such as beach renourishment. While many separation techniques are not applicable to the high volumes associated with dredging operations, the dewatering wheel and hydrocyclone have been identified as the most promising dewatering mechanisms for use in conjunction with the disposal of dredged material resulting from maintenance dredging in the Texas GIWW.

11. Recommendations for the optimum discharge operation that reduces turbidity, mixing zone size, and deposits more of the discharged sediment on the bottom are:

    a) The ambient current velocity has an important influence on the dilution process. The smaller the ambient current, the faster the sediment is deposited. So, the disposal site should be chosen in a small ambient current field.

b) The angle between the ambient current direction and the slurry discharge direction must not be greater than 90 degrees. If the angle is greater than 90 degrees, then the jet produces a large tubulence within the ambient water body. The sediment is suspended for a long time in the turbulence, and the diffusion region is much wider.

c) In the same ambient conditions and the same discharge operations, the large dredge always produces higher turbidity (concentration) and a larger mixing zone region than the small size dredge for the same discharge velocity, mean grain size, and slurry concentration.

d) The plume of an above-water surface discharge is always larger than that of a submerged discharge as a result of the influence of turbulence.

e) For the same ambient conditions and the same discharge operations, the plume sizes of slower discharge velocity are always smaller than that of a higher discharge velocity for a specific dredge. Discharging at a velocity just above the critical velocity for heterogeneous flow is the recommended operational procedure for the purpose of reducing mixing region size.

f) The lowest centerline concentration of suspended sediment occurs at the lowest discharge velocity, so a small dredge is more desirable in the same dredging condition for small plume size and lowest concentration.

g) The plume size of a more submerged vertical downward discharge is always smaller than that of above water disharge, 45 degree downward submerged discharge, and submerged horizontal discharge.

12. The numerical model LTFATE is used for estimating the long-term response of a dredged material disposal site to local environmental forces such as waves, currents, and tides over a period of time on the order of months to years. A database of environmental forces is required to provide a means of defining realistic boundary conditions at a proposed or existing disposal site. Additional work is needed to get the database of environmental forces (tides, waves, and currents) for a specific disposal site in the vicinity of the GIWW. It is recommended that a first time user obtain assistance from the Corps of Engineers or the authors of this report.

13. SETTLE is another numerical model that facilitates proper dredged material management by providing an effective and efficient means of performing CDF design calculations. SETTLE is relatively easy to use and encourages the evaluation of an array of design alternatives. It does not, however, preclude the need for laboratory settling tests on the dredged material to be placed in the CDF.

CHAPTER 1 INTRODUCTION

ORGANIZATION

This research project entitled "Alternative Dredging and Disposal Methods for the Texas Gulf Intracoastal Waterway (GIWW)" began September 1, 1996. The research supervisor is Dr. Billy L. Edge, Bauer Professor of Dredging and Head of the Ocean Engineering Program at Texas A&M University in College Station, Texas. Dr. Robert E. Randall, Professor of Ocean Engineering and Director of the Center for Dredging Studies and Mr. John Basilotto, Director of the Center for Ports and Waterways, in Galveston, Texas assisted him. Graduate research assistants involved in the research include Ms. Sara Graalum, Mr. Michael Miertschin, Mr. David Cobb, and Mr. Qi He. The purpose of this report is to describe the final results of this two-year project.

The project is divided into six tasks. Task 1 is entitled "Cost and Engineering of Long Distance Pumping" and investigates the engineering issues and costs related to long distance pumping of dredged material. Task 2 entitled "Beneficial Uses of GIWW Dredged Material for the Texas Coastal Zone" addresses beneficial uses of dredged material for the GIWW and investigates some relative new ways to use dredged material beneficially. The third task is entitled "Identify Separation Techniques Applicable to GIWW Dredged Material." The fourth task is concerned with the development of a PC computer software for evaluating the cost of pumping slurries over long distances, and Task 4 is entitled "Develop Computer Software for Evaluating the Cost of Pumping Dredged Material through Long Pipes." Task 5 is entitled "Optimum Slurry Flow" and it addresses cutterhead dredge placement conditions in open water that minimize turbidity generation while maintaining optimum dredge production. The final task, Task 6, is entitled "Alternatives for Analyzing Dredged Material Disposal" and it investigates and demonstrates the use of existing software for managing the disposal of GIWW dredged material.

This final report is organized to address each task in the individual chapters that follow. Dr. Billy L. Edge, Dr. Robert E. Randall, and Mr. John Basilotto have been involved in the development of all tasks, but the research assistants have addressed only specifically assigned tasks. Mr. Michael Miertschin specifically worked on Tasks 1 and 4, and Ms. Sara Graalum has been working on Task 2 (Manufactured Soil as a Beneficial Use) and Task 3. Mr. Qi He worked on Task 2 (Thin-Layer Disposal as a Beneficial Use), Task 5, and Task 6. Mr. David Cobb conducted the work on Task 2 (Geotubes as a Beneficial Use).

BACKGROUND

The main channel of the Texas GIWW was completed in 1949 with a minimum depth of 3.7 m (12 ft), width of 38 m (125 ft), and length of 682 km (423 mi). Figure 1-1 illustrates the GIWW main channel path through Texas. The GIWW passes through wetlands that are very productive and ecologically sensitive areas of the Texas coastline. The wetland areas serve as nurseries for commercial fish and nesting grounds for aquatic animals and plants.

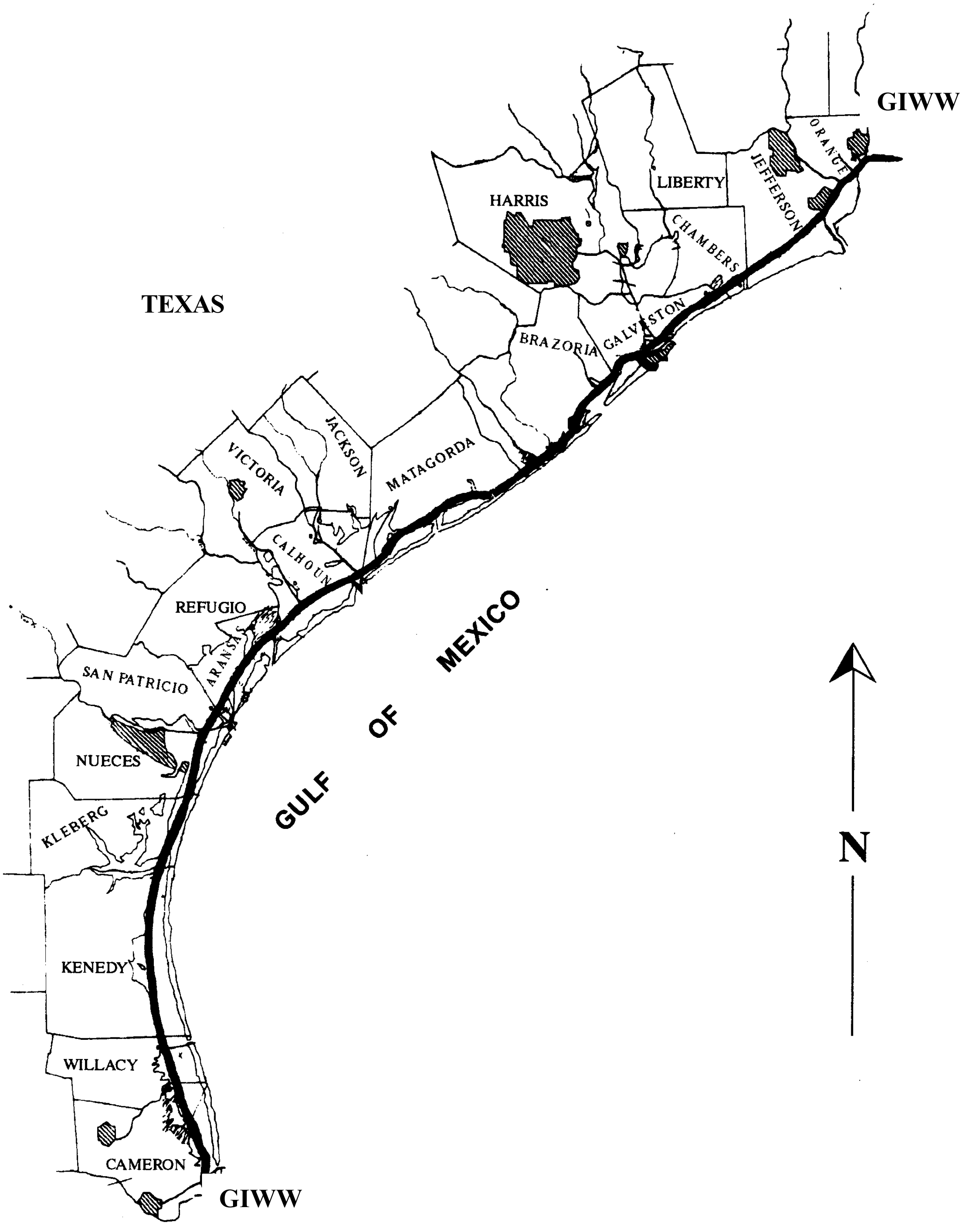


Figure 1-1. Path of Gulf Intracoastal Waterway (GIWW) Main Channel through Texas (TxDOT 1994).

The waterway has a very significant economic impact on the state of Texas. Garret and Burke (1989) reported that it carried approximately 73 million tons of commodities with an approximate value of $21 million in 1989. The inland waterway supports about 110,000 jobs in Texas alone, and it supports other activities such as manufacturing, petroleum production, and other commerce. It also provides year round access to sport and commercial fishing and recreational activities. The expenditures related to recreational activities are estimated as over $586 million annually (Garrett and Burke, 1989). The significant economic importance of the Texas GIWW suggests how important it is to keep all sections operable. Dredging of the waterway to keep its designed depth and the disposal of the resulting dredged material are essential in maintaining the operability of all sections of the waterway.

Expenditures on the order of millions of dollars are made every year to dredge material from the Texas GIWW and the associated ports and entrance channels. The method of disposing of dredged material is a major factor in the cost of dredging. Typically the dredged material is placed in approved open water or upland disposal sites. The use of upland (confined) disposal sites is further complicated by the fact that these sites are required to satisfy increasingly stringent environmental regulations. Open water disposal sites are sometimes economically attractive but also face more stringent environmental regulation. As these sites become full, the task of attaining new open water disposal sites is difficult because of new environmental regulations and opposition from special interest groups. In some cases open water disposal sites are forced into much deeper waters located further offshore, and the distance offshore increases the cost of disposal and overall dredging activity.

Open water disposal sites are located just outside the deep draft port entrance channels of Sabine, Port Arthur, Beaumont, Orange, Galveston, Houston, Texas City, Freeport, Matagorda, Corpus Christi, Port Isabel, and Brownsville. Dredging the GIWW produces dredged material that is placed in upland or open water disposal areas or used beneficially for artificial island construction (bird sanctuaries), wetland development (thin-layer disposal), cover for landfills, material, and beach nourishment for land and port development along the Texas coast.

The Texas Department of Transportation (TxDOT) is a non-federal sponsor of the Texas GIWW, and therefore, is very interested in exploring alternative dredging and disposal methods in order to reduce costs, maintain viable ports, beneficially use the dredged material, and provide economical water transport along the Texas coast. A private support organization for the GIWW is the Gulf Intracoastal Canal Association. The state of Texas has organized the Gulf Intracoastal Waterway Advisory Committee (GIWAC) to evaluate issues and advise concerning the operation and dredging of the Texas GIWW.

The Texas GIWW dredging sections have an average amount of dredged material placement and dredging frequency as tabulated in Table 1-1. These data indicate the largest amount of dredged material placement occurs north of Matagorda Bay, and the frequency of dredging is slightly greater south of Matagorda Bay. The average amount of dredged material placed for each of the 18 reaches during a dredging cycle is 470,229 m^3 (615,000 yd^3) and the average dredging frequency is 30 months. Reducing this volume of dredged material and the frequency of dredging can yield large economic savings, increase the life of existing disposal sites, and reduce the environmental effects on the ecologically diverse wetlands.

Table 1-1. Frequency and Yardage Dredged from the Main Channel of the GIWW (USACE 1975).

Reach	Material Disposed 1,000 m^3 (1,000 yd^3)	Frequency (months)
Port Arthur to High Island	306 (400)	60
High Island to Port Bolivar	841 (1,100)	18
Port Bolivar to North Deer Island	382 (500)	24
North Deer Island through Chocolate Bay	573 (750)	24
Chocolate Bay to Freeport Harbor	573 (750)	36
Freeport Harbor to Cedar Lakes	765 (1,000)	24
Cedar Lakes to Colorado River	765 (1,000)	24
Colorado River to Matagorda Bay	765 (1,000)	24
Matagorda Bay to San Antonio Bay	459 (600)	30
Across San Antonio Bay	573 (750)	24
San Antonio Bay to Aransas Bay	229 (300)	48-72
Across Aransas Bay	76 (100)	24-48
Aransas Bay to Corpus Christi Ship Channel	76 (100)	60
Corpus Christi to Baffin Bay	573 (750)	24
Baffin Bay to Mud Flats	612 (800)	18
Mud Flats to Channel to Port Mansfield	413 (540)	15
Channel to Port Mansfield to Arroyo Colorado	187 (245)	20
Arroyo Colorado to Port Isabel	298 (390)	18
Total	**8,468 (11,075)**	**Ave Freq. = 30**

The environmental impacts of dredging have been studied as part of two national research programs known as the Dredged Material Research Program (DMRP) in the 1970s and the Dredging Research Program (DRP) starting in the late 1980s and completing in 1995. The U.S. Army Corps of Engineers and the U.S. Army Engineer Waterways Experiment Station (WES) was the government agency conducting and overseeing the related research. A new federal research program called “Dredging Operation and Environment Research (DOER)” is currently underway at the Waterways Experiment Station. A large number of public reports are available from these projects related to dredging and dredged material disposal. Additionally, there are some excellent Corps of Engineers Engineering Manuals such as Dredging and Dredged Material Disposal (USACE, 1983), Confined Disposal of Dredged Material (USACE, 1987), and Beneficial Uses of Dredged Material (USACE, 1987) that discuss the general subject of this research. The Corps of Engineers and the Environmental Protection Agency have also jointly published guidance documents for evaluating dredged material for disposal in inland and ocean waters (USEPA/USACE, 1996) and guidance for evaluating management alternatives (USEPA/USACE, 1992). Smith (1978) discusses methodologies for choosing between wetland, upland, island, and aquatic habitat development, and Gupta et al. (1978) describes agricultural uses for dredged material.

Palermo et al. (1978) suggest methods for designing dredged material containment areas and Raster et al. (1978) discuss the concept of reusable disposal sites. Leslie et al. (1980) and Glover and Herbich (1989) describe methodology for evaluating upland (confined) disposal sites, and Giammona et al. (1989) discuss optimum disposal methods for dredged material resulting from dredging in the GIWW.

CHAPTER 2 COST AND ENGINEERING OF LONG DISTANCE PUMPING (TASK 1)

INTRODUCTION

In order to assess the best options for removal and disposal of channel sediment, it is necessary to examine the possibility of using a cutter suction dredge to excavate and transport the dredged material slurry by pumping the slurry through a long discharge pipeline. Many factors are considered when determining the most economic method of transporting the dredged material to a containment area. Some knowledge of the engineering processes that occur in a cutter suction dredging project is necessary to accurately weigh the options.

ENGINEERING OF A CUTTER SUCTION DREDGING PROJECT

A cutter suction dredge (Figure 2-1) is a hydraulic dredge that uses a large centrifugal pump to remove material from the bottom of the channel and pump it as a sediment-water slurry through a pipeline to a containment facility. The dredge itself is a barge that typically has no means of self-propulsion. On the forward part of the barge is the suction pipeline that is mounted on a moving support structure, called the "ladder." At the end of the ladder is the cutter, which cuts into the sediment in a rotary fashion in order to free it up to be taken into the suction line. The suction line is attached to the main dredge pump located on the barge. The sediment-water slurry is then transported through the main pump and into the discharge pipeline that delivers the slurry to the disposal site. On non-self-propelled dredges, two long vertical poles, called "spuds," are mounted on the stern of the dredge. The dredge moves itself forward by anchoring one spud and pivoting around it to a certain angle, at which point the other spud is dropped and becomes the anchor and pivot point. The ladder is lowered down to the channel bottom and a swath is cut through the sediment as the dredge swings on one of the spuds.

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. If the main pump head is less than 5 percent greater than the head losses, then a booster pump is added to the system. When a booster is added in the discharge line, the head of the booster is simply added to the head of the main pump to obtain the total system head. When a sufficient number of booster pumps are added to the system, the total system head will be greater than the head losses, and the slurry is able to reach the disposal area.

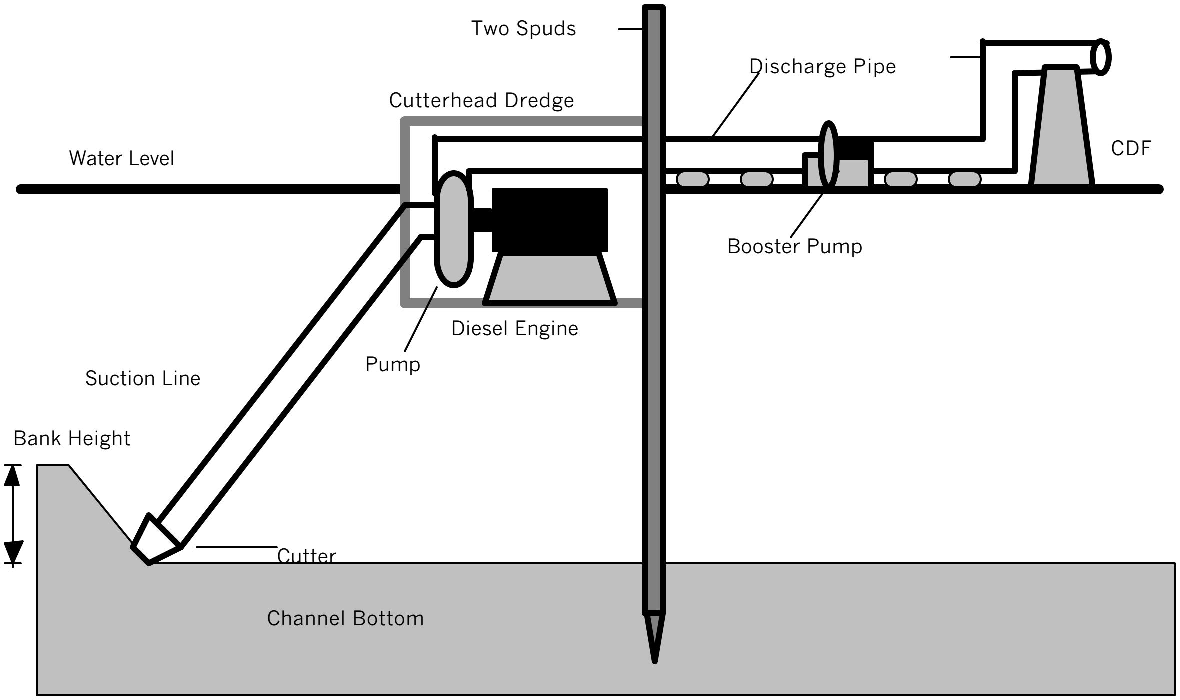


Figure 2-1. Diagram of a Cutter Suction Dredge.

There are many options for dredged material placement along the GIWW. Confined disposal facilities (CDFs) and open water disposal sites are the current preferred locations for dredged material placement. There are numerous confined disposal facilities all along the shores of the GIWW, and thus there has not historically been a need for long distance pumping of dredged material. However, as the CDFs approach their full capacity and environmental concerns in certain areas of the GIWW increase, then long distance pumping may become a viable alternative in the future.

PRODUCTION

One of the key factors in determining the feasibility of a dredging project is the production rate that can be achieved. The production rate is defined as the volume of dredged material removed from the channel as a function of time, usually expressed as cubic yards per hour or cubic meters per hour. If a high production rate is maintained, then the project can be completed more quickly and at a lower cost than if lower production rates are used. There are many factors that contribute to the production rate:

- In situ sediment specific gravity – high in situ specific gravity results in a higher delivered concentration of solids by volume (C_v). A higher concentration means a more efficient dredging operation because less water and more sediment is transported.

- Sediment grain size – small grain size sediments are more easily transported and induce smaller frictional head losses.

- Discharge lift – this quantity describes the elevation difference between the dredge and the disposal end of the discharge line. This quantity adds directly to the head losses, so it is desirable to have a small value for this quantity.

- Discharge pipe length – it may be cheaper sometimes to lower the production rate rather than add a booster pump when the discharge line is too long for the main pump.

- Minor losses – head losses also occur at discontinuities in the pipeline such as valves, joints, and bends.

- Pump efficiency – the efficiency of the dredge pump itself also has a direct effect on the production rate.

- Bank height – dredge cutters are typically about one meter or several feet in diameter, and sometimes the depth of the cut (called the "bank height") is smaller than the cutter diameter. In this situation, the optimum production is not achieved because not as much material is being taken into the suction line.

- Dredge cycle efficiency – due to the nature of the dredge "walking" process, sediment is not being excavated from the cut 100 percent of the time. In fact, with a typical walking spud dredge, only about 50 percent of the time is the cutter in the sediment. Higher efficiencies can be attained through the use of a spud carriage dredge, but such dredges are uncommon.

DREDGE COST COMPONENTS

It is no simple matter to quantify all the costs involved with a dredging project. Capital investment, operating costs, and mobilization and demobilization costs are some of the many costs that are considered.

Dredges are expensive pieces of machinery, and for this reason, many dredges in use today are very old. Capital investment is very substantial for the contractors, and this investment is reflected in their bids for dredging work. Dredges are not the only large items of capital investment for the contractors. Other large and expensive items include work tugs, crew and survey barges, derrick barges, fuel and water barges, work barges, and pipeline sections. Booster pumps are also very expensive, and therefore it is prudent to consider other options before adding a booster.

The most complex part of determining a cost estimate is the dredge operating costs. The major cost factors are summarized as follows:

- Fuel costs – great quantities of fuel are consumed during a typical dredging project. The horsepower of the dredge and supporting equipment will determine how much fuel is used. However, one also must consider the number of hours the dredge is in use and at what percentage of full power it is operating. Also, if the dredge is not operating at a high efficiency, it may consume excessive amounts of fuel.

- Lubricants – with all the machinery incorporated into dredges and the supporting equipment, large amounts of lubricants are used as well. It is common practice to estimate the cost of lubricants at about 10 percent of the total fuel cost.

- Dredge crew – a large contingent of labor must be employed on dredging projects, including the captain, officers, engineers, dredge operator, winch operators, welders, deckhands, cooks, and electricians.

- Land support crew – there is also a need for personnel to be working apart from the dredge, including pipeline handlers, booster pump operators, fill foremen, and equipment operators.

- Routine maintenance and repairs – in every dredging project, many minor repairs need to be made, as well as just routine maintenance. Replacing worn engine parts, damaged pipes and hoses, electrical consumables, and lubrication of equipment are all done regularly.

- Major repairs and overhauls – though major repairs usually will not take place during a project, they will still show up in contract bids as a small percentage of the cost of the actual repairs.

- Other considerations – general overhead costs are usually taken at around 9 percent of the total cost of the project. Depreciation of the equipment is a fairly major item, especially for the pipelines that wear much more quickly than other components. Lastly, the contractor has the right to make a profit on the job, so a small percentage of the total must be added for this purpose.

One of the more abstract concepts when trying to quantify the cost of a dredging project is the cost of mobilization and demobilization. This amount varies greatly from contractor to contractor and job to job based on the distance from the site and readiness to mobilize. Before starting a dredging project, all the equipment involved is inspected, some parts are assembled, and everything is prepared for transport to the dredge site. The move to the job site involves paying for tugs and relocating personnel. During the move the dredge and other equipment are sitting idle when they could be making money for the contractor somewhere else, so this is an indirect cost that must be considered. Once at the site, the equipment is assembled and prepared for work and the discharge pipeline is put in place. All of these tasks are done in reverse for the demobilization process, unless the contractor has to begin work somewhere else immediately after finishing work at this site.

PRINCIPLES OF HYDRAULIC DREDGING

When pumping dredged material long distances, the main pump may not have enough "head" to transport the slurry to the disposal area. Head is a measure of energy per unit weight of fluid, and is given in units of ft-lb/lb = ft, or m-N/N = m. The total pump head is the difference between the discharge head (H_d) and the suction head (H_s), or

$$H = H_d - H_s \tag{2-1}$$

and

$$H_d = \frac{P_d}{\gamma} + \frac{V_d^2}{2g} + z_d \tag{2-2}$$

$$H_s = \frac{P_s}{\gamma} + \frac{V_s^2}{2g} + z_s \tag{2-3}$$

where γ is the specific weight of the fluid, P is the pressure in the pipe, V is the mean velocity in the pipe, z is the elevation of the centerline of the pipe with respect to the centerline of the pump, and the subscripts d and s stand for discharge and suction pipe, respectively. These equations are taken from Bernoulli's equation and assume steady flow, incompressible fluid, and frictionless pipe. Since real pipes are not frictionless, an additional term must be incorporated to account for the head losses.

When the pipeline is horizontal, as is the case for most dredging operations, gravity does not directly play a significant role in preventing the slurry from moving through the pipe. However, there is a large amount of friction between the slurry and the pipeline. These frictional forces, with the addition of "minor losses" from discontinuities in the pipeline (e.g., valves, bends, sudden increases/decreases in diameter, etc.) subtract from the energy of the system. 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. The frictional component of the head losses is determined by the Wilson et al. (1997) equation described later in this paper, and the minor head losses are given by

$$h_m = K\frac{V^2}{2g} \tag{2-4}$$

where V is the mean velocity of the mixture, g is the acceleration due to gravity, and K is a constant dependent on the type of discontinuity in the pipeline. The minor loss coefficients, or K values, for various pipeline system components are given in Table 2-1.

If the main pump head is less than 5 percent greater than the head losses, then a booster pump must be added to the system. When a booster is added in the discharge line, the head of the booster is simply added to the head of the main pump to obtain the total system head. When a sufficient number of booster pumps are added to the system, the total system head is greater than the head losses, and the slurry is able to reach the disposal area.

Table 2-1. Minor System Head Loss Coefficients (Basco, 1973).

System Component	K
Suction Entrance	
Plain end suction	1.0
Rounded suction	0.05
Elbows	
Long radius suction	0.6
45° elbows	0.4
90° elbows	0.9
Stern swivel	1.0
Ball joints	
Straight	0.1
Medium cocked	0.4-0.6
Fully cocked	0.9
End section	1.0

Sediment transport in pipelines is divided into three categories of flow: homogeneous, heterogeneous, and flow with a moving bed (Figure 2-2). 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.

Difficulties Associated with the Development of Cost Estimation Software

Due to the large number of factors considered when estimating the cost of a dredging project, it is quite a challenge to develop a general cost estimation program that yields accurate results. The most difficult aspect of creating such a program is the fact that each dredging contractor has different dredging equipment, different methods of completing a project, and different considerations for mobilization and demobilization. Also, each dredging project has its own unique set of problems associated with different aspects of its completion. For instance, some areas have strict environmental regulations that may prove costly to the dredging contractor. Problems such as these and numerous other unforeseen difficulties present a challenge to both the individual who develops the program and the individual making the cost estimate. While every effort may be made by the programmer to compensate for all possible scenarios, there will inevitably arise some additional problems. Hence, the cost estimator must pay careful attention to every detail pertaining to the dredging project in question.

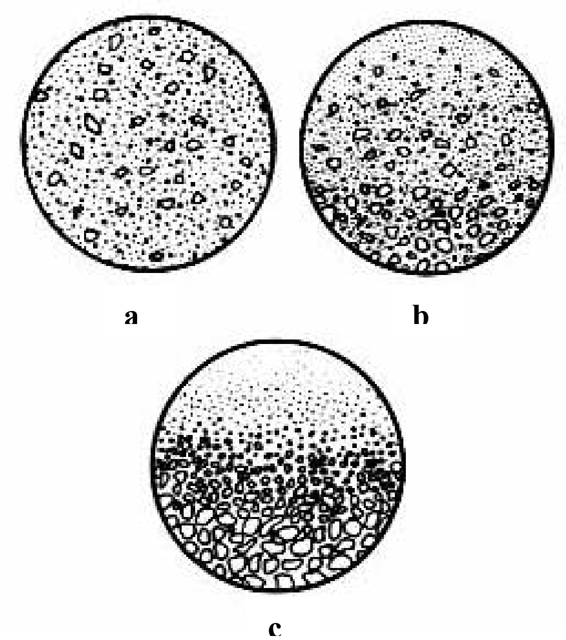


Figure 2-2. Sediment Distribution in a Pipeline (Herbich, 1992). (a) Homogeneous Flow, (b) Heterogeneous Flow, (c) Flow with a Moving Bed.

PREVIOUS RESEARCH

Cost estimation methods have been in existence since the early days of the dredging business. Unfortunately contractors have conducted most of the research, and they tend to keep their findings within the company. However, there has been research conducted by outside sources as well.

Estimating Cost

Bray et al. (1997) present an excellent outline for developing a cost estimating program. They have published a book that details most of the dredging processes, which includes information on many of the major factors that influence the dredging cost. Much of the operating cost portion of the CSDCEP program is taken from this source. Huston (1970) also gives some general guidelines for cost estimating and presents a large amount of practical knowledge that was obtained through many years in the dredging industry. Some of these guidelines are utilized in CSDCEP.

The United States Army Corps of Engineers (USACE, 1988) has done extensive research on the cost estimation procedure. USACE has developed their own program, but it has not been published in open literature. However, many of the procedures used in the program are published. The research conducted by USACE in the areas of labor cost estimation and mobilization/demobilization costs is particularly useful and is included in CSDCEP.

Estimating Production

Durand and Condolios (1952) pioneered the area of sediment transport research. From their extensive experimental studies, they were able to derive the following equation for flow in the heterogeneous flow regime:

$$\frac{i_m - i}{C_v i} = 81\left[\frac{gd(\rho_s/\rho - 1)}{V^2}\left(\frac{1}{C_D}\right)\right]^{1.5} \qquad \textbf{(2-5)}$$

where i_m is the hydraulic gradient (head loss in meters or feet of water per unit pipe length) of the mixture, i is the hydraulic gradient for water, d is the median particle diameter, ρ_s and ρ are the density of the solids and of water respectively, V is the mean velocity of the mixture, g is the acceleration due to gravity, C_v is the delivered concentration by volume, and C_D is a drag coefficient for the individual solid particles.

Newitt et al. (1955) conducted similar experiments and derived another formula for heterogeneous flow:

$$\frac{i_m - i}{C_v i} = 1100\left(\frac{\rho_s}{\rho} - 1\right)\frac{gd}{V^2}\frac{V_t}{V} \qquad \textbf{(2-6)}$$

where V_t is the particle settling velocity. In the early 1960s, the Durand equation became generally accepted in the dredging industry. Zandi and Govatos (1967) and Babcock (1971) conducted further experiments and found that Durand's equation correlated poorly with their results. Babcock found that Newitt's equation more accurately described his data, though the error was still large.

Wilson et al. (1997) have developed a more accurate method of determining frictional head losses. They concluded that much of the error associated with earlier attempts at describing slurry flow could be contributed to the degree of stratification within the heterogeneous suspension. Wilson et al. (1997) introduced the parameter V_{50}, which signifies the mean mixture velocity at which half of the mass of the solids is suspended by the fluid and half by contact with other particles. Through the addition of this parameter and further analysis of data, a more accurate head loss determination procedure was obtained. The Wilson et al. (1997) methods for calculating friction losses and critical velocities in pipelines are widely accepted in the dredging industry today. Further description of their results is given later in this paper. Due to the general acceptance within the industry of the Wilson et al. (1997) method, it was decided to use this method in CSDCEP.

Non-dimensional pump characteristics curves (Herbich, 1992) are used in CSDCEP to make the production estimation. By using his procedure, described later in this paper, it is possible to determine the operating characteristics of any similar pump with any size impeller operating at any speed.

Turner (1996) provides many useful practical guidelines, but the key contribution is related to the “bank factor.” This factor, simply stated, is the ratio of bank height to the diameter of the cutter head. The bank factor has a significant effect on the production, and is crucial to the development of an accurate cost estimate.

METHODOLOGY FOR ESTIMATING PRODUCTION

Perhaps the most crucial piece of the cost estimating puzzle is the estimate of production. The rate of production is the number of cubic yards of sediment per hour that are removed from the channel bottom by the dredge. From a cost estimation standpoint, this is an important factor simply because it determines how much time it takes to complete the project. More time on the job means more wear on the machinery, more fuel used, and more pay for the workers. It is therefore imperative that the estimate of the production be as accurate as possible. CSDCEP provides such an estimate through a combination of sediment transport theory, non-dimensional pump characteristics curves, and factors used by experienced dredgers.

Determination of Critical Velocity

As a grain of sediment travels through a pipeline, there is a certain velocity that the fluid around it must maintain in order to prevent the grain from falling to the bottom of the pipe and becoming stationary. If this velocity is not maintained, much of the sediment will settle and clog the pipeline. This condition is very undesirable, because it means shutting down the operation while the line is being unclogged. This “critical velocity” is a function of the specific gravity of the sediment, the grain size, and the diameter of the pipe. Wilson et al. (1997) presented a convenient method of determining the critical velocity using a nomograph (Figure 2-3). This nomograph has been entered into the CSDCEP spreadsheet and yields the critical velocity based on an assumed specific gravity of 2.65 (quartz) and median grain diameter of 0.4 mm. It is desirable to pump near the critical velocity based on the fact that head losses, power requirements, and pipeline wear are minimized at this value. However, pumping at a higher velocity results in higher production and less time on the job. Also, as observed by Matousek (1996), the solids concentration and particle size distribution vary locally in the slurry within long pipelines.

Higher slurry velocities than predicted should therefore be maintained in order to achieve continuous delivery of solids. Keeping these facts in mind, CSDCEP uses a value for the slurry velocity of 30 percent of the range between the critical velocity and the threshold velocity.

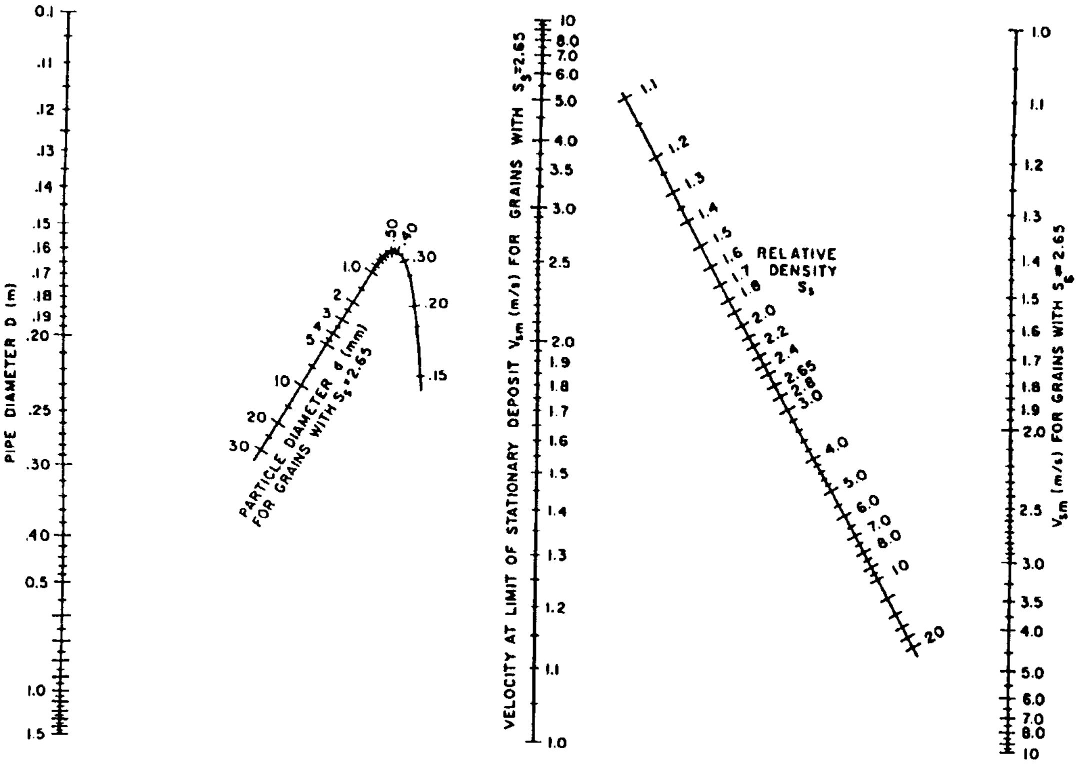


Figure 2-3. Velocity at Limit of Stationary Deposition (Wilson et al., 1997).

Determination of Head Losses

It is important to calculate the head losses for the system because this is how the maximum pumping distance for a particular pump is determined. The major component of the head losses of a system is the frictional head loss. There are also minor losses due to pipe joints and bends, but when you are dealing with thousands of feet of pipe, the frictional losses far outweigh the rest. Head losses due to friction are determined in the program by the procedure outlined by Wilson et al. (1997). The head losses per unit length (feet of head per feet of pipe) are given by

$$i_m = \frac{fV^2}{2gD} + 0.22(S_s - 1)V_{50}^{1.7}C_v V^{-1.7} \tag{2-7}$$

$$V_{50} = w\sqrt{\frac{8}{f}}\cosh\left[\frac{60d}{D}\right] \tag{2-8}$$

$$w = 0.9V_t + 2.7\left[\frac{(\rho_s - \rho_f)g\mu}{\rho_f^{\,2}}\right]^{\frac{1}{3}} \tag{2-9}$$

where i_m is the head loss due to friction per unit length, d is the median particle diameter, D is the pipe inside diameter, ρ_s and ρ_f are the density of solid and fluid, respectively, V is the mean velocity of the mixture, f is the friction factor for water, g is the acceleration due to gravity, μ is the dynamic viscosity of the fluid, S_s is the specific gravity of solids, C_v is the delivered concentration by volume, and V_t is the particle terminal velocity. The value of 0.22 in the equation for i_m is a typical value for the ratio

$$\frac{i_m - i_f}{S_m - S_s} \tag{2-10}$$

where i_f is the hydraulic gradient of the fluid and S_m is the mean specific gravity of the mixture. Sellgren et al. (1997) have experimentally determined several different values for this ratio based on grain size, delivered concentration, and pipe diameter. For typical dredging operations, 0.22 is the appropriate value for this ratio, and therefore CSDCEP uses this value.

Dimensionless Pump Characteristics Curves

In order to create a dredge production program that can be applied to any size dredge pump, Herbich's (1992) method of using dimensionless parameters in the pump characteristics curves is incorporated. A typical set of pump characteristics curves shows the pump head, brake horsepower (or shaft horsepower), and pump efficiency as a function of discharge rate. In a dimensional format, these curves are only valid for a pump with the same specifications and operating at the same speed. However, when translated into a dimensionless format, the values of head (H), horsepower (P), and discharge (Q) may be calculated for any similar pump operating at any speed (Figure 2-4). Since efficiency (η) is a percentage, it is already dimensionless. The dimensionless values are determined by:

$$Q_{\text{dim}} = \frac{Q}{\omega D^3} \tag{2-11}$$

$$P_{\text{dim}} = \frac{P}{\rho \omega^3 D^5} \tag{2-12}$$

$$H_{\text{dim}} = \frac{gH}{\omega^2 D^2} \tag{2-13}$$

where the subscript "dim" indicates a dimensionless quantity, g is the acceleration due to gravity, D is the impeller diameter, ω is the pump speed in radians per second, and ρ is the fluid density.

The curves that are used in the program were created by transforming a number of dimensional curves obtained from Georgia Iron Works and Mobile Pulley literature and forming a composite set of dimensionless curves from them. With this set of dimensionless curves it is now possible to obtain the values of pump head, brake horsepower, discharge, and pump efficiency simply by entering any one of the values listed along with an impeller diameter and pump speed. Also, there is an option to input values for pump characteristics curves if the user knows the values for a particular pump.

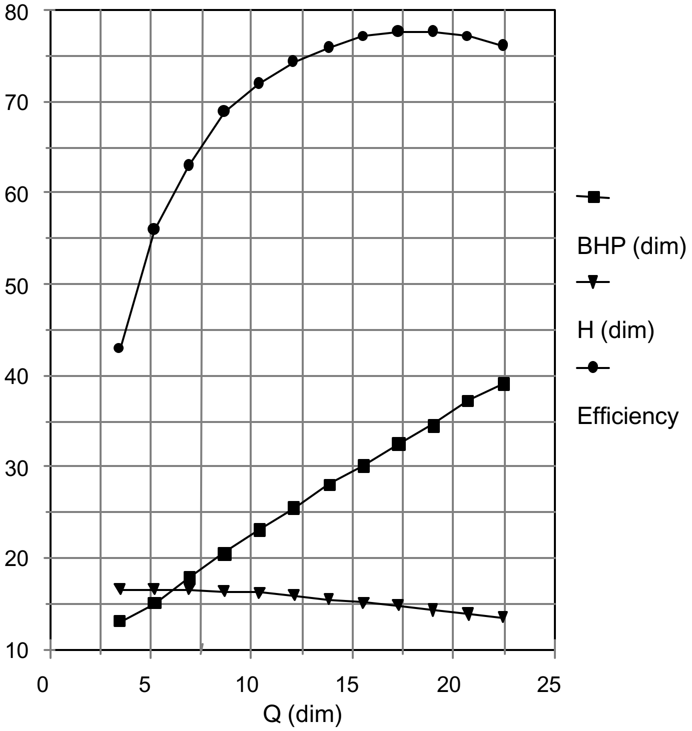


Figure 2-4. Dimensionless Pump Characteristics Curves Used by CSDCEP.

The Production Estimate

The production rate of a cutter suction dredge is calculated using the following equation:

$$P(cy/hr) = Q(GPM) \times C_v \times 0.297 \times PF \times DE \quad \textbf{(2-14)}$$

where DE is dredge cycle efficiency (~ 0.5 for a walking spud dredge), P is the production rate in cubic yards per hour, C_V is the maximum concentration of solids by volume, PF is the production factor that accounts for material differences, bank height, and other factors, and 0.297 is a units conversion factor. In order to calculate the production using the above method, four values are needed: specific gravity of the mixture, impeller diameter, pump speed, and discharge rate.

Specific Gravity of the Mixture

This value is assumed to be 1.4 initially, but may become smaller if the friction head losses are too large at this value. It is desirable to pump at the highest possible specific gravity, because this means a greater concentration of solids by volume, which results in a higher production rate. This number changes incrementally down to a value of 1.2 in order to reduce head losses. It would be very inefficient to pump at a lower specific gravity than this, and a booster should be added at this point.

Impeller Diameter

From examining the dimensionless pump curve equations, it is obvious that the impeller diameter of the pump must be specified in order for the user to obtain the proper values. The problem here lies in the fact that a number of different sized impellers may be used in any given pump. Contractors usually change the impeller depending on the length of pipeline used on a job. It is common practice to use a smaller impeller for shorter line lengths, thus conserving horsepower, and larger impellers for longer pipe lengths, thereby maximizing pump head. In order to simplify the input for this program, a list of typical impeller diameters is incorporated into the program (Table 2-2), with different diameters listed for each dredge size and pipe length. These values were obtained from pump specifications listed in various pump manufacturers' catalogues and from personal communication (Roman, 1997). A selection does not need to be made by the user for this quantity because the program determines the appropriate value.

Pump Speed

This value is equally as important as the impeller diameter for the calculations. Each pump has its own most efficient operating speed, and this value does not vary nearly as much as the impeller size. With this in mind, the program accesses another table of typical values (Table 2-2) in order to obtain a suitable pump speed for its calculations. These values were obtained by examination of the pump characteristics curves provided by Georgia Iron Works and Mobile Pulley.

Discharge Rate

As shown in Figure 2-4, the pump head decreases with increasing discharge rate. The discharge rate chosen by the program is 30 percent of the range between the critical velocity and the threshold velocity. The threshold velocity is defined as the velocity above which the slurry becomes homogeneously mixed throughout the pipe. The pump head is then obtained from the dimensionless pump curves. If there is insufficient pump head to overcome the head losses, and the specific gravity has already been incremented downward to the minimum, the program prompts the user to add a booster to the system.

Table 2-2. Impeller Diameters and Pump Speeds Used in CSDCEP.

Pump Size (in)	Short Pipeline Impeller D (in)	RPM	Long Pipeline Impeller D (in)	RPM
12	36	535	42	500
14	42	510	50	485
16	44	480	56	450
18	48	450	60	425
20	56	425	68	400
22	62	400	72	385
24	68	385	80	360
26	74	360	88	335
28	80	350	94	315
30	84	325	98	300

The addition of a booster increases the head of the total system by the amount of pump head achieved by the booster. The above process is then repeated for the new system configuration. Once an acceptable number of boosters has been selected, the pump efficiency is obtained from the curves and the production is calculated using the formula stated above. Figure 2-5 illustrates a flowchart of the production estimation procedure.

U.S. Army Corps of Engineers Method of Production Estimation

Based on previous dredging experience, the Corps has compiled a database of typical dredge production rates based on dredge size and pipeline length. The program calls three values of pipeline lengths and their corresponding production rates from the database based on dredge size. Using the pipeline length entered on the main page, a production rate is linearly interpolated from these values. If the resulting production rate is insufficient for an efficient operation, a message indicates that another booster is needed. After adding a booster, the line lengths corresponding to the production rates are multiplied by a “booster factor” which is roughly equal to one plus the number of boosters. This works on the principle that pumps in series simply add to the head of the system. Or, simply stated, the length that pumps in series can pump is equal to the sum of the lengths that each can pump individually. Thus, the production rates in the table remain the same, but the line lengths are multiplied by the booster factor. This process repeats until a suitable number of boosters are reached and a sufficient production rate is obtained.

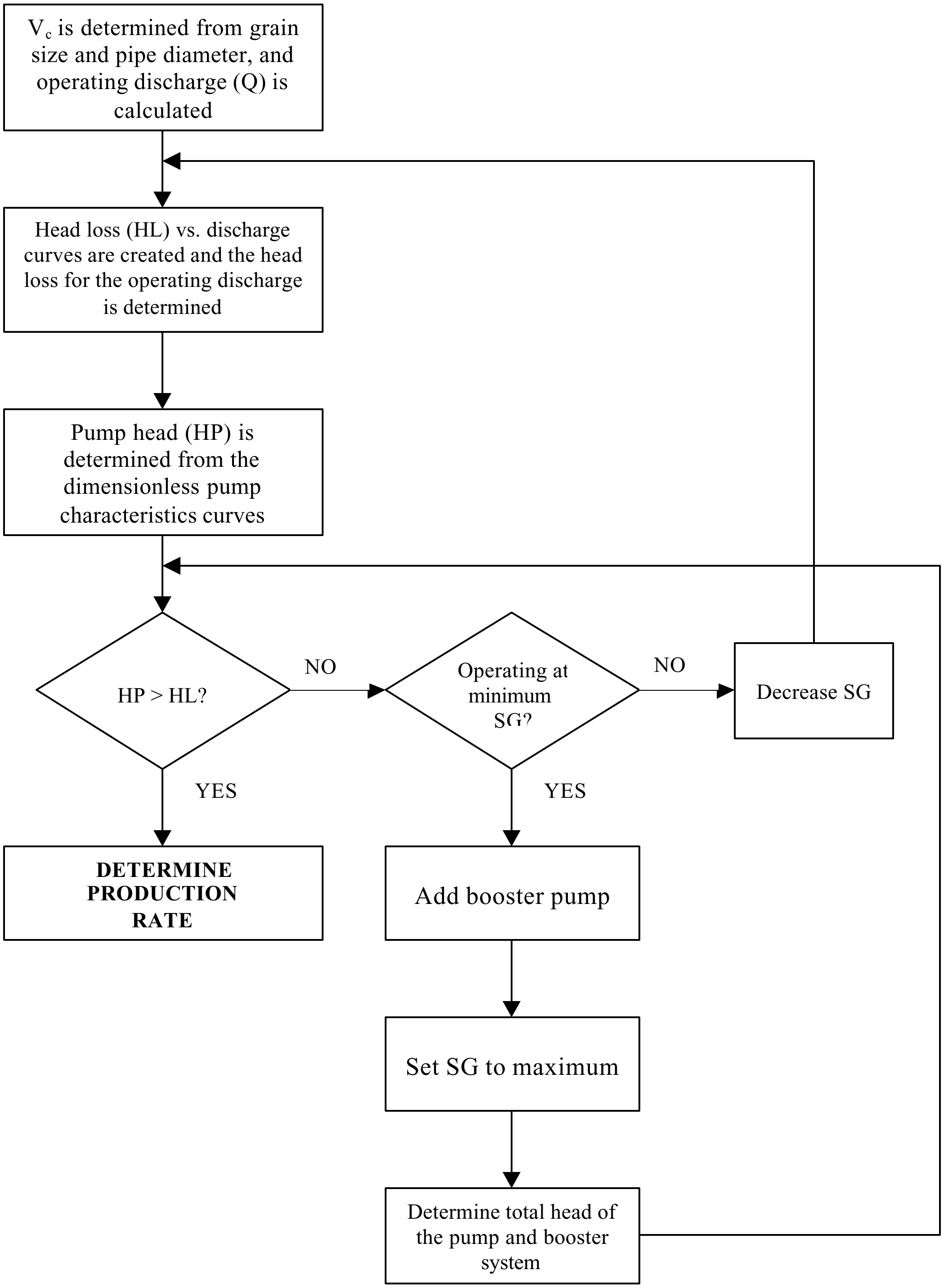


Figure 2-5. Flowchart of Production Estimation Procedure Used in CSDCEP.

Other Factors Affecting Production

Both the built-in production estimation program and the Corps method yield production rates for slurry composed entirely of clean sand with a median grain diameter of 0.4 millimeters. Since the characteristics of sediments vary widely and have a great influence on the actual production rates, the Corps has introduced the concept of a “material factor” to account for the difference (USACE, 1988). This factor takes into account different viscosities, grain sizes, and in situ consolidation to provide a description of relative ease of pumping. For instance, silt is easily excavated and, due to its tendency to remain in suspension, is easily transported. On the other hand, compacted clay is difficult to excavate and, once excavated, is difficult to pump through the line due to its tendency to consolidate and create “clay balls.” Values for the USACE material factors used in CSDCEP are shown in Table 2-3. Since the sediment at a particular job site is seldom composed of a single type, the user is allowed to enter percentages of the whole of 10 different sediment types to create a composite material factor. This factor is then applied to the calculated production rate. Therefore, the silt mentioned above has a factor of greater than one while the clay has a factor of less than one.

Table 2-3. Material Factors Used in CSDCEP (USACE, 1988).

Material	Specific Gravity	Factor
Mud & silt	1.2	3.0
Mud & silt	1.3	2.5
Mud & silt	1.4	2.0
Loose sand	1.7	1.1
Loose sand	1.9	1.0
Compacted sand	2.0	0.9
Stiff clay	2.0	0.6
Compacted shell	2.3	0.5
Soft rock	2.4	0.4
Blasted rock	2.0	0.25

Another significant factor that must be considered is the bank height efficiency, or “bank factor.” In order to calculate the bank factor, the ratio of the cutter diameter to the bank height entered in the main page must be determined. This value is then used in conjunction with Figure 2-6 to obtain the bank factor. Two cells are left open for additional factors to be entered manually. Typical factors that may be necessary depending on the job site conditions are wind and wave factors. All of these factors are then applied to the production rate to yield the final production rate estimate.

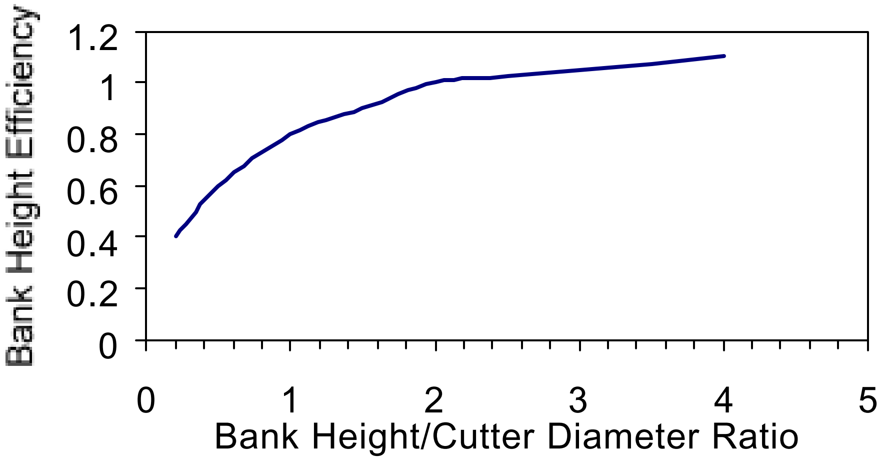


Figure 2-6. Bank Factor Determination Chart (Scott, 1997).

METHODOLOGY FOR ESTIMATING COST

Once the production rate is determined, the length of time required to complete the project is easily calculated. The operating costs and labor costs may then be determined based on the length of time that the equipment is in use and the workers are being paid. Other components of the final cost such as mobilization and demobilization are independent of the production rate and are calculated separately.

Mobilization and Demobilization

Mobilization and demobilization costs are perhaps the most difficult to accurately estimate in a program of this type. The main problem lies in the fact that no two dredges have to travel the same distance to arrive at a job site. Also, different dredges are always in different stages of readiness to mobilize. For example, contractor A may be completing a project 10 mi away from the site being considered, while contractor B may have a dredge not in use 100 mi away. In this example, contractor A has less distance to travel to the job site, but has more preparation to do before moving his operation. Also, contractor A's mobilization costs are basically included in the demobilization costs for the last project. Contractor B, however, has little preparation to do but must travel a greater distance. In this scenario, contractor A would likely have substantially less costs associated with mobilization, and would therefore give a lower bid price for the project. A flowchart of the mobilization and demobilization process is displayed in Figure 2-7. Many times the contractors are not compensated for demobilization costs and therefore do not include them in their bids. For this reason an option is provided in the program to leave the demobilization costs out of the estimate.

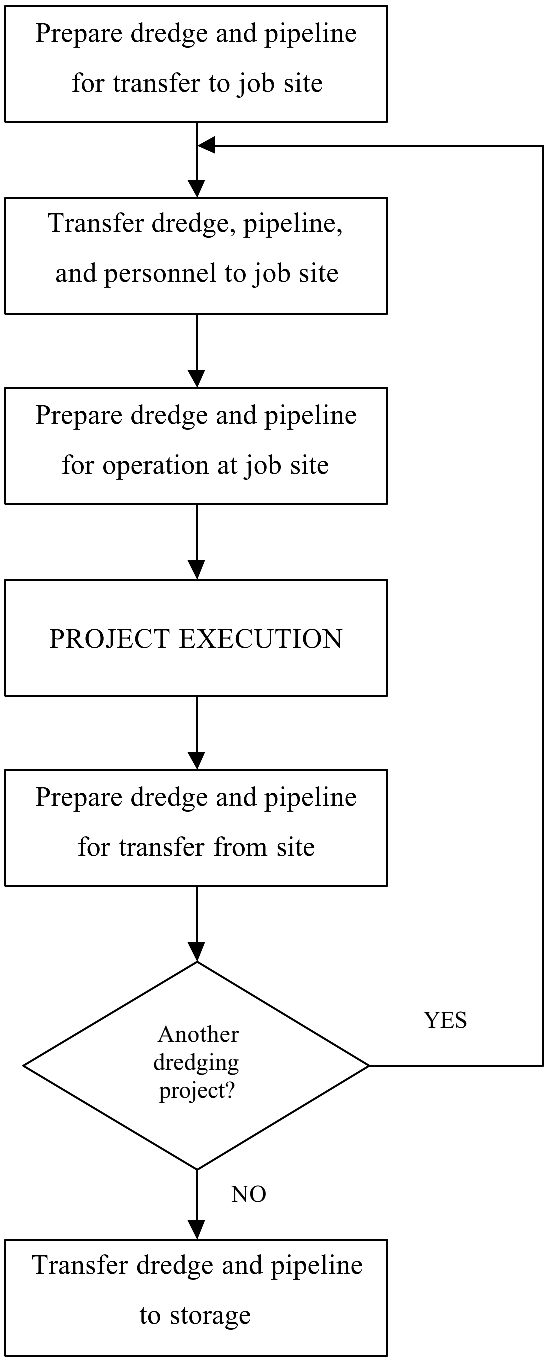


Figure 2-7. Mobilization and Demobilization Flowchart.

The calculations on the mobilization/demobilization page are based on the assumption that all dredges are not in use immediately prior to transfer to the job site. The main factors, therefore, in determining costs for this portion of the dredging project are the distance to and from the job site, the size of the dredge, and the length of pipeline used on the job. The mobilization/demobilization page is broken down into five main sections: the mobilization and demobilization input parameters, the working rates for labor and equipment, standby rates for equipment, and the calculations.

Mobilization Input Parameters

The only manual inputs in this section are the distance to the job site, the number of crew needed for the tow to the site, and an input for any lump sums required by the site, such as cost of buoy placement, etc. The other parameters in this section are calculated based on size of dredge and length of pipeline. These calculations yield values for the length of time and number of crew required for the preparation and transfer of personnel, pipeline, and the dredge itself.

Demobilization Parameters

The distance of relocation and the lump sum value are the only manual entry values in this section. Other values are taken from the defaults page or calculated. These parameters describe only the length of time necessary for transfer and preparation for storage of the dredge and pipeline.

Working Rates

Costs per hour of the tugs and barges in operation as well as hourly labor rates are calculated here. The monthly working rates for the tugs and barges are taken from the database and divided by the hours operating time per month. The labor rates are calculated on the execution page.

Standby Rates

It also costs the contractor to have his equipment sitting idle while it could be earning money, so standby rates must also be taken into account. Once again, the values for the tugs and barges are taken from the database, this time with the addition of pipeline standby rates.

Calculations

For each of the following sections costs are calculated for both mobilization and demobilization.

- Prepare dredge for transfer – standby costs are calculated for the dredge and booster pumps. Also, labor costs, subsistence, fuel, and miscellaneous supplies are considered.
- Prepare pipeline for transfer – here standby costs are calculated for the pipeline, as well as for the tugs and barges. The additional costs listed above are also calculated for this section.

- Transfer to and from site – towing vessel, relocation of personnel, subsistence, and labor costs are calculated. In this section, working rates are used for the work tug, but for all other equipment standby rates are used.
- Prepare dredge after transfer – for mobilization purposes, this section computes costs of preparation for work. For demobilization, this section computes costs of preparation for storage. Miscellaneous supplies, fuel, subsistence, and labor costs are calculated, as well as standby costs for the dredge and boosters.
- Preparation of pipeline after transfer – for mobilization, this section yields the cost of laying the pipeline at the job site and preparing it for work. For demobilization, this cost is simply preparation for storage. The tugs and barges are once again considered, as well as the miscellaneous costs listed above.

Labor Costs

The largest component of the cost of a dredging project is the cost of hired labor, usually accounting for about 40 percent of the total cost. A dredging operation requires the services of many different personnel. A typical project requires a number of crewmen and laborers, both salaried and hourly. For a typical job, there is one each of the following salaried workers: a captain, officer, chief engineer, and an office worker. Depending on the size of the dredge being used, the number of the following hourly paid workers will vary: levermen, dredge mates, booster engineers, tug crew, equipment operators, welders, deckhands, electricians, dump foremen, oilers, and shore crew. Data for the number of crew and their respective pay rates are taken from the database. Wages are then adjusted using the values from the defaults page for fringe benefits, overtime pay, holidays, vacation time, taxes, and workers' compensation. The resulting total hourly rate is multiplied by the hours per day each crewmember works to obtain the total daily cost of labor. These adjustments are not made to the salaried workers.

Data for the number and cost of crew were obtained through the Texas Department of Transportation for dredging operations on the GIWW. The pay rates for the crew vary geographically, and a scaling factor is used to adjust the rates accordingly.

Equipment and Operating Costs

After the labor costs, the equipment costs are the largest part of the total project cost. The capital costs of the dredge, boosters, tugs, and barges are obtained from the database along with the number of each needed for the project. Bray et al. (1997) provide the method for computing each of the following:

Routine Maintenance and Repairs

For all of the equipment listed above, it is recommended to multiply the capital value by 0.00014 to obtain the daily costs for minor repairs that can be completed while the dredge is operating.

Major Repairs

For the average daily cost of repairs requiring the dredge or any other piece of equipment to be shut down, it is recommended to use a value of 0.0003 times the capital value.

Insurance

Insurance is suggested to be calculated by multiplying the capital cost by 0.025 and dividing by the average number of working days per year.

Fuel Cost

In order to calculate the fuel consumption, one must determine the effective hours per day that the dredge operates at 100 percent power. The defaults page provides the user with the option of entering the hours per day of the dredge operating at 100 percent power, 75 percent power, and 10 percent power. From these values the effective hours at 100 percent are determined. The fuel cost per day is then taken as the item's horsepower times the hours per day at 100 percent times fuel cost per gallon times 0.048079. This is another value recommended by Bray et al. (1997).

Cost of Lubricants

It is suggested to use 0.1 times the fuel cost to obtain this value.

Depreciation

To calculate this value, the useful life of the piece of equipment in question must be known. These values are contained in the database and accessed here by the program. The depreciation is then calculated as the capital cost divided by the useful life and the number of days per year in operation.

Pipeline Costs

The total capital cost of the pipeline is determined by multiplying the total number of pipe sections by the cost per section obtained from the database. The same methods used above are used to calculate depreciation and repair costs, keeping in mind that the useful life of a section of pipe is much shorter than the equipment items due to the constant abrasive wear of the material being pumped through it. The average pumping distance entered on the main page is used to determine the costs of the main pipe lengths. The remaining length of pipe suffers less wear and therefore has a longer useful life and needs fewer repairs than the main pipe length.

After the equipment and pipeline costs are determined, the overhead costs are then taken to be 9 percent of the total daily costs of equipment and pipeline. Several cells are left open where additional specific costs can be entered and added, either as lump sums or as daily costs. The time required to complete the project is calculated based on the production rate and the hours per month that the dredge is in operation. This value is then multiplied by the daily costs to obtain the total cost of execution.

Additional Considerations

In addition to the actual cost of the dredging project, the contractor's profit and bond are considered. These factors typically add up to roughly 10 percent of the total cost.

Each dredging project is unique, and when determining the cost of the project, one must take into account the "big picture." There are aspects of each project that may reduce or increase the final price, and care must be taken to include these factors when making a cost estimate. For example, a particular project may necessitate additional effort to comply with local environmental restrictions. It is impossible to include every possible scenario in a cost estimation program, so these considerations must be included after obtaining the program's estimate.

CONCLUSIONS

Long distance pumping of dredged material requires the addition of booster pumps located along the discharge pipeline. Cutter suction dredges have centrifugal pumps on board to pump the dredged material through the discharge pipeline. However, if the pipeline is sufficiently long (e.g., greater than 2 mi for large dredges), then the total head of the pump may not be sufficient to accomplish the task. Therefore, a booster pump station must be added to provide the additional head to transport the dredged material to the required discharge location. Several booster pumps may be required for very long pipes.

Estimating the cost of dredging is very complicated. First, the dredge production (cubic yards or cubic meters of dredged material removed) must be estimated. Important factors in production estimation include in situ sediment specific gravity, mean grain size, discharge elevation, discharge pipe length, pipeline energy losses, pump efficiency, and dredge efficiency. These factors have been incorporated in a spreadsheet platform to estimate the dredge production rate that is subsequently used in estimating the cost of the dredging project.

The main components involved in the cost of dredging are fuel and lubricant costs, dredge and land crew labor costs, routine maintenance and repairs, major repairs and overhauls, overhead costs, depreciation, profit, mobilization and demobilization, booster pumps, and capital investment. These cost items have been identified and incorporated in the development of cost estimating software for a cutter suction dredge similar to those used in dredging in the GIWW.

CHAPTER 3 BENEFICIAL USES OF GIWW DREDGED MATERIAL FOR THE TEXAS COASTAL ZONE (TASK 2)

INTRODUCTION

Dredged material from the Texas Gulf Intracoastal Waterway (GIWW) provides many opportunities for using this valuable resource to benefit the state of Texas. The U.S. Army Corps of Engineers identifies 10 categories of beneficial uses of dredged material. The categories include: habitat development (wetlands, bird islands, upland habitat), beach nourishment, aquaculture, parks and recreation, agriculture, land reclamation and solid waste management, shoreline stabilization and erosion control, industrial use (port development, airports, residential), material transfer (dikes, levees, parking lots, highways), and multiple purposes (USACE, 1987). Another useful guide for beneficial uses of dredged material has been published by the Permanent International Association of Navigational Congresses (PIANC, 1992). In this study, relatively new beneficial uses of dredged material are investigated and special emphasis is placed on dredged material from the Texas GIWW. Three new concepts are discussed that include manufactured soil, thin-layer disposal, and geotubes for erosion control.

MANUFACTURED SOIL AS A BENEFICIAL USE

Introduction

Approximately 24.5 million cubic meters (mcm) or 32 million cubic yards (mcy) of sediment are dredged each year from Texas ports and waterways. The Galveston District of the U.S. Corps of Engineers is responsible for maintaining the navigable waterways of the state, as well as identifying and developing dredged material disposal management strategies for long-term needs. The Corps of Engineers also assists local and state governments with the maintenance of the states' navigation channels. The local sponsors of dredging projects in Texas include the Texas Department of Transportation (TxDOT) and several local Port Authorities. TxDOT, in conjunction with the Corps of Engineers, is responsible for the management and maintenance of the Texas Gulf Intracoastal Waterway (GIWW).

Each year nearly 7.5 mcm (10 mcy) are dredged from the GIWW. The majority of this dredged material is placed in open water bay disposal sites and confined disposal facilities (CDFs). Recently, beneficial use projects such as beach nourishment, bird island development, and marsh rehabilitation have been investigated and implemented. Still, both the Corp and TxDOT are concerned with the amount of dredged material placed into CDFs each year. While current disposal sites begin to fill, and new sites become difficult to acquire, the state and Corps of Engineers are looking for alternative uses and placement sites.

In addition, there are more restrictions being placed on the regulation of sewage sludge. Sewage sludge can no longer be placed in the ocean. This has sparked interest by the U.S. Environmental Protection Agency (EPA) to issue new regulations concerning sewage sludge. EPA's 503 Regulations promote the reuse of bio-solids derived from reconditioned sewage sludge. Although most areas in Texas do not appear to have a problem with disposal of their sewage sludge, consider that nearly 229,380 m^3 (300,000 cy) of sewage sludge are imported to Texas from other states each year (TNRCC, 1995).

A potential solution to the problem of "what to do with the dredged material" is the manufacture of artificial soil. Manufactured soil helps reduce and recycle wastewater sludge and provides an alternative for the long-term management of dredged material disposal sites by reducing the amount of land needed for the CDFs. By combining dredged material with organic waste materials and bio-mass (cellulose or sawdust), an artificial soil can be created. Research to evaluate the potential of combining these materials was initiated by the Environmental Laboratory at the USACE Waterways Experiment Station (WES) in Vicksburg, Mississippi. As a result, several Cooperative Research and Development Agreements (CRDAs) have been developed. The purpose of a CRDA is to develop and demonstrate technology with the mutual effort of commercial companies.

Objective

One purpose of this study is to determine alternative uses and their feasibility for dredged material from the Texas GIWW. Although there are many alternatives and beneficial uses of dredged material being developed and implemented throughout the county, the manufacturing of soil from dredged material is a relatively new and unknown concept. Few pilot studies have been performed and information regarding this technology has been scarce to date. This study discusses the system of manufactured soil, including the process and requirements. Several case studies and their results, as well as current and past research in the field show the feasibility of this technology and how it can be implemented. Several anticipated problems and factors in the selection of a test site are discussed. In addition, to demonstrate the applicability and feasibility of this technology in Texas, the paper includes two suggested experimental test studies from disposal sites along the Texas GIWW.

Manufactured Soil (MS)

What is manufactured soil? Manufactured soil is created using dredged material and recyclable organic waste materials such as bio-solids (sewage sludge), animal manure, yard waste, and bio-mass (cellulose or saw dust).

Dredged Material (DM)

The dredged material should be analyzed for both physical and chemical properties. The physical properties of the dredged material, i.e., the sediment grain size should be measured to determine the most appropriate use of the manufactured soil. In addition, the following chemical concentration levels should be determined: pesticides, PAHs, PCBs, and metals. These chemical characteristics need to be determined so contaminants and salt may be removed if necessary. Since the majority of dredging along the GIWW is maintenance projects with little or no contamination, it is unlikely that the removal of contaminants is a concern. However, the presence of salt, due to the brackish water, may pose a problem. The effects and problems of salt in the dredged material are discussed further under section entitled “Anticipated Problems for Converting Dredged Material to Topsoil.”

The chemical composition of the material will also be used to determine the growing conditions, or productivity of the soil. Germination and growth tests for various combinations of the dredged material, bio-solids, and bio-mass must be performed to determine the optimal percentage of each component (Lee and Sturgis, 1996). In addition, sewage sludge may be reconditioned so that by combining it with the dredged material and bio-mass, a well productive soil can be produced. For example, N-Viro™ is created to adapt to the chemical composition of the site specific DM and bio-mass (Drill, 1997). N-Viro™ soil is a patented reconditioned sewage sludge product from the N-Viro™ alkaline stabilization process. Materials such as N-Viro™ are developed to enhance the germination and growing characteristics of the manufactured soil.

Bio-Solid (BS)

Bio-solids are treated or reconditioned sewage sludge. Bio-solids can also be produced from reconditioned animal waste, such as cow manure. In a typical sewage treatment facility, the sewage sludge is reconditioned such that the pathogens in the sewage are reduced to appropriate levels. These levels are referred to as Class B. The use of class B bio-solids is restricted by the Environmental Protection Agency (EPA). Restricted materials must be used in accordance with the requirements of the EPA. The material must also be registered with the EPA (Warden, 1997). For example, Class B bio-solids can not be used in locations where the material has a high potential of direct contact with people. In some cases, the sewage many be reconditioned through chemical and thermal processes to obtain a Class A level. Some sewage treatment facilities and private industries have the capability of neutralizing the pathogens in the sewage sludge (Warden, 1997). Class A bio-solids are unrestricted in how they are used.

Bio-Mass (BM)

Bio-mass is another name for cellulose. Bio-mass can be compost material from a landfill, sawdust, yard waste or rice hulls.

Manufacturing Process

The volume of suitable dredged material at the confined disposal facility, or the estimated amount to be dredged, is determined in order to calculate the amount of topsoil to be produced. For a given amount of dredged material, the volume of bio-mass and bio-solid is determined. Plant screening tests should be conducted to determine the required percentages of material. For example, studies using the N-Viro^{TM} methodology by Lee et al. (1996) at WES show ratios of 60 percent DM, 30 percent BM and 10 percent N-Viro^{TM} BS for the Toledo project. Ratios of 30 percent DM, 60 percent BM, and 10 percent N-Viro^{TM} BS were used for the New York/New Jersey project (Mears, 1996). The amount of material to be processed is then dependent on the amount designated by the screening tests, as well as the amounts of dredged material and bio-solids available. Once the volumes of the materials are determined, they can be used to calculate the costs associated with excavating and transporting the materials for the manufacturing process.

The manufacturing of soil process involves several steps shown in Figure 3-1. Although each site is unique, the process requires certain elements that are common for all sites. The initial step in developing a manufacturing process for soil is to determine the amount of material required as discussed above. Not only does this information assist in determining the capacity of the blending equipment and an estimated time of production, but it also assists in developing transportation costs.

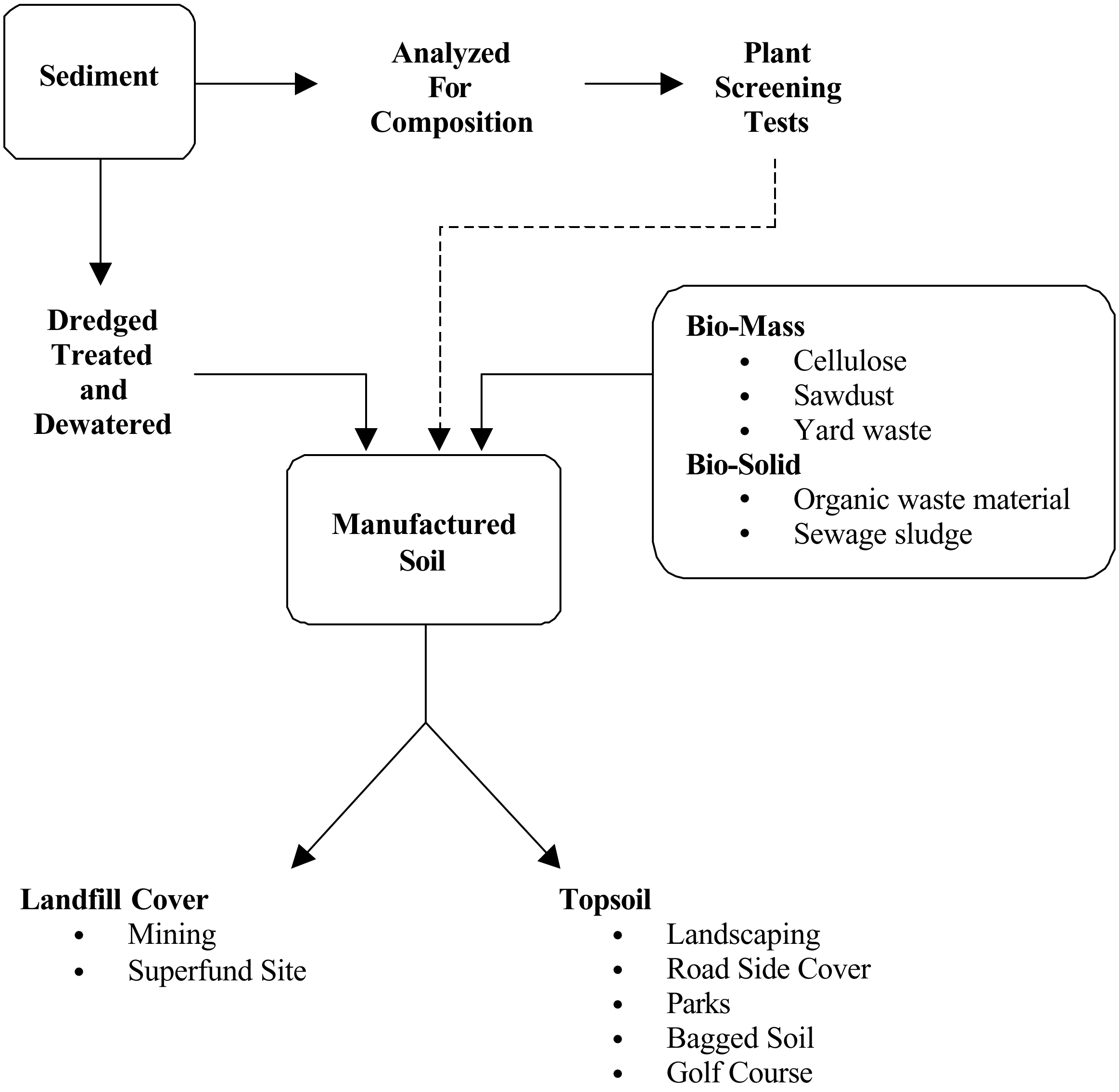


Figure 3-1. Manufacturing Soil Process.

Samples of the DM should be analyzed for both physical and chemical properties. If the material is contaminated, treatment options must be examined to determine the feasibility of the material for use as a manufactured soil. Plant screening tests are then used to determine the optimum ratio of DM, BS, and BM. Several different ratios are used in the screening test ranging from 90 percent DM and 10 percent BS to 60 percent DM, 30 percent BM, and 10 percent BS (Lee, 1997a). The sediment is dredged and dewatered either within the CDF or by mechanical methods. In the case of contaminated sediments the DM should be treated in addition to being dewatered.

Next, the soil is processed using the estimated combination of dewatered dredged material, bio-solid, and bio-mass. The mixing segment of the manufacturing soil process has two options: mixing by mechanical means or using agricultural equipment within the CDF. Mixing by mechanical means involves a compost like blender where the materials are combined (Lee, 1997a). Mixing within the CDF can be accomplished using common agricultural equipment (Perry, 1997). Spreaders are used to distribute the reconditioned sewage sludge and bio-mass throughout the CDF. The materials are then mixed using a cultivator or rototiller. The mechanical blender is recommended for a more thorough mixing, whereas the agricultural equipment is suitable for applications such as landfill cover and construction material. The finished product is shipped to the intended use site or market. Contaminated dredged sediments may be converted to topsoil and used as cover material for superfund, mining, and landfill sites. Uncontaminated material can be used as unrestricted topsoil, if Class A bio-solids are used, for landscaping, roadside cover, parks, and bagged soil.

Case Studies

Toledo Harbor Project

The Buffalo District of USACE initiated the project. The Corps district identified manufactured soil as an alternative for the long-term management of dredged material from Toledo Harbor. The U.S. Army Engineer Waterways Experiment Station (WES) was asked to develop technology to manufacture soil. A Cooperative Research and Development Agreement was developed between WES, Scott & Sons Company, Abaris Design (now Terraforms), and N-Viro International. The project was based on the premises that there was an existing market for the manufactured soil. Scott & Sons Company, a fertilizer manufacturer and distributor, had expressed an interest in receiving 3 million m^3 of silt each year for their bagged soil product. Lee et al. (1996) describes a demonstration project held September 19-24, 1996, in Toledo, OH. A summary of this project was produced by the cooperative effort of the Buffalo District of USACE, WES, the city of Toledo, N-Viro International, and Terraforms (USACE, 1996).

Dredged Material Properties

Core sediment samples of the dredged material were taken from the CDF from depths ranging from 0 to 3.6 m. Scott & Sons and WES determined the chemical and physical composition of the dredged material. The sediment particle characteristics were 18.9 percent sand, 58.9 percent silt, and 22.1 percent clay. The Scott & Sons Company used this information to conduct plant-screening tests to evaluate the material for use in bagged soil products. Compositions of 60 to 80 percent DM, 30 to 10 percent BM (yard waste) and 10 percent N-Viro^{TM} (patented reconditioned sewage sludge) were analyzed using plant screening tests. Based on the chemistry of the dredged material from the Toledo Harbor, a new N-Viro^{TM} product suitable for bagged soil was developed with a pH value of 7.0. For Toledo Harbor dredged material the optimum mixture was found to be between 50 and 60 percent DM, 30 and 40 percent BM, and 10 percent N-Viro^{TM} when applicable.

Manufacturing Process

The Port Authority of Toledo Harbor was authorized to develop a manufactured soil (Nu-Soil) from Island 18 within Cell 1 of the CDF. The site of the demonstration project was located on the CDF. A process pad was built on the CDF to decrease transportation costs. The report includes a sketched layout of the MS processing site. The amount of material for the demonstration was 80 percent DM, 10 percent BM, and 10 percent N-Viro™ BS, or approximately 1376 m^3 (1,800 cy) of DM, 107 m^3 (140 cy) of BM, and 107 m^3 (140 cy) of N-Viro™ BS. A mechanical blender developed by Abaris Designs was used to mix the materials. The MS was placed in trucks that are covered to prevent material from blowing out and transported to the use sites.

Results and Conclusions

The manufactured soil was used for landscaping and as topsoil for the University of Toledo and the Toledo Botanical Gardens. Each activity of the project was recorded and documented with photographs, slides, and/or video tape. The yard waste and reconditioned N-Viro BS were donated and transported to the manufacture site by Scott & Sons Company and N-Viro International N-Viro, respectively, in accordance with the CRDA agreement. The production cost for the manufacturing of the soil was approximately $13 per m^3 ($10 per cy) which includes the transportation between the CDF and use site. The N-Viro Corporation states that the material is sold in Toledo for $2.65 per ton, or $1.96 per m^3 ($1.50 per cy). The wholesale price, based on a customer taking 5,000 tons per year, or 2,141 m^3 (2,800 cy) is $0.65 per m^3 ($0.50 per cy) for Toledo (Drill, 1997). In addition, Terraforms has proposed an estimated production rate near 612,680 m^3 (800,000 cy) of manufactured soil per year.

New York/New Jersey Harbor Project

The New York/New Jersey Harbor Project was initiated by the New York District USACE and WES (Mears, 1996). The CRDA Partners for this project include Scott & Sons, Terraforms, N-Viro International, and Bio Technology, Inc. The purpose of this project was to evaluate the potential of manufacturing soil from contaminated and treated dredged material. Logan (1993) performed preliminary tests similar to the Toledo Harbor project on the dredged material. The dredged material was salty, untreated, and under anaerobic conditions in situ. The demonstration took place at the Port of Newark. Lee (1997b) used 30-80 percent DM, 10-60 percent BM, and 10 percent Bionsoil (reconditioned cow manure) for the demonstration. Bionsoil was used instead of typical sewage sludge to reduce the amount of metals in the MS. Results showed that grass could grow in the salty soil and that the best use of the dredged material is for cover at superfund sites, mining, or landfill sites. The use of hyper-metal accumulator plants to extract metals from CDFs was also studied (Lee, 1997b).

Alabama

The USACE Mobile District in conjunction with WES wished to use dredged material from CDFs adjacent to Mobile Harbor for use in developing a manufactured soil (Mears, 1996). Bio-mass was obtained using International Paper (IP) cellulose and sawdust. The bio-solids consisted of reconditioned sewage sludge (N-Viro^{TM}). The project consisted of a greenhouse test where various amounts of the materials were mixed. Screening tests were completed in November 1996. Excessive sodium in the IP cellulose produced poor results in the MS. The sawdust produced better results when 40 percent DM was used. The manufactured soil is to be used for highway projects by the Federal Department of Highways.

Florida

There were two projects in Florida initiated by WES and the Jacksonville District USACE. Both involve the Herbert Hoover Dike surrounding Lake Okeechobee in central Florida (Mears, 1996). Initially the dike was constructed using dredged material from a nearby lake and canal. The dredged material comprising the dike consists of sand and marl. A manufactured soil was created using 60 percent dike soil, or dredged material, and 40 percent organic wastes. The cellulose was obtained from sugar cane. The second part of the project consists of dredged material from the St. Lucie Estuary. The district was approved to evaluate the manufacturing of soil from muck dredged from the North Fork of the St. Lucie Estuary. The dredge material from the estuary could be used on the Herbert Hoover dike system. Screening tests were conducted and it was determined that up to 50 percent of the St. Lucie muck could be used for grass growth.

Other Sites

The conversion of manufactured soil from dredged material is being considered in several locations throughout the United States. Investigations into the use of manufactured soil from contaminated dredged material are being conducted in Chicago and Bridgeport, CT (Mears, 1996). In Illinois, the manufactured soil from contaminated dredged material will be used for mining reclamation at an acid coal mine in Ottawa, IL. In Connecticut, the MS will be used with special plant species to stabilize and contain contaminants. The plants are tolerant of acidic soils, toxic metals, and saline soil. The plants, after collecting the toxic materials and contaminants in their root system, can be disposed of in a safe manner. In addition to the USACE districts stated above, there are several other districts investigating this technology. The Little Rock, Wilmington, and Detroit Districts are all looking into the feasibility of manufacturing soil using dredged material.

Methodology for Determining Feasibility

The selection of manufactured soil as a beneficial use of dredged material can be difficult. The first step is the feasibility study. The project must be a cost effective and environmentally friendly option for the disposal of the dredged material. The feasibility study determines the potential of undertaking such a venture. Figure 3-2 shows a flowchart of the steps in the feasibility study of creating a manufactured soil. The feasibility study should include a discussion of the technology or methodology, material characteristics, site location, transportation factors, and directions or steps to be taken for a pilot test. Once the study has been completed, small-scale pilot tests should be performed. The pilot test is the final indicator of the success of a large-scale project. Although many questions are answered in a feasibility study concerning the applicability of the technology, the pilot test answers far more questions.

The feasibility of converting manufactured soil to topsoil depends on several factors shown in the flowchart in Figure 3-2. First, a background study should be performed on the existing technologies. The basic factors include finding a market or use for the converted topsoil, determining the optimum site for the project, deciding which bio-mass should be used, and acquiring the bio-solid or reconditioned sewage sludge. These factors will assist in determining the direction of the project. A discussion on the anticipated problems is also included in the flowchart. The foreseeable problems are location, accessibility, dewatering, and salinity of the dredged material. Restrictions placed on the use of the bio-solids may also pose a problem. As multiple pilot tests are created, a cost feasibility study must be performed for each test. If a pilot test is not considered cost effective, the feasibility factors must be reexamined to determine any alternatives. If the project is deemed cost effective, the project must then be analyzed for its environmental impact. Once the pilot test is completed, the results will indicate the likelihood of a successful full-scale project. In addition, complex issues may present themselves once a pilot or full-scale project is completed.

Finding a Use or Market for the Topsoil

The use or market must be determined for each manufacturing site. Multiple uses or markets for the manufactured soil from a particular manufacturing plant should also be considered. Large manufacturing plants should consider several smaller requirements uses and markets instead of relying on one large requirement. In many areas, there will be no predetermined use for the converted topsoil. For the Toledo Harbor Project, a fertilizer company requested the large-scale production of manufacture soil. The issue of site selection is solved when a particular company requests an intended use or market for the converted topsoil. However, due to the novelty of this product, the reaction of other soil processing and fertilizer companies around the country is unknown at this time.

Site Selection

Several factors affect the site selection for both a pilot study and real project. This thesis focuses on the site selection for a pilot study, although several of the factors are the same. Most dredged material has very little or no contaminants, and almost all of the dredging work is maintenance dredging. The primary factors are market, location, accessibility, and volumes available. The overall primary factor is the cost analysis of the project, which includes the transportation of the materials. The costs associated with the manufacturing equipment are somewhat negligible when considering the costs associated with transporting large volumes of dredged material to the manufacturing site. The distance from the production site to the intended use site is also important when determining the feasibility of the project.

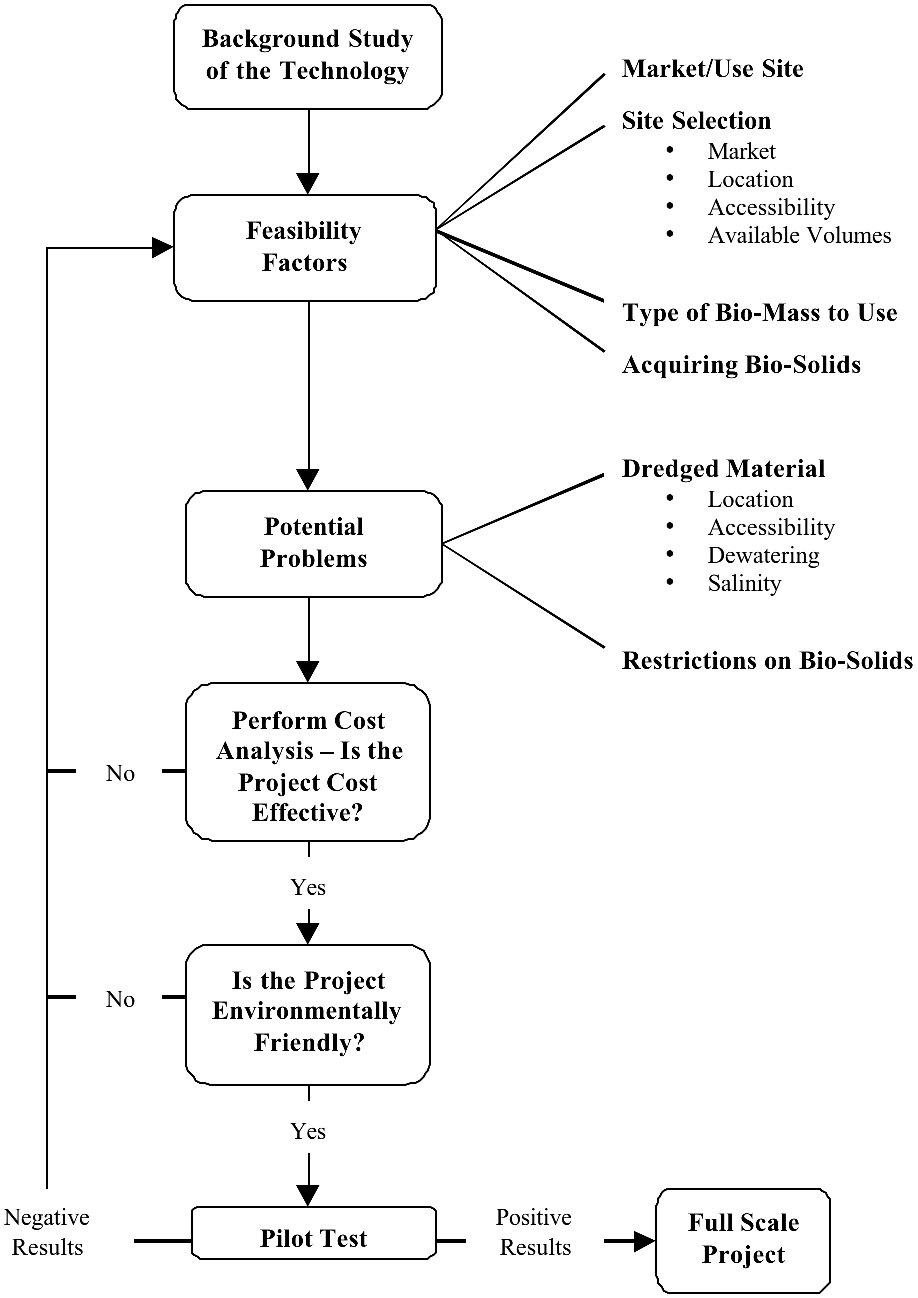


Figure 3-2. Flowchart Showing Methodology to Determine Feasibility of Converting Dredged Material to Topsoil.

Market/Use Site of Converted Topsoil

There needs to be a market for the manufactured soil. The manufacturing site should be located near the market or potential use site where the converted topsoil is comparable to the material it will replace. In addition, the amount required must be large enough to make this a viable alternative to other uses. As stated earlier, there may be multiple uses for the converted topsoil from any one manufacturing site.

Location

Location is the distance between the materials and the intended use site. For the dredged material and the disposal area, there are three alternatives:

(1) dredged material is pumped directly to the manufacturing facility from the dredge site via pipelines and dewatered at the facility using mechanical methods,
(2) dredged material is placed in a disposal area and mixing takes place in the disposal area, or
(3) dredged material is placed in a disposal area, dewatered, excavated, and mixed with a mechanical blender.

The costs of transporting dredged material to a manufacturing site via pipeline are compared to the combined transportation costs. The combined cost consists of transporting the material to the disposal area, excavating the dredged material or manufactured soil after dewatering or mixing, and transporting the material to the manufacturing or use site. Confined disposal facilities (CDFs) are often located offshore or in low, wetland, and marsh areas (Keller, 1997). Although many of these areas are not easily accessible by truck, barge transportation could be used. The location of the sewage treatment facility is not as significant as that of the other materials. Since the amount of bio-solids are less than the amounts of the dredged material and bio-mass, then transportation costs are less and the location can be further away.

Accessibility of Dredged Material

Accessibility of the CDF and the dredged material must be considered. Although many CDFs are located in upland areas with relatively easy access, there are many located along the shoreline. For example, many of the CDFs along the Texas GIWW are accessible only by water (Whitmire, 1997). In addition, many of the CDFs that are accessible by land have high dikes and potential excavation problems. Suitable roads for the movement of the excavation equipment may also pose a problem.

Volumes

The amount or volume of materials may also incur restrictions. The limiting factor is the amount required for the particular use and the frequency of its use. How much manufactured soil does the intended use require and how often is needed. Another important factor is the amount of bio-solids and bio-mass available. The amount of bio-solids required is small

(~10% of the total volume) compared to the amount of dredged material required (~60% of the total volume).

Type of Bio-Mass to Use

Bio-mass is the same as cellulose. Bio-mass can be compost material from a landfill, sawdust from a wood processing facility, yard waste, or even rice hulls. The type of bio-mass selected is based on the results of the plant-screening test. For the type of cellulose available, the growing conditions for plants in the manufactured soil can be determined using the screening tests. Obtaining the bio-mass is relatively easy since there are many different types to choose from and most are very common.

Acquiring Reconditioned Sewage Sludge

Several questions need to be addressed when deciding whether to convert dredged material to topsoil. Where are you going to get the bio-solids? To what level are they treated? Sewage sludge is readily available in most parts of the country. Many municipalities are more than happy to dispose of their bio-solids in a beneficial way (Peterson, 1997). Therefore, the concern is not whether the sewage sludge is available, but what the condition is, and how it is obtained. In remote coastal areas with small populations, many residents still use septic systems. In these areas, the cost of transporting reconditioned bio-solids must be weighed carefully versus the location of the dredged material and the intended use site.

Once the source of the sewage sludge has been determined, other questions come into play. Who pays for the transportation costs of the sewage material to the manufacturing site? Although the sewage sludge is taken "off the hands" of the local municipality, the question is whether they are willing to pay for the transportation cost? Is the manufacturing site located closer or farther from where the sewage sludge is currently disposed? Most sewage treatment facilities recondition the sludge to a Class B level. Must the sewage sludge be reconditioned to a Class A level? This will depend on the use of the converted topsoil.

Anticipated Problems for Manufacturing Soil in Texas

Location and Accessibility

As stated earlier, many CDFs are located in remote areas with difficult access. In addition, excavation of the dredged material may pose a problem since many CDFs have large dike systems. Access to the CDF by blending equipment may also be complex due to the dikes. For example, many of the CDFs located along the Texas GIWW are accessible only by water. Several of the remaining disposal areas are accessible by roads through private property, or small access roads typically not fit for large construction and excavation machinery (Rozsypal, 1997).

Dewatering

The length of time for a CDF to dewater varies from several months to several years (Keller, 1997). Dewatering time depends on CDF management practices, like trenching, as well as the weather. The CDF must be dewatered so the excavation or blending equipment can access the site. In addition, many the CDFs located along a shoreline are in low marsh and wetland areas. This often poses a problem since these areas typically do not dewater very well (Rozsypal, 1997). Separation devices, such as hydrocyclones, dewatering wheels, etc., might be a solution to the dewatering problem, although they can be expensive.

Salinity

Salinity levels vary along the shorelines of the U.S. Seasonal variations also affect salinity levels. When placed in a CDF, salt leaches out of the top layer of the dredged material, and the concentration level is around 5 ppt. This value is still relatively high for most plant species (Vargo, 1997). Most plants grow best at a pH range of 5.5 to 7.0. Values of pH below 4 or greater than 9 can be toxic to roots (Seliskar, 1997). Since the cost associated with desalting the dredged material is extremely high, it must be determined whether desalting the dredged material is necessary (Vargo, 1997).

The removal of salt depends on the use of the soil. Salt is not a factor if the soil is used for construction purposes. Soil used for landscaping purposes may need to be treated. For example, if the soil is used for landfill cover, or some other low maintenance use, there are many types of salt grasses capable of growing in brackish soil. Since it takes 8-10 months for salt to leach out, the salt-resistant plants will probably be taken over by typical freshwater plants after about a year.

Logan (1993) reported the effects of using marine sediments to manufacture a soil product and the characteristics of the manufactured soil. The study describes the greenhouse tests associated with the combination of marine sediments with N-Viro^{TM} BS and sand. It shows that manufacturing soil with brackish dredged material is feasible when the ratio between dredged material and bio-mass is roughly 1 to 2. In addition, the plant-screening tests used freshwater plants that are more susceptible to salt than salt-tolerant plants. A list of salt-tolerant grasses are tabulated in Table 3-1 (Seliskar, 1997). Spartina alerniflora grows well in very saline conditions that range from 15 to 35 ppt, while spartina cynosuroides grows well in brackish water with salinities from 5 and 8 ppt.

Table 3-1. Selected Gulf of Mexico Salt Water Grasses (Seliskar, 1997).

Plant (Grass) Name	Characteristics
Distichlis Spicata	Very salty water – seawater salinity
Spartina Alterniflora	Very salty water – seawater salinity
Spartina Cynosuroides	Brackish water – salinities up to 8 ppt
Sporobolus Virginicus	Salty water
Spartina Patens	Very salty water

Note: All grow in salt marshes along the Gulf coast and are flooding tolerant.

Restrictions on the Use of Bio-Solids

The costs for reconditioning sewage sludge to a Class A level varies between $28 and $33 per m^3 ($21.4 and $25.2 per cy). The material is then classified as an unrestricted bio-solid. Depending on the use of the dredged material, one must decide whether this additional treatment and cost is necessary. For example, if the material were to be used for landscaping purposes where there would be significant human contact, Class B bio-solids are unsuitable and Class A material needs to be used. However, if the manufactured soil is to be used for landfill cover, the Class B bio-solid is adequate.

Methodology for Determining Cost

Determining the cost of a pilot or full-scale operation to convert dredged material to a manufactured topsoil involves excavation, transportation, and manufacturing costs. The dredged material may be obtained directly from the dredge via pipeline, or excavated from a confined disposal facility after being dewatered. Due to potential accessibility problems of the disposal area, an accessibility factor has been created. The costs associated with the various transportation modes are developed to assist in determining the overall cost of the project. The manufacturing costs are based on two processes. The first process involves in situ manufacturing using agricultural equipment such as spreaders and rototillers. The second process blends the materials in a mechanical compost mixer. Based on the above costs, a spreadsheet was developed to calculate the overall cost estimate of a manufactured soil project.

Excavation

Excavation costs are dependent on the type of equipment needed for the excavation. Excavation equipment includes hydraulic excavators (backhoes), power shovels, drag-lines, and loading tractors. In addition, front-end loaders and clamshells may be used. Equipment selection is based on the following factors (Means, 1996):

- Quantity/type of material,
- Depth or height of cut,
- Length of haul and condition of haul road,
- Accessibility of site,
- Moisture content and dewatering requirements, and
- Availability of excavating and hauling equipment.

From the above factors, the accessibility of the site and the condition of the haul road are very significant when excavating from a disposal area. The moisture content of the material is an important factor in the accessibility of the material, as well as in determining the quantity of material. The type of material varies within the disposal area with fines located near the overflow and larger particles near the discharge. The type of material is also used in determining the quantity of material to be excavated and transported.

The total cost for excavation, *E*, involves the excavation of all materials. For example, if blending takes place within the disposal area, the volume of material to be excavated is the sum of all the materials used to convert the dredged material to topsoil. However, manufacturing using a mechanical blender only required that the dredged material be excavated. The excavation cost, E, is

$$E = \sum_i \left(R_{excav} \;\; V_i\right) \tag{3-1}$$

where R_{excav} is the unit excavation cost in dollars per m^3, and V_i is the volume of each material to be excavated in m^3.

The unit excavation cost is determined using an excavation factor, f_{excav}. The excavation factor is dependent on the accessibility of the confined disposal facility and the excavation equipment. The factor is also based on the premise that excavation projects, with good accessibility, cost between \$2.60 to \$3.90 per m^3 (\$2 to \$3 per cy). Excavation costs requiring specialized equipment or modifications to the construction site vary between \$13 and \$15 per m^3 (\$9.9 and \$11.5 per cy) (Whitmire, 1997). Construction site modifications include adding or enhancing access roads or altering the height or structure of the dike for access. Characteristics of the excavation factors are shown in Table 3-2.

Table 3-2. Excavation Factor (f_{excav}) Characteristics.

f_{excav}	Characteristic
1.0	• CDF is easily accessible (dike height/structure) • Typical excavation equipment required • Good roadway access
2.5	• CDF is easily accessible (dike height/structure) • Typical excavation equipment required • Roadway requires modifications
4.0	• CDF requires minimal modifications(dike height/structure) • Typical excavation equipment required • Good roadway access
4.5	• CDF requires minimal modifications(dike height/structure) • Specialized equipment required • Good roadway access
5.0	• CDF requires modifications (dike height/structure) • Typical excavation equipment required • Roadway requires modifications
6.0	• CDF requires modifications (dike height/structure) • Specialized equipment required • Roadway requires modifications

The excavation factor shows the difference between the accessibility of the disposal area as a whole and the dredged material within the disposal area. For example, an excavation factor of 3.0 is applied when the dredged material within the disposal area is accessible (low dike height, good structure) and the roads to the disposal area require modifications. An excavation factor of 4.0 is applied when the disposal area is inaccessible and requires modifications (high dike height) and the roads to the disposal area are adequate. This shows that the cost associated with rehabilitating roadways is considered less than the costs associated with modifying the dike system of a confined disposal facility. The type of excavation equipment required is also taken into account when determining the excavation factor.

The excavation cost in dollars per m^3, or R_{excav}, is determined by multiplying the base rate (\$2.60 per m^3) times the excavation factor, f_{excav} as shown in Equation 3-2.

$$R_{excav} = 2.60 \ f_{excav} \tag{3-2}$$

The base rate is the minimal price for excavation. The base (\$2.60 per m^3) and maximum (\$15.60 per m^3) rates were the standards used when determining the excavation factors. Therefore, the highest excavation factor is 6.0. For example, the R_{excav} for a project where both the disposal area and road required major modifications is \$15.60 per m^3 if typical equipment can be used.

In each of the cases presented in Table 3-2, the disposal area is accessible by land either with or without modifications. For the special case when the disposal area is accessible by water only, a mechanical dredge and barge may be used for excavation. For example, 1,000 m^3 of dredged material needs to be excavated from a disposal area. The cost to dredge 1,000 m^3 of material using a clamshell or bucket dredge can be determined. In this situation, the cost of dredging (1,000 m^3) is used as an estimate for the excavation costs.

Transportation

Transportation costs include, but are not limited to transporting dredged material, sewage sludge, and other bio-solids to the manufacturing site. In addition, the cost of transporting the finished manufactured topsoil to the market or intended use site must also be determined. The transportation rates used to determine the costs are adjusted according to the type of material transported.

Transportation Modes

Barge

Barges may be use to transport:

(1) dredged material from the disposal area to the manufacturing site,
(2) bio-solids and bio-mass to the manufacturing site, and
(3) the finished product from the site to the final destination.

Rail

Rail transportation may be used if:

(1) a large volume of dredged material, bio-solids, and/or bio-mass must be transported a long distance (For long distances it is more economical to use the rail system.), or
(2) the finished product needs to be transported a large distance to the use site.

Truck

Transportation involving trucks may also be used to transport:

(1) dredged material out of the disposal area if necessary,
(2) dredged material, bio-solids, and bio-mass or from the barge or rail car for additional transport, and
(3) the finished product from the site to the final destination.

Hauling routes should be major highways as much as possible. Possible routes should be studied to determine the road conditions. In addition, manufacturing sites located near residential areas may have designated truck routes that limit traffic. At heavily used sites, roads will need to be widened to handle traffic increases and heavier vehicles. For a small-scale test, less than 3,900 m^3 (3,000 cy) manufactured soil, all materials should be transported by truck. For a large-scale operation, the transportation of raw and finished products might benefit from the lower transportation costs involving rail and barges.

Pipeline

Transportation involving a pipeline occurs if (1) the dredged material is taken directly from the dredge while the operation is in progress or (2) a hydraulic unloader is used at the disposal area. A hydraulic unloader reslurries the material so it can be piped to another location. The costs associated with transporting the dredged material to the manufacturing site via pipeline are similar to the costs associated with placing the dredged material in a disposal area.

Transportation Costs

The transportation costs of the manufacturing process are determined using the following flowchart (Figure 3-3). The flowchart describes the steps necessary to determine the overall transportation costs for each project. Step 1 in the flowchart requires the sediment grain size or percent sand in the dredged material. The amount of dredged material or the amount of topsoil to be produced is also required in step 1.

In step 2 the amount of dredged material or manufactured soil is determined using the relationship between the percent of dredged material in the manufactured soil and the percent of sand in the dredged material. If the amount of dredged material for the manufacturing process is known, the amount of topsoil produced can be calculated. Likewise, if the amount of topsoil to be produced is known, the volume of dredged material can be determined. This relationship is based on data from the Toledo Harbor Project (USACE, 1996) and the New York/New Jersey Harbor Project (Logan, 1993). For the Toledo Harbor Project, the dredged material was 19 percent sand and the percent of dredged material used for the manufacturing of the soil was 75 percent. The New York/New Jersey Project, the percent sand was 8 percent and 30 percent dredged material was used. In addition, a maximum amount of dredged material in the manufactured soil was set at 80 percent. Figure 3-4 shows the relationship between the percent sand in the dredged material and the percent of dredged material required in the manufactured soil up to 30 percent sand. For dredged material with a percent sand greater than 30 percent, a greenhouse screening test must be performed due to the limited data available.

Equation 3-3 is used to determine the percent of dredged material in the manufactured soil. The polynomial trend-line of the data values graphed in Figure 3-4 is

$$y = -0.1056x^2 + 5.8583x \qquad \textbf{(3-3)}$$

where y is the percent of dredged material in the manufactured soil, and x is the percent of sand in the dredged material. For example, if the sediment grain size is 15 percent sand, the manufactured soil is comprised of approximately 65 percent dredged material. This equation and the relationship between the percent sand in the dredged material and the percent dredged material in the manufactured soil is limited by the available data. This equation should not be used for percent sand values greater than 30 percent. Instead, greenhouse screening tests should be used to determine the appropriate percentage of dredged material in the manufactured soil.

Step 3 of the flowchart uses the volumes of dredged material and manufactured soil to determine the amount of bio-solids and bio-mass required. These volumes can be determined using the equations shown in the flowchart under step 3. Research shows that the general rule for determining the amount of bio-solids to be used is based on 10 percent of the manufactured soil, or total product.

Step 4 of the flowchart requires the selection of the bio-mass and bio-solid materials for the manufacturing process. The transportation modes for each of the materials (DM, BM, BS, and MS) must also be selected. Using this information and the volumes of the materials determined in step 3, the total transportation cost can be calculated.

In step 5 the transportation cost is based on the type of materials used, the amount of materials, the transportation modes, and the distances. To calculate the cost of transportation based on the transportation mode, the values in Table 3-3 were obtained from the Texas Transportation Institute (McFarland, 1997). The transportation cost for a pipeline is not included since it is very site specific and depends on several variables like the production rate, number of booster pumps, etc.

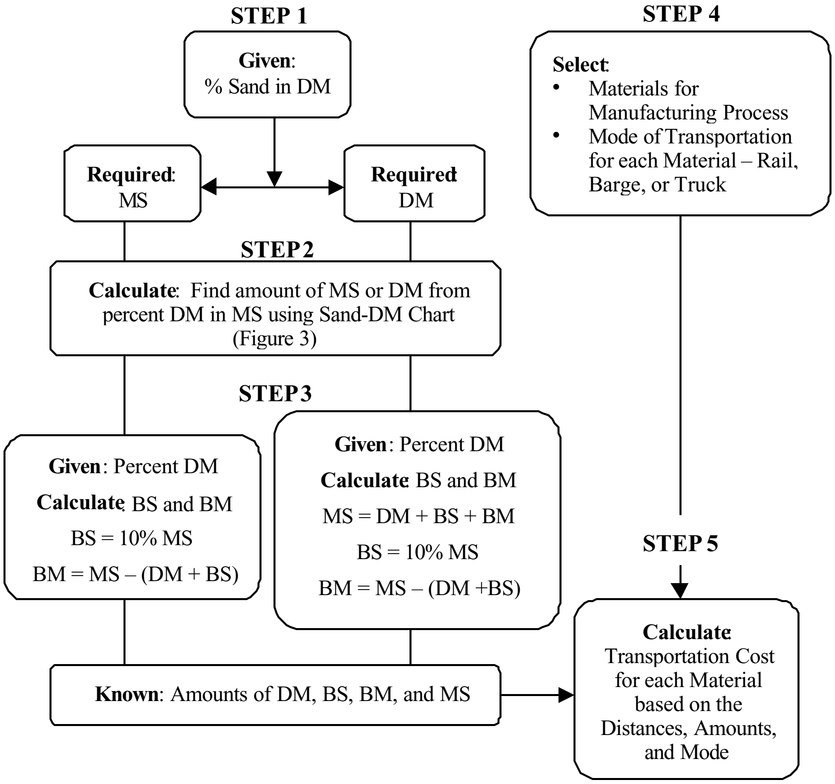


Figure 3-3. Flowchart of Transportation Costs.

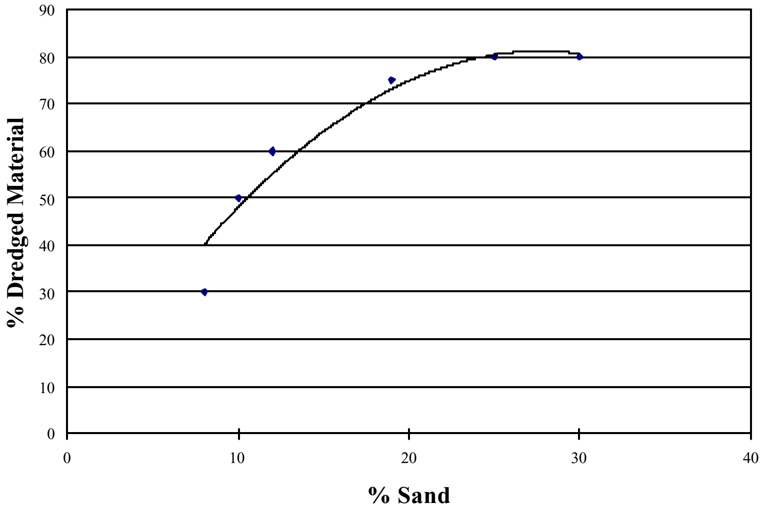


Figure 3-4. Sediment Grain Size Versus Percent of Dredged Material in Manufactured Soil.

Table 3-3. Transportation Rates for Each Mode (McFarland, 1997).

Transportation Mode	Cost (cents per metric ton-km)	Cost (cents per ton-mile)
Barge	1.01	1.48
Rail	2.67	3.9
Truck	5.69	8.3

Using the specific weight of the material, the values can be converted to a price per volume-distance, or cents per m^3-km. Table 3-4 is a list of the costs associated with the different transportation modes for three general specific gravity values. The table is based on the transportation values shown in Table 3-3.

Table 3-4. Unit Transportation Cost for Each Mode.

Transportation Mode	Costs (cents per m^3-km)			Costs (cents per cy-mile)		
	SG 0.5	***SG 1.0***	***SG 1.5***	***SG 0.5***	***SG 1.0***	***SG 1.5***
Barge	0.51	1.01	1.52	0.63	1.24	1.87
Rail	1.34	2.67	4.00	1.65	3.28	4.92
Truck	2.84	5.68	8.53	3.49	6.99	10.49

Table 3-5 shows the specific gravity values for a variety of materials. Each of these materials may be used to convert dredged material to topsoil. For example, manure, with a specific gravity of 0.4, may be used as a bio-solid in combination with sawdust, specific gravity of 0.3, and soft, loose dredged material (specific gravity 1.75). The specific gravity of the dredged material varies with the amount of water in the disposal area, or how well the disposal area is dewatered.

Table 3-5. Specific Gravity Values of Materials Used in Manufactured Soil Process (McDonald, 1997).

Material	Specific Gravity	Specific Weight kN/m^3	lb/ft^3
Dredged Material (dry – wet, excavated)	1.2 – 1.6	11.8 – 14.8	75 – 94
Dredged Material (soft loose mud)	1.75	17.3	110
Manure	0.4	3.9	25
Peat (dry – wet)	0.4 –1.2	3.9 – 11.8	25 – 75
Rice Hulls	0.75	7.4	47
Sawdust	0.3	3.1	20
Sewage Sludge	0.7	6.8	43

As stated before, the total transportation costs are a function of the volume of material, distance transported, and the transportation cost for each segment of the project. Therefore,

$$T = \sum \left(V_i \ D_i \ R_i \right) \qquad \textbf{(3-4)}$$

where T is the total transportation cost in dollars, V is the volume of material in m^3, D is the distance in km, R is the transportation cost in dollars per m^3-km, and "i" is the number of times each material is transported.

Manufacturing

Two types of manufacturing processes have been identified. The first process involves the mixing of the dredged material with the bio-solids and bio-mass within the CDF using agricultural equipment. The cost for manufacturing or mixing the soil within the CDF is based on the use of spreaders and rototillers. The second process involves the use of a mechanical, portable mixer. A description of the manufacturing and blending costs for both of these processes are tabulated in Table 3-6.

Table 3-6. Summary of Manufacturing and Blending Costs.

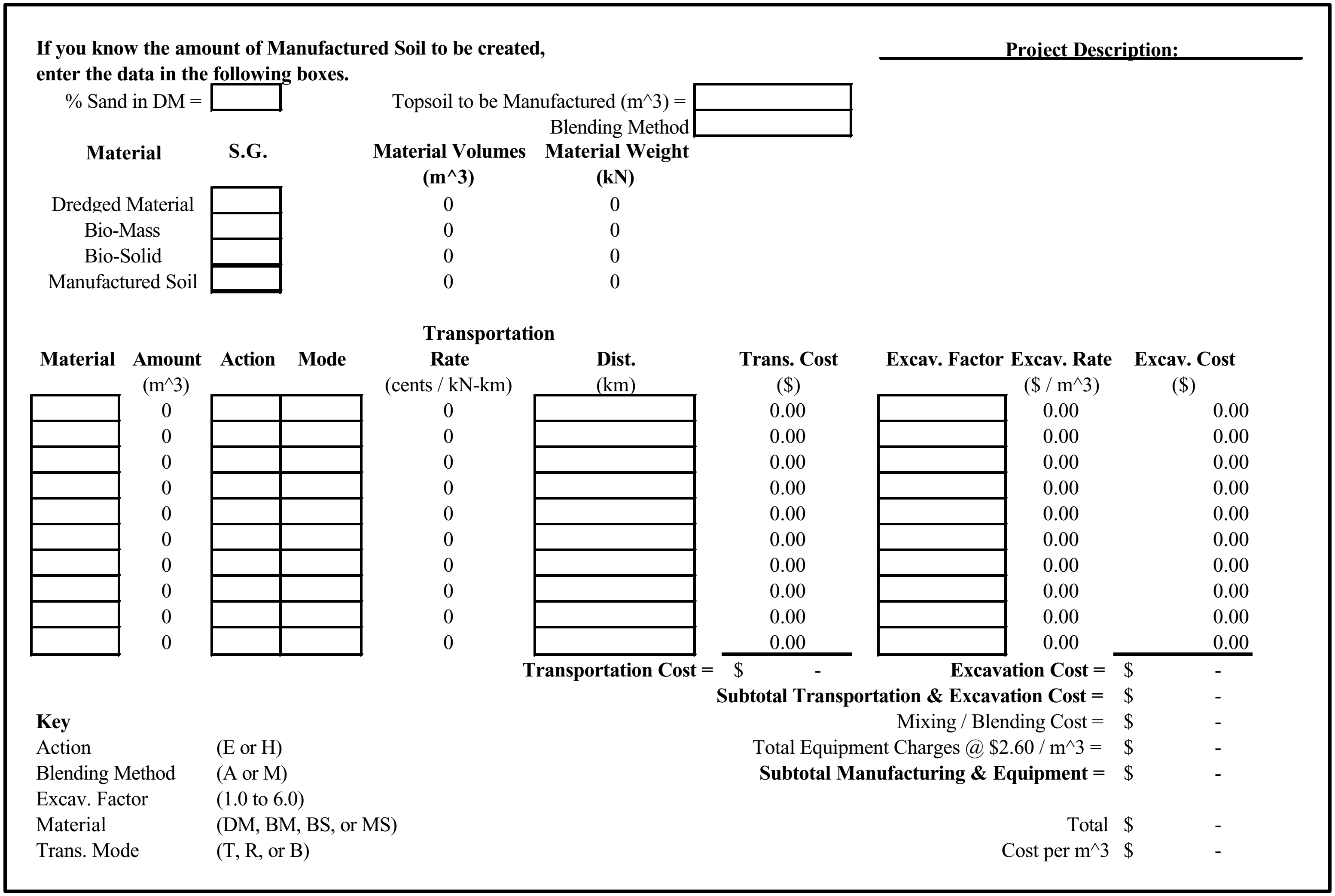
Manufacturing & Blending Costs	National Average Prices	
Agricultural Equipment in CDF	($ / m^3)	($/cy)
Backhoe crawler, 2.3 m^3 (1.76 cy) capacity, 125 m^3 / hr (163.5 cy/hr), $3.10 per m^3 ($2.37 per cy)	3.10	(2.37)
Mixing using an excavator bulldozer, $2.60 per m^3 ($1.99 per cy) for mixing	2.60	(1.99)
Estimate $2.60 per m^3 ($1.99 per cy) for spreading bio-solids and bio-mass	2.60	(1.99)
Total Costs	**8.30**	**(6.35)**
Mixer or Blender		
Backhoe crawler, 2.3 m^3 ($1.76 cy) capacity, 125 m^3 / hr (163.5 cy/hr), $3.10 per m^3 ($2.37 per cy)	3.10	(2.37)
Mechanical blending using portable mixer from Abaris Design, approximately $13 to $16 per m^3 ($9.94 to $13.2 per cy)	14.00	(10.70)
Total Costs	**17.10**	**(13.07)**

The prices used to estimate the manufacturing within the CDF using common earth-moving equipment were determined using Means Building Construction Cost Data (Means, 1996). In addition, operational, rental, and mobilization costs must be considered. To account for equipment rental and operation an additional $2.60 per m^3 was included in the manufacturing costs. Cost information regarding the transportable mechanical blender designed by Terraforms is estimated to be approximately $13 to $16 per m^3 for 2,880 m^3 of manufactured soil (Lee, 1997a). Using this estimate, $14 per m^3 ($10.7 per cy) was used in determining the cost for mixing the topsoil. The costs associated with operating the manufacturing equipment can be somewhat negligible when considering the costs associated with transporting large volumes of dredged material to the manufacturing site. However, for a pilot study involving small volumes, the manufacturing equipment costs can be significant.

The values in the Table 3-6 are the national averages. The national average cost is multiplied by a City Cost Index Factor to obtain the regional cost. The City Cost Index Factors can be obtained from Means Construction Cost Data (Means, 1996).

Cost Analysis

The cost analysis provides a detailed discussion of the costs associated with converting dredged material to topsoil. Transportation, excavation, and manufacturing costs are determined for each of the required materials. A spreadsheet was developed using Microsoft Excel 97 to analyze these costs. Each spreadsheet is based on the methodology shown in the flowchart in Figure 3-3. Table 3-7 is a list of the input values required for determining the cost of a manufactured soil project. In addition, the table describes where the information may be found. The input values required for the spreadsheet are indicated in Figures 3-5 and 3-6 by boxes.



If you know the amount of Manufactured Soil to be created, enter the data in the following boxes.

Project Description:

% Sand in DM = ☐

Topsoil to be Manufactured (m^3) = ☐

Blending Method ☐

Material	**S.G.**	**Material Volumes (m^3)**	**Material Weight (kN)**
Dredged Material	☐	0	0
Bio-Mass	☐	0	0
Bio-Solid	☐	0	0
Manufactured Soil	☐	0	0

Material	**Amount** (m^3)	**Action**	**Mode**	**Transportation Rate** (cents / kN-km)	**Dist.** (km)	**Trans. Cost** ($)	**Excav. Factor**	**Excav. Rate** ($ / m^3)	**Excav. Cost** ($)
☐	0	☐	☐	0	☐	0.00	☐	0.00	0.00
☐	0	☐	☐	0	☐	0.00	☐	0.00	0.00
☐	0	☐	☐	0	☐	0.00	☐	0.00	0.00
☐	0	☐	☐	0	☐	0.00	☐	0.00	0.00
☐	0	☐	☐	0	☐	0.00	☐	0.00	0.00
☐	0	☐	☐	0	☐	0.00	☐	0.00	0.00
☐	0	☐	☐	0	☐	0.00	☐	0.00	0.00
☐	0	☐	☐	0	☐	0.00	☐	0.00	0.00
☐	0	☐	☐	0	☐	0.00	☐	0.00	0.00
☐	0	☐	☐	0	☐	0.00	☐	0.00	0.00

Transportation Cost = $ -

Excavation Cost = $ -

Subtotal Transportation & Excavation Cost = $ -

Mixing / Blending Cost = $ -

Total Equipment Charges @ $2.60 / m^3 = $ -

Subtotal Manufacturing & Equipment = $ -

Total $ -

Cost per m^3 $ -

Key

Action	(E or H)
Blending Method	(A or M)
Excav. Factor	(1.0 to 6.0)
Material	(DM, BM, BS, or MS)
Trans. Mode	(T, R, or B)

Figure 3-5. Spreadsheet for Given Amount of Manufactured Soil.

If you know the amount of Dredge Material to be used, enter the data in the following boxes.

Project Description:

% Sand in DM = ☐

Dredged Material Required (m^3) = ☐

Blending Method ☐

Material	**S.G.**	**Material Volumes (m^3)**	**Material Weight (kN)**
Dredged Material	☐	0	0
Bio-Mass	☐	0	0
Bio-Solid	☐	0	0
Manufactured Soil	☐	0	0

Material	**Amount** (m^3)	**Action**	**Mode**	**Transportation Rate** (cents / kN-km)	**Dist.** (km)	**Cost** ($)	**Factor**	**Excavation Rate** ($ / m^3)	**Cost** ($)
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00

Transportation Cost = $ -   **Excavation Cost =** $ -

Subtotal Transportation & Excavation Cost = $ -

Mixing / Blending Cost = $ -

Total Equipment Charges @ $2.60 / m^3 = $ -

Subtotal Manufacturing & Equipment = $ -

Total $ -

Cost per m^3 $ -

Key

Material	(DM, BM, BS, or MS)
Action	(E or H)
Trans. Mode	(T, R, or B)
Excav. Factor	(1.0 to 6.0)
Blending Method	(A or M)

Figure 3-6. Spreadsheet for Given Amount of Dredged Material.

Table 3-7. Spreadsheet Input for Cost Estimation.

Spreadsheet Inputs	Where Obtained
Percent sand in dredged material	Sediment analysis or data from previous dredging project.
Amount of topsoil to be created OR Amount of dredged material to be used	Market or use site requirement. Amount of dredged material in CDF, or amount of dredging project.
In situ S.G. values for all materials	Table 3-5 lists S.G. values for materials typically used in manufacturing soil.
For each material:	
The type of action: excavation or hauling	Dependent on project requirements
The mode of transportation and distance transported, if applicable	Dependent on material volumes and location of available materials.
An excavation factor, if applicable	Table 3-2 contains a list of excavation factors from 1.0 to 6.0 used for this study.
Blending method:	
Mechanical mixer	For manufacturing on-site or to have a permanent manufacturing facility.
In situ using agricultural equipment	When disposal area is accessible. No permanent equipment.

Table 3-8 summarizes the outputs of the spreadsheet. The amount of materials required applies to the volume of dredged material, bio-solid, and bio-mass. The total transportation costs are based on Equation 3-4 and the total excavation cost estimate is based on Equations 3-1 and 3-2. The mixing and blending costs are obtained using the values from Table 3-6. The price of the manufactured soil is in dollars per m^3 of topsoil produced.

Table 3-8. Spreadsheet Output for Cost Estimation.

Amount of Materials Required (m^3)
Total Transportation ($)
Total Excavation ($)
Mixing/Blending ($)
Total Project Cost ($)
Price of Manufactured Soil ($/m^3)

The following spreadsheets, Figures 3-5 and 3-6, show the layout used to determine the cost of converting dredged material to topsoil. In Figure 3-5, the amount of topsoil to be created is the basis for the cost analysis. The layout shown in Figure 3-6 is used when the amount of dredged material for the project is known. A key, which describes the terminology of the input, is located on the lower left corner of the spreadsheets to assist in entering the values. Action refers to whether the material is excavated (E) from the disposal area or hauled (H) to different locations. The blending method is using either agricultural equipment (A) or the mechanical mixer (M). The excavation factor is estimated using Table 3-2 and ranges in value from 1.0 to 6.0. The materials are dredged material (DM), bio-mass (BM), bio-solids (BS), and manufactured soil (MS). Transportation modes include truck (T), rail (R), and barge (B).

The top portion of the spreadsheet requires (1) the percent sand in the dredged material, (2) the amount of topsoil to be manufactured, or the amount of dredged material to be used, (3) the blending method, and (4) the S.G. values for all the materials (DM, BM, BS, and MS). The bottom portion of the spreadsheet is based on an action for each of the materials. For each material, an action code (E or H) is required. If the material is to be hauled, the mode of transportation and the distance traveled must be entered. This results in the transportation cost of the particular material. If the material is excavated, an excavation factor must be entered. An excavation cost estimate for the material is then determined. As stated earlier, the mixing and blending costs are based on the amount of topsoil to be manufactured and the rates in Table 3-6. Total equipment charges are also included at the end of the spreadsheet. A total estimate of the manufacturing project and the cost per m^3 of manufactured soil produced is shown in the lower right corner of the spreadsheet. Examples of how the spreadsheets operate are shown in the next section.

Demonstration of the Methodology: Texas GIWW

Over 7.6 million cubic meters (10 mcy) of dredged material are removed from the GIWW each year. This amount does not include the individual ship channels, rivers, or channels that access the Gulf of Mexico. The Galveston District Corps of Engineers estimates that during the 1997 fiscal year over 23 million m^3 (30 mcy) will be dredged throughout Texas and over 17 million m^3 during the 1998 fiscal year. Although many of the disposal sites along the Texas GIWW have not reached their capacity, new places and a long-term plan must be determined to address the problem of capacity. In addition, dredged material should be considered a resource while open-water disposal is less of an option.

Applicability to the Texas GIWW

Several alternatives have been considered for the beneficial use of dredged material. New mandates under the Texas Coastal Zone Management Program (CZMP) request that all dredging projects attempt to use 100 percent of the dredged material beneficially (USDOC, 1996). As with the rest of the country, many disposal areas are reaching their capacity. Among the alternatives for the beneficial use are:

- Thin-layer disposal for wetland restoration and creation,
- Manufactured soil,
- Beach nourishment,
- Erosion control along the GIWW,
- Parks and recreation, and
- Commercial (highways, expansion for airports and ports).

For example, the Houston Ship Channel widening and deepening project is using nearly 100 percent of the dredged material beneficially for bird island habitats. Over 13.7 million m^3 of dredged material have been used for beach renourishment projects in Texas to date (Rozsypal, 1997).

The Environmental Protection Agency is promoting the re-use of bio-solids in Texas. Many sewage treatment facilities have the capability of reconditioning their sewage sludge to a Class B level. Although the use of the Class B sewage sludge in manufacturing a soil would restrict the use of the manufactured soil, applications such as landfill cover, highway construction, and land reclamation would be acceptable (Peterson, 1997). An example of the re-use of bio-solids in Texas is the manufacture of soil in Huntsville (GCA, 1995). Wastewater sludge was combined with wood chips and rice hulls to form a soil product for Scott's Lawn Care Products Company.

Site Selection for the Texas GIWW

The Texas GIWW stretches over 640 km along the Texas coast. Potential sites along the Texas GIWW are shown in Figure 3-7. There are many locations along the GIWW suitable for the development of this technology. The task here is to limit the locations to a selected number of sites that meet the requirements as stated above. Many areas along the coast of Texas are remote with small populations where some residents still use septic tanks. In addition, many smaller communities may not have the capability of reconditioning the sewage sludge to the appropriate levels. In these areas, the cost of transporting reconditioned bio-solids must be weighed carefully versus the location of the dredged material and the intended use site.

- Sabine/Port Arthur to Galveston – There are several CDFs along the Sabine Neches Canal near Port Arthur in addition to some wildlife areas. The area is rather remote with limited access and many FM roads. Wood pulp processing plants are nearby.

- Galveston Bay from High Island to the southern end of Galveston Island – Good access with major interstate and state highways. Large cities nearby with plenty of bio-mass and bio-solid resources. Large potential market area.

- Galveston Bay to Matagorda Bay – There are two sites in Freeport, one at Bryan Beach located along FM 1495 (USACE Disposal Area #85), and one at Brazos Harbor (USACE Disposal Area #1). Both locations offer good highway access and a large city for a source of bio-mass and bio-solids. There are two National Wildlife

Refuges one north and one south of Freeport. East Matagorda Bay and the city of Matagorda are located near the intersection of the GIWW and the Colorado River.

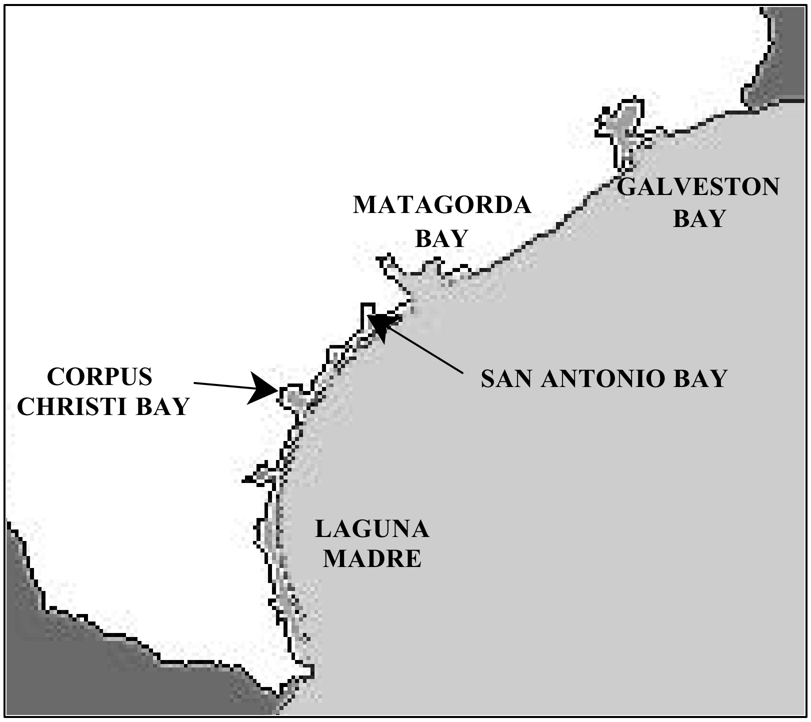


Figure 3-7. Potential Sites along the Texas GIWW.

- Matagorda Bay to San Antonio Bay – Most disposal areas are accessible by water only. The area is very remote and sparsely populated.

- San Antonio Bay to Corpus Christi Bay – Similar to Matagorda Bay in that most disposal areas are water accessible only and very remote.

- Corpus Christi Bay to Brownsville – The south shore of Nueces Bay in Corpus Christi would be a suitable site. The Laguna Madre, Padre National Seashore, and Aransas National Wildlife Refuge extend down the coast from Corpus Christi to Brownsville. The area has limited access with most disposal areas accessible only by water until Brownsville.

- Brownsville – Good access via state and interstate highways. Large city with accessible bio-mass and bio-solids resources.

The two selected potential test sites for the Texas GIWW are Bolivar Peninsula and Matagorda/Bay City. These sites were selected due to the accessibility of the disposal areas as well as the potential projects or use sites in the area. It is important to note that a majority of the dredging projects on the GIWW use hydraulic or pipeline dredges.

The amount of material available in the confined disposal facilities is not known at this time. The volumes of dredged material in the disposal areas along the GIWW are not currently available in database form. Individual sites that are surveyed for future projects and a few selected past projects are available in graphical form at the District Office in Galveston. Any information regarding the dike heights and acreage of a particular disposal facility is also available in graphical form. Changes to the current confined disposal facilities for future dredging projects, like increasing the dike height, are also available.

The amount of materials, DM, BS, and BM, used for the following potential test sites was approximated using the results from the Toledo Harbor study. Results showed that 60 percent DM, 30 percent BM, and 10 percent BS produced the most favorable results. It is important to note that these results were obtained using freshwater dredged material. Another study, Logan (1993) indicated that the reconditioned bio-solids should be combined with the marine, or brackish, dredged material at a ratio of 1 to 2. An alternative to this is to use equal parts of dredged material, bio-solids, and sand.

The spreadsheet developed in the previous section and shown in Figures 3-5 and 3-6 were used to calculate the project costs for Bolivar Peninsula and Matagorda/Bay City. The transportation costs are typically low since the material is usually located within 8 km of the construction site. Due to potential excavation problems at the selected disposal facility, excavation costs of \$6.50 and \$10.50 per m^3 were applied to the test situations at Bolivar Peninsula and Matagorda, respectively. Each site must be further investigated to determine costs that are more accurate.

Bolivar Peninsula

The intended use of the manufactured soil for the Bolivar Peninsula test site is landfill cover. The manufactured soil can be used in either a Galveston or other local landfill site. The rectangle in Figure 3-8 shows the location of the landfill on Galveston Island. In Texas, landfills require a minimum of 15 cm (5.9 in) cover material per day on newly placed landfill material. Most landfills use 20-25 cm per day (7.9 – 9.8 in per day) (Peterson, 1997). The majority of this material is obtained from borrow pits located either at the landfill site or nearby (O'Neil, 1997). The North County Landfill in Galveston has a permit for 20 acres and excavates their cover material from a nearby sandpit.

The triangle near Port Bolivar in Figure 3-8 represents the location of a CDF (USACE Disposal Area #42). An additional CDF was considered near High Island. It is also designated by a triangle near the intersection of state highways 87 and 124 (USACE Disposal Area #28). The CDF at Port Bolivar was selected due to accessibility problems at the High Island site. A culvert would need to be installed and other roadwork completed before any excavation equipment could access the CDF at High Island (Whitmire, 1997). The CDF at Port Bolivar is accessible by SH 87 and is approximately 3 km east of the intersection of the GIWW and the Houston-Galveston Ship Channel. The dredge material at the site is a sandy-silt. During the 1997 fiscal year, 0.45 million m^3 of material was dredged from High Island to Port Bolivar and used as beach nourishment for Rollover Pass.

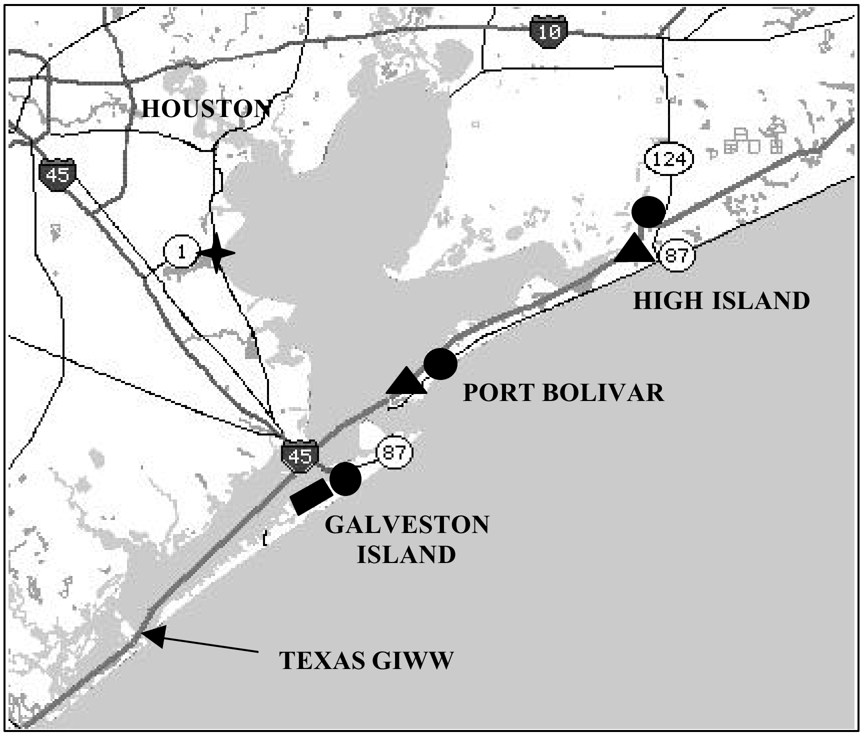


Figure 3-8. Bolivar Peninsula and Galveston Bay.

Note: All maps were obtained from the U.S. Census Department (www.tiger.census.gov)

The reconditioned bio-solids are to come from the Black Hawk Treatment Plant (Peterson, 1997). The sewage treatment facility (STF) is located on NASA 1 near I-45 and is designated by a star in Figure 3-8. The distance from the sewage treatment facility to the CDF is approximately 65 km via road, or 40 km via waterway.

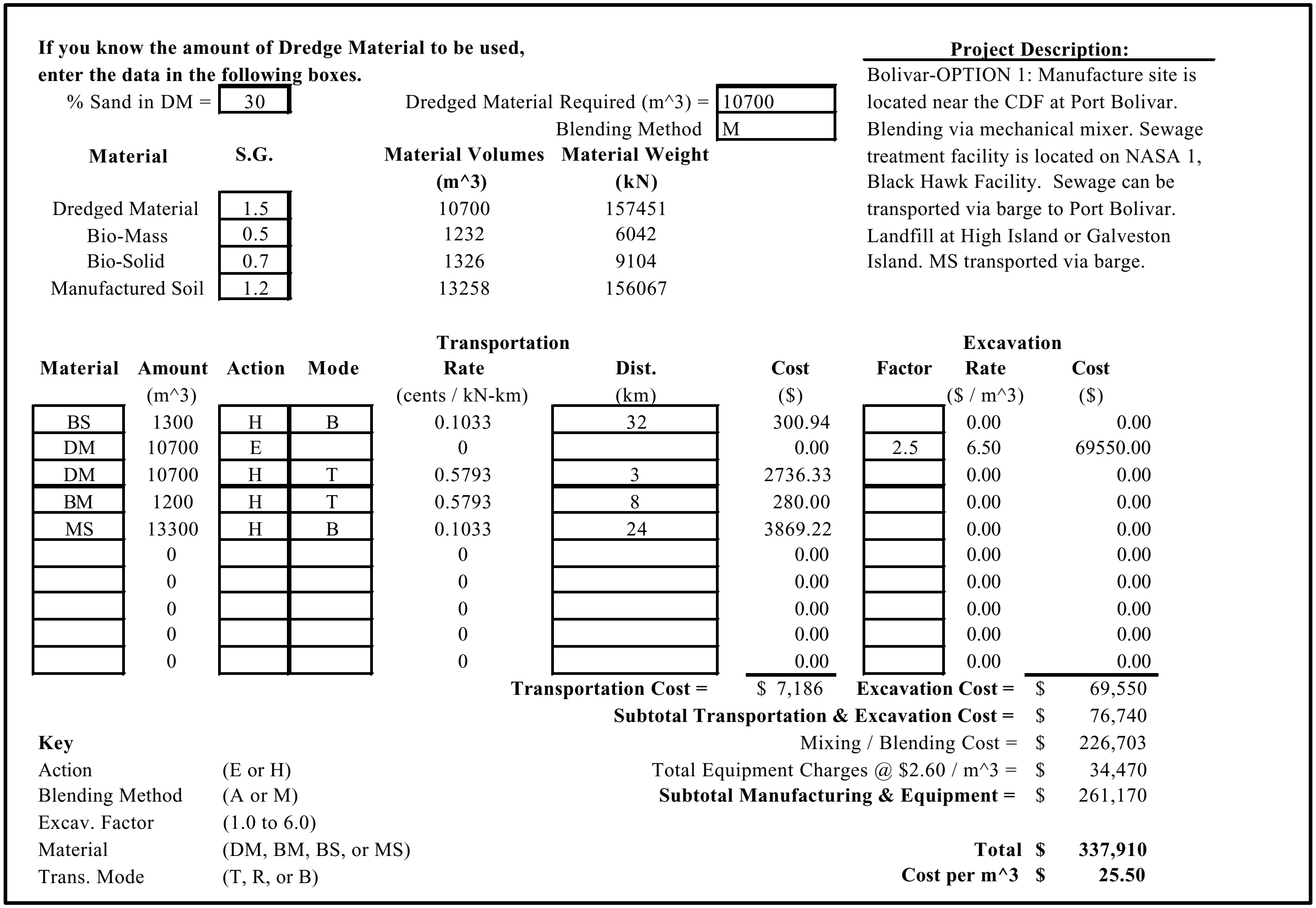
This feasibility study looked at a project requirement of 10,700 m^3 (14,000 cy) of dredged material to be used. The dredged material is a sand-silt and is approximately 30% sand. Using the relationship between the percent sand and the percent dredged material in the manufactured soil, the amount of manufactured soil is 13,300 m^3 (17,300 cy). This amounts to over 13 acres of 25 cm deep soil. The amounts of BM and BS required are 1,300 and 1,200 m^3, respectively.

The project was separated into two options in order to compare the two processing methods and their associated costs. For both options, the bio-solids are transported via barge from the Black Hawk sewage treatment facility. Since the manufactured soil is to be used for landfill cover, it is not necessary to recondition the bio-solid to a Class A level. Option 1 involves the dredge material being excavated and placed at a nearby manufacturing site. The dredged material is to be transported via truck not more than 8 km from the CDF. The manufacturing process involves a mechanical blender. Option 2 involves the in situ mixing of the dredged material, bio-solids, and bio-mass. This process uses agricultural equipment as discussed previously. The finished product, or manufactured soil, is then barged and/or trucked to a landfill near High Island or on Galveston Island.

Table 3-9 shows the results of the cost analysis of the project. The values in the following spreadsheets are the national averages. A City Cost Index Factor of 0.936, based on the city of Houston, was used to calculated the values in Table 3-9 (Means, 1996). The total project costs ranged from approximately $220,000 for option 2 to $320,000 for option 1. Overall, the cost of the manufactured soil per m^3 was between $17 and $24 per m^3 ($13 and $18.3 per cy). A complete cost breakdown of options 1 and 2 are illustrated in Figures 3-9 and 3-10, respectively.

Table 3-9. Estimated Cost Summary for the Bolivar Peninsula Project.

	Option 1	**Option 2**
Transportation and Excavation	$71,800	$86,300
Manufacturing and Equipment	$244,500	$135,300
Total	$316,300	$221,600
Cost per m^3 Manufactured Soil	$24	$17
Cost per cy Manufactured Soil	$18.3	$13



If you know the amount of Dredge Material to be used, enter the data in the following boxes.

% Sand in DM = 30

Dredged Material Required (m^3) = 10700

Blending Method M

Material	**S.G.**	**Material Volumes (m^3)**	**Material Weight (kN)**
Dredged Material	1.5	10700	157451
Bio-Mass	0.5	1232	6042
Bio-Solid	0.7	1326	9104
Manufactured Soil	1.2	13258	156067

Project Description:

Bolivar-OPTION 1: Manufacture site is located near the CDF at Port Bolivar. Blending via mechanical mixer. Sewage treatment facility is located on NASA 1, Black Hawk Facility. Sewage can be transported via barge to Port Bolivar. Landfill at High Island or Galveston Island. MS transported via barge.

Material	**Amount** (m^3)	**Action**	**Mode**	**Transportation Rate** (cents / kN-km)	**Dist.** (km)	**Cost** ($)	**Factor**	**Excavation Rate** ($ / m^3)	**Cost** ($)
BS	1300	H	B	0.1033	32	300.94		0.00	0.00
DM	10700	E		0		0.00	2.5	6.50	69550.00
DM	10700	H	T	0.5793	3	2736.33		0.00	0.00
BM	1200	H	T	0.5793	8	280.00		0.00	0.00
MS	13300	H	B	0.1033	24	3869.22		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00

Transportation Cost = $ 7,186 **Excavation Cost =** $ 69,550

Subtotal Transportation & Excavation Cost = $ 76,740

Mixing / Blending Cost = $ 226,703

Total Equipment Charges @ $2.60 / m^3 = $ 34,470

Subtotal Manufacturing & Equipment = $ 261,170

Total $ 337,910

Cost per m^3 $ 25.50

Key

Action	(E or H)
Blending Method	(A or M)
Excav. Factor	(1.0 to 6.0)
Material	(DM, BM, BS, or MS)
Trans. Mode	(T, R, or B)

Figure 3-9. Cost Estimate for Port Bolivar Option 1.

Note: The prices are the national average. A cost index factor must be applied for each location.

If you know the amount of Dredge Material to be used,
enter the data in the following boxes.

% Sand in DM = 30

Dredged Material Required (m^3) = 10700

Blending Method A

Material	**S.G.**	**Material Volumes (m^3)**	**Material Weight (kN)**
Dredged Material	1.5	10700	157451
Bio-Mass	0.5	1232	6042
Bio-Solid	0.7	1326	9104
Manufactured Soil	1.2	13258	156067

Project Description:

Bolivar-OPTION 2: Manufacture site is located within the CDF at Port Bolivar. Blending via agricultural equipment. Sewage treatment facility is located on NASA 1, Black Hawk Facility. Sewage can be transported via barge to Port Bolivar. Landfill at High Island or Galveston Island. MS transported via barge.

Material	**Amount** (m^3)	**Action**	**Mode**	**Transportation Rate** (cents / kN-km)	**Dist.** (km)	**Cost** ($)	**Factor**	**Excavation Rate** ($ / m^3)	**Cost** ($)
BS	1300	H	B	0.1033	32	300.94		0.00	0.00
BM	1200	H	T	0.5793	8	280.00		0.00	0.00
MS	13300	E		0		0.00	2.5	6.50	86450.00
MS	13300	H	B	0.1033	32	5158.96		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00

Transportation Cost = $ 5,740 **Excavation Cost =** $ 86,450

Subtotal Transportation & Excavation Cost = $ 92,190

Mixing / Blending Cost = $ 110,037

Total Equipment Charges @ $2.60 / m^3 = $ 34,470

Subtotal Manufacturing & Equipment = $ 144,510

Total $ 236,700

Cost per m^3 $ 17.90

Key

Action	(E or H)
Blending Method	(A or M)
Excav. Factor	(1.0 to 6.0)
Material	(DM, BM, BS, or MS)
Trans. Mode	(T, R, or B)

Figure 3-10. Cost Estimate for Port Bolivar Option 2.

Note: The prices are the national average. A cost index factor must be applied for each location. (Matagorda/Bay City)

Matagorda/Bay City

The intended use of the manufactured soil for the Matagorda/Bay City test site is highway construction material or general construction material. For this example, highway construction material is addressed. The sample use site consists of a highway project along Texas State Highway 35 (SH 35) from Bay City to the Jackson County line. The dotted line in Figure 3-11 shows the location of the construction project that involves approximately 65 km of shoulders added to the highway. Typically the material is obtained by the contractor from nearby borrow sites. Typical costs associated with excavating material from private property are \$0.65 per m^3 in addition to excavation and transportation costs (Dennis, 1997). The project ends near Palacios, TX, a small port on Matagorda Bay, generally used for recreational fishing.

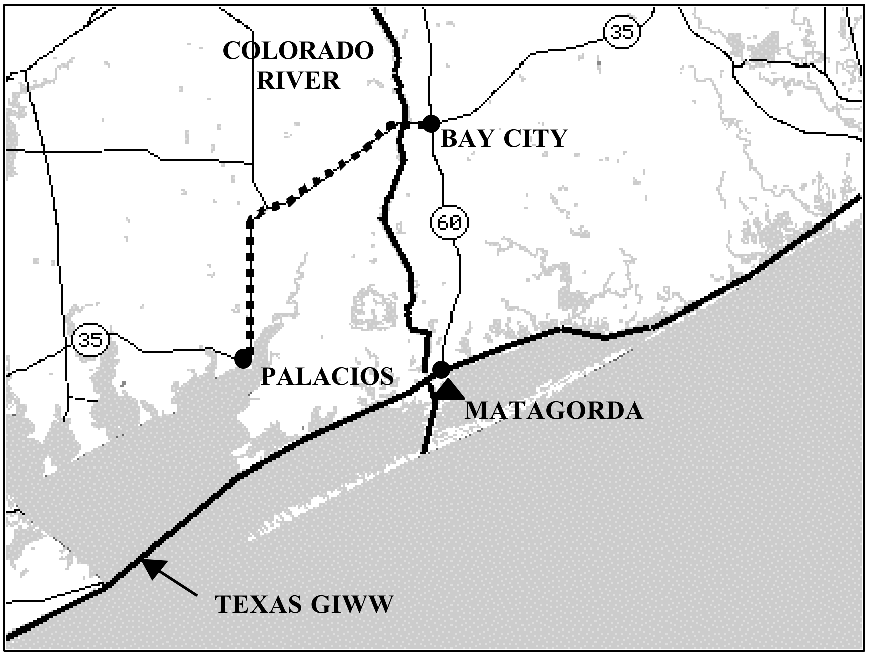


Figure 3-11. Matagorda/Bay City Project Site.

The triangle in Figure 3-11 shows the CDF (USACE Disposal Area #6) south of the city of Matagorda. The disposal site is located on Egret Island and is accessible by FM 2031 that passes through Matagorda. The CDF is approximately 1.6 km upstream from the intersection of the GIWW and the Colorado River. The dredged material in the CDF is a sandy-silt. During the 1998 fiscal year, 1.5 million m^3 will be dredged between the mouth of the Colorado River to Matagorda Bay. State Highway 60 connects Matagorda to Bay City. The distance between Matagorda and Bay City is approximately 32 km by road and 40 km via the Colorado River.

This feasibility study addressed the volumes required for the construction of shoulders for 65 km along SH 35. It was estimated that 191,000 m^3 (250,000 cy) of manufactured soil should be created. Using the relationship between the percent sand and percent dredged material in the manufactured soil, if 30% of the dredged material is sand, 154,000 m^3 of dredged material is required. In addition, 18,000 m^3 (23,544 cy) of bio-mass and 19,000 m^3 (24,852 cy) of bio-solids are needed to manufacture the soil.

The following options are similar in that most dredging projects along the GIWW involve hydraulic dredges. In addition, both options involve obtaining BS from a sewage treatment facility in Bay City and the dredged material from the Matagorda CDF. The bio-mass can be found in Matagorda.

Option 1 – The dredged material is placed in the CDF and dewatered. The bio-solids are transported by barge along the Colorado River from Bay City to Matagorda. Transportation by SH 60 can also be considered. Manufacturing of the soil is to take place at the CDF. Spreaders are used to distribute the bio-mass and bio-solids over the dredged material in the CDF. Cultivators and roto-tillers are used to mix the materials. The manufactured soil is then excavated from the CDF. The manufactured soil is then transported back to the Bay City area via barge or towards Palacios for use on SH 35.

Option 2 – Again, the dredged material is placed in the CDF and dewatered as in Option 1. The dredged material is excavated and transported to Bay City or sites located on the construction site. The dredged material is transported by barge or truck to the selected areas. The manufacturing process takes place either in Bay City or at the construction site. Mixing is accomplished using a mechanical blender.

Table 3-10 shows the results of the cost analysis of the project. The values in the following spreadsheets are the national averages. A City Cost Index Factor of 0.887, based on the city of Corpus Christi, was used to calculate the values in Table 3-10 (Means, 1996). The total project costs varied from \$3.7 to nearly \$5 million for options 1 and 2. Many of the high costs associated with this project are due to the transportation of the manufactured soil and dredged material to the intended use sites. Overall, the cost of the manufactured soil is between \$19 and \$26 per m^3 (\$14.5 and \$19.9 per cy). Figures 3-12 and 3-13 contain a complete cost breakdown of both options associated with the test site. Figure 3-12 shows the results from Option 1 and Figure 3-13 shows the results from Option 2.

Table 3-10. Estimated Cost Summary for the Matagorda/Bay City Project.

	Option 1	Option 2
Transportation and Excavation	\$1,853,000	\$1,607,000
Manufacturing and Equipment	\$1,847,000	\$3,338,000
Total	\$3,700,000	\$4,945,000
Cost per m^3 Manufactured Soil	\$19	\$26
Cost per cy Manufactured Soil	\$14.5	\$19.9

If you know the amount of Manufactured Soil to be created, enter the data in the following boxes.

% Sand in DM = 30

Topsoil to be Manufactured (m^3) = 191000

Blending Method A

Project Description:

Matagorda-OPTION 1: Manufacture site is located within the CDF in Matagorda. Blending within the CDF using agricultural equipment. Sewage is transported to Matagorda via barge. Highway construction site near Bay City. MS transported via barge back to Bay City.

Material	**S.G.**	**Material Volumes (m^3)**	**Material Weight (kN)**
Dredged Material	1.5	154154	2268379
Bio-Mass	0.5	17746	87043
Bio-Solid	0.7	19100	131160
Manufactured Soil	1.2	191000	2248452

Material	**Amount** (m^3)	**Action**	**Mode**	**Transportation Rate** (cents / kN-km)	**Dist.** (km)	**Trans. Cost** ($)	**Excav. Factor**	**Excav. Rate** ($ / m^3)	**Excav. Cost** ($)
BS	19100	H	B	0.1033	40	5419.52		0.00	0.00
BM	17700	H	T	0.5793	8	4033.93		0.00	0.00
MS	191000	E		0		0.00	4	10.40	1986400.00
MS	191000	H	B	0.1033	40	92906.04		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00

Transportation Cost = $ 102,359.49

Excavation Cost = $ 1,986,400.00

Subtotal Transportation & Excavation Cost = $ 2,088,760.00

Mixing / Blending Cost = $ 1,585,300.00

Total Equipment Charges @ $2.60 / m^3 = $ 496,600.00

Subtotal Manufacturing & Equipment = $ 2,081,900.00

Total $ 4,170,660.00

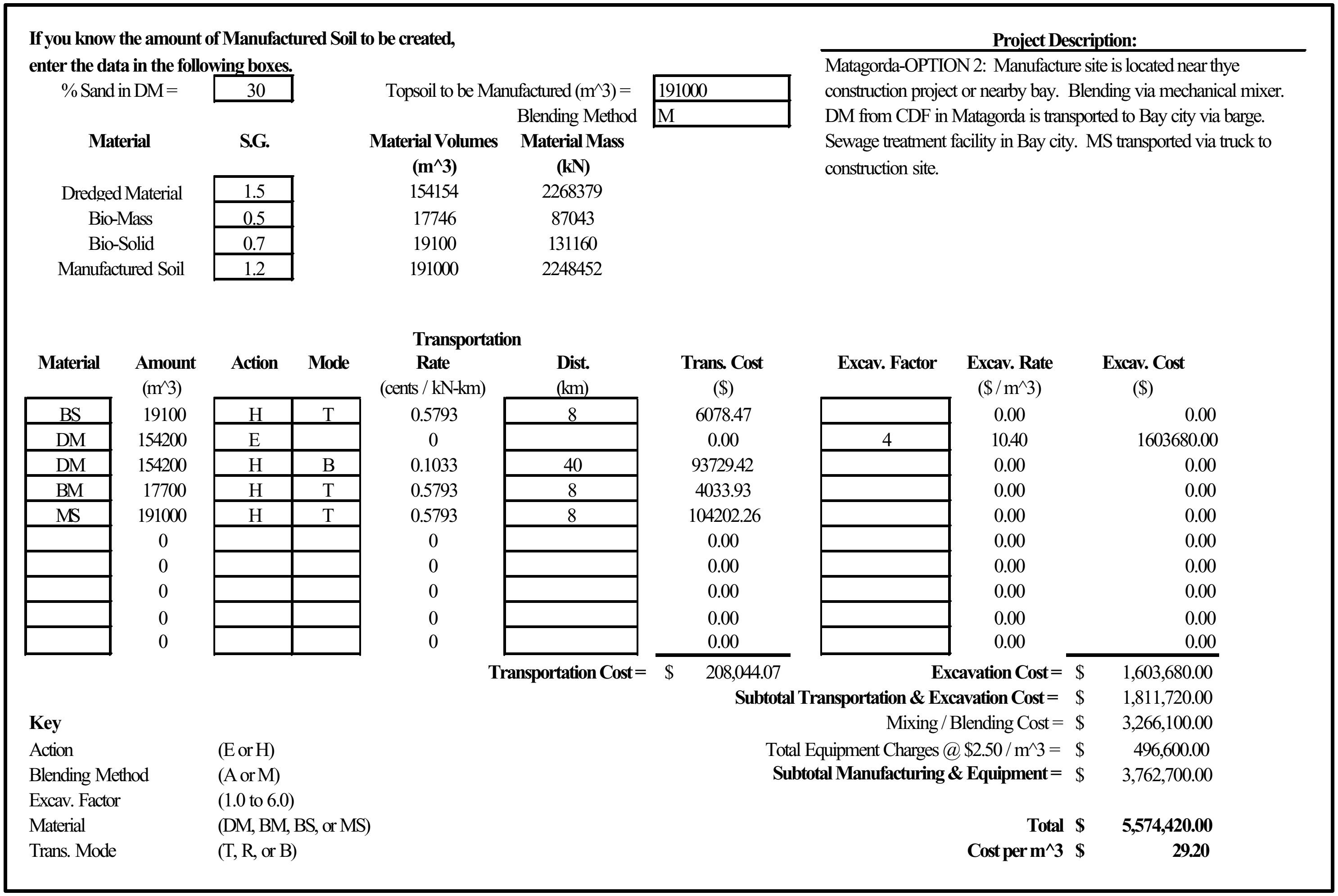
Cost per m^3 $ 21.80

Key

Action	(E or H)
Blending Method	(A or M)
Excav. Factor	(1.0 to 6.0)
Material	(DM, BM, BS, or MS)
Trans. Mode	(T, R, or B)

Figure 3-12. Cost Estimate for Matagorda/Bay City Option 1.

Note: The prices are the national average. A cost index factor must be applied for each location.



If you know the amount of Manufactured Soil to be created,
enter the data in the following boxes.

% Sand in DM = 30

Topsoil to be Manufactured (m^3) = 191000
Blending Method M

Project Description:

Matagorda-OPTION 2: Manufacture site is located near thye construction project or nearby bay. Blending via mechanical mixer. DM from CDF in Matagorda is transported to Bay city via barge. Sewage treatment facility in Bay city. MS transported via truck to construction site.

Material	**S.G.**	**Material Volumes (m^3)**	**Material Mass (kN)**
Dredged Material	1.5	154154	2268379
Bio-Mass	0.5	17746	87043
Bio-Solid	0.7	19100	131160
Manufactured Soil	1.2	191000	2248452

Material	**Amount** (m^3)	**Action**	**Mode**	**Transportation Rate** (cents / kN-km)	**Dist.** (km)	**Trans. Cost** ($)	**Excav. Factor**	**Excav. Rate** ($ / m^3)	**Excav. Cost** ($)
BS	19100	H	T	0.5793	8	6078.47		0.00	0.00
DM	154200	E		0		0.00	4	10.40	1603680.00
DM	154200	H	B	0.1033	40	93729.42		0.00	0.00
BM	17700	H	T	0.5793	8	4033.93		0.00	0.00
MS	191000	H	T	0.5793	8	104202.26		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00
	0			0		0.00		0.00	0.00

Transportation Cost = $ 208,044.07

Excavation Cost =	$	1,603,680.00
Subtotal Transportation & Excavation Cost =	$	1,811,720.00
Mixing / Blending Cost =	$	3,266,100.00
Total Equipment Charges @ $2.50 / m^3 =	$	496,600.00
Subtotal Manufacturing & Equipment =	$	3,762,700.00
Total	**$**	**5,574,420.00**
Cost per m^3	**$**	**29.20**

Key

Action	(E or H)
Blending Method	(A or M)
Excav. Factor	(1.0 to 6.0)
Material	(DM, BM, BS, or MS)
Trans. Mode	(T, R, or B)

Figure 3-13. Cost Estimate for Matagorda/Bay City Option 2.

Note: The prices are the national average. A cost index factor must be applied for each location.

Summary, Conclusions, and Recommendations

This section addresses the issue of manufactured soil as a beneficial use of dredged material. In the first section, the concept of manufactured soil was introduced. The materials involved and the manufacturing process were discussed, as well as the feasibility of converting dredged material to topsoil. Studies and pilot tests show that manufactured soil can be created using dredged material, recyclable organic waste materials (sewage sludge), and bio-mass (cellulose or saw dust). Research by the Waterways Experiment Station in conjunction with local USACE districts produced favorable results for the use of manufactured soil. An example of creating a manufactured soil, although not using dredged material, has been performed in Texas. The re-use of bio-solids for the creation of a manufactured soil was used in Huntsville, TX, for a fertilizer product. These results demonstrate the feasibility of manufactured soil as a beneficial use of dredged material and suggest its broad applicability in Texas and around the country.

This section of the report looks at the issues affecting the feasibility of manufacturing soil. The issues include:

- Finding a market or use for the converted topsoil,
- Determining the optimum site for the project,
- Deciding which bio-mass should be used and from where it will come, and
- Acquiring the bio-solid or reconditioned sewage sludge.

Some of the anticipated problems, like salinity and excavation of the dredged material, associated with converting dredged material to topsoil are also discussed.

The focus of this section is on developing a methodology for determining the costs associated with converting dredged material to topsoil and developing two example manufactured soil scenarios. Excavation, transportation, and manufacturing costs are applied to each of the materials used in the creation of the topsoil. Sample spreadsheets that reflect the methodology are developed and discussed. The cost analysis is applied to two potential pilot sites along the Texas GIWW to demonstrate the methodology. The two sites, Matagorda Bay and the Bolivar Peninsula near Galveston Bay, show that manufactured soil for use in construction and landfill projects is feasible with prices ranging from \$17 to \$26 per m^3 (\$13 to \$19.9 per cy) of manufactured soil.

The results show:

- Converting dredged material is technically feasible. Studies conducted at the regional USACE districts, and by the Waterways Experiment Station, demonstrate the applicability of this new technology. Individual feasibility studies need to be performed for each site to determine if dredged material has the properties necessary for producing a high quality manufactured soil.

- Site selection is paramount in selecting a disposal area where excavation equipment can work. Many disposal areas are located along the coastlines, and the Texas Gulf

Intracoastal Waterway in particular. Most sites are remote with limited land access. Alternatives to excavating the dredged material using land-based equipment should be investigated. One potential solution is to excavate the disposal area using a clamshell dredge or a drag-line. Depending on the dike heights, the dredge could remove the material from the disposal area and place it in a barge or scow.

- Manufactured soil can be created and transported small distances (<40 km, < 24.8 mi) at a cost of \$17 to \$26 per m^3 (\$13 to \$19.9 per cy) of topsoil depending on the blending method, mode of transportation, and ease of excavation. This price is based on the bio-solid reconditioned to a class B level for restricted uses and donated by a sewage treatment facility. An additional cost of \$28 to \$32 per m^3 (\$21.4 to \$24.5 per cy) is necessary if the bio-solids are reconditioned to an unrestricted Class A level.

- Although manufactured soil is more expensive than typical landfill cover and construction materials, it must be emphasized that the goal, or purpose of converting dredged material to topsoil, is to reduce the volume of dredged material placed into a disposal area. In addition, use of dredged material from the disposal site will save costs associated with the purchase of land for new disposal areas.

- It is recommended that plant-screening tests be performed on the dredged material for suitability as a manufactured soil and potential growing capacity. These tests determine the percentages of each material, dredged material, bio-solid, and bio-mass, for optimal plant growth. In addition, the screening test would also be used to determine the effects of salinity on selected plant types. The change of the plant species in the manufactured soil could be studied as the salt leaches out of the system. A pilot study could then be performed at a small or medium size scale (800 to 8,000 m^3 or 1,046 to 10,464 cy of dredged material) to answer questions. Only through an actual hands-on demonstration can the many unexplored questions be addressed.

- The creation of a methodology for adequately addressing costs for this new technology is essential. Previous research in the field of manufactured soil has not addressed the overall feasibility and cost effectiveness of manufactured soil. This is due to the donation of materials and transportation costs for the pilot tests described in the section on Previous Research. This study developed two methodologies to assess the feasibility and estimate project costs. A spreadsheet, available in English and metric units, will estimate the project costs based on the developed methodology. The strength or value of the methodologies will be undetermined until a pilot or large-scale test can verify the results.

THIN-LAYER DISPOSAL AS A BENEFICIAL USE

Background

An alternate dredging disposal method is called thin-layer disposal, and it may be considered a beneficial use in that the dredged material is spread in a thin-layer over wetlands to help build up and preserve the wetland. Wilber (1992a and 1992b) defines thin-layer disposal as any disposal of dredged material involving the planned placement of the material at a thickness that will either reduce the immediate impact to biota or hasten the recruitment of native biota to the material without transforming the habitat's ecological function. Zaremba and Leatherman (1984) and Maurer et al. (1986) have shown that impacts to infauna and marsh vegetation are correlated with the thickness of the thin layer. Thin-layer disposal is an environmentally acceptable management strategy that places a 5 to 15 cm (2 to 6 in) thick dredged material layer in marshes or wetland areas. This method typically uses high and low pressure hydraulic disposal units to spray the dredged material slurry over wetland areas.

The use of thin-layer disposal has been employed occasionally since the 1930s as a management procedure for dredged material from channels that pass through marshes (Krishnamohan, 1995). Concerns over the placement of dredged material from bucket dredges and hydraulic dredges in marshes arose in the 1970s and 1980s and as a result thin-layer disposal technology was developed further. In some states, thin-layer disposal is the required method for managing dredged material disposal for wetland areas.

A patented thin-layer disposal system, JET SPRAY®, was developed in 1988 by the Aztec Development Company (Deal, 1998 and 1995). This system uses aerial placement of slurried dredged material in thin layers of approximately 5 cm (2 in) or less onto existing marshes by spraying material in 75-100 m (250-350 ft) wide bands using elevated directional spray nozzles. Figure 3-14 shows dredged material being placed by the JET SPRAY® thin-layer disposal technique. Pipelines connected to mobile spray heads through retractable reels allow thin-layer disposal over larger areas deeper into the marsh areas from the channels being dredged. This high-pressure spray disposal is an innovative modification of the standard hydraulic dredging equipment. It consists of a rotating cutter head that is mounted at the bottom of a swinging ladder, and the cutter excavates the bottom sediments. These sediments pass through a pump that uses cutting blades to further break down the dredged material. The slurry is then sprayed from a rotating nozzle as liquefied slurry. Horizontal augers have also been used as the excavating device that makes the sediment available to the pump.

High-pressure spray (thin-layer) disposal technology has several advantages as indicated in Table 3-11. The high-pressure spray nozzle can be aimed in any direction so that the dredged material can be deposited discontinuously in order to completely avoid small natural drainage streams or sensitive habitats. Cahoon and Cowan (1988) indicate that the sprayed material has been observed to mostly remain in place during dredging, with little or no runoff into the canal. Further, high-pressure spray disposal technology can deposit sediments over a distance of up to 76 m (250 ft) wide as compared to conventional techniques that have disposal widths of approximately 23 m (75 ft). The high-pressure spray (thin-layer) disposal technology differs from conventional low-pressure hydraulic dredging and bucket dredging in terms of the disposal area dimensions, material deposition pattern, cost of dredging, and environmental impacts.

Figure 3-14. Thin-Layer Disposal from a Channel through a Wetland (Deal, 1998).

Table 3-11. Potential Advantages and Disadvantages of Thin-Layer Disposal (Deal, 1995).

Advantages
Eliminates need for containment ponds
Disposal process is similar to natural overlay processes
Reduces cost
Eliminates long distance pumping
No need for spuds and anchors in the dredging
Disadvantages
Requires trained operators and careful supervision
High winds can change dispersal patterns and shorten spray distances
Not cost effective in non-slurrying materials

The JET SPRAY® wide-area disposal system can place sediments in wide areas. The system consists of a manifold pipe and several stations spaced along it at 61 m (200 ft) intervals. Each station consists of two electrically driven retraction-reels, one on either side of the manifold pipe. One 305 m (1,000 ft) small diameter pipe extends into the marsh from each retraction reel. At the end of the reel pipe is a semi-amphibious sled carrying an opposed-pair of Jet-Spray nozzles. The line pressure rotates the nozzles to spray the sediment in a 30.5 m (100 ft) radius. Placement begins with the reel pipes fully extended, as the reel retracts, the sleds are pulled back, covering their tracks. Snaking minimizes damage to the marsh. The winch, anchors, reels, pipe, and sleds can be placed in the marsh with marsh buggies using

1.8 m (6 ft) wide soft tires that produce very low ground loading. A generator set adjacent to the marsh provides electrical power to the reels and winches, so that no fueling takes place within the marsh.

Thin-layer disposals generally have the capability to deposit the liquefied slurry discontinuously around the canal and marsh surfaces such that sensitive areas can be avoided. The thin-layer disposal allows disposal of material without destruction of aquatic life and without creating typical water flow impediments such as berms, containment ponds, border elevations, or disruption of water flow patterns. Placement of the organic silts in a thin lift over the marsh has been shown to enhance the marsh in similar projects that used the Jet-Spray disposal equipment. In most cases, the only evidence that dredged material had been sprayed on the marsh was crushed vegetation. Other environmental impacts associated with these projects were considered minimal.

Summary of Completed Thin-Layer Projects

Krishnamohan (1995) reviewed some of the recent thin-layer disposal projects that include Lake Landing Canal, Raphael Pass 8 and Plaquemine Parish Wetlands, Hawthorn Gas Line Project, St. Bernard Terrebone Parish Project, Atchafalaya Bay Maintenance Dredging, Mississippi Delta Rehabilitation Project, Nairn Wetland Nourishment/Creation Demonstration Project, Portable Water Supply Project, and Skidaway Inlet Dredging Project. These projects took place in Louisiana, Florida, Georgia, North Carolina, and Mississippi and are briefly summarized in the following sections.

Lake Landing Canal Project, North Carolina

Place and Time

The Lake Landing and Boundary Canals in Hyde, North Carolina, were maintenance dredged in 1982 to a depth of –2.1 m (-7 ft*)* MSL and a width of 9.1 m (30 ft). Another part of the project was the construction of a 122 m (400 ft) access channel to the Lake Landing Canal along Wysocking Bay (Wilber et al., 1992).

Volume

About 8,028 to 12,004 m^3 (10,500 to 15,700 cy) of material was excavated consisting primarily of clay, silt, and fine sand.

Equipment

Along the canals, dredged material was excavated with a barge-mounted, high-pressure hydraulic dredge that slurried the material before spraying it onto the marsh along both sides of the canals. The dredge had an auger-type cutterhead, a 20.3 cm (8 in) intake, and a 15.2 cm (6 in) discharge pump. At the discharge, a 15.2 cm (6 in) booster pump and a 8.9 cm (3.5 in) nozzle was used to spray the material onto the marsh through a single pipeline.

Thickness and Width

The approximate range of the spray along the canals was 45.7 m (150 ft) and the thickness of accumulated material varied from 1 to 20 cm (0.4 to 7.9 in) with an average of 10 cm (4 in).

Vegetation

The vegetation at the site consisted of *Juncus roemerianus* (black needle rush), *distichlis spicata* (saltgrass), *Spartina alterniflora* (smooth cordgrass), and *Spartina patens* (saltmeadow cordgrass).

Raphael Pass 8 and Plaquemine Parish Wetlands 456 Projects, Louisiana

Place and Time

During 1982-1983, two 143.3 m (470 ft) and 183 m (600 ft) canals/slips were dredged through floating roseau cane (*Phragmites australis*) marsh in Louisiana.

Volume

The project involved dredging 29,819 m^3 (39,000 cy) of material.

Equipment

The dredge was equipped with a Jet-Spray. The dredged material was sprayed onto floatant along the adjoining waterway using Jet-Spray's thin-layer material placement technology.

Vegetation

The sprayed material did not accumulate subaerially because the material sank into the soft, highly organic substrate or became resuspended in the water column and drifted off the site.

Hawthorn Gas Line Project, Mississippi

Place and Time

The maintenance dredging was in salt-water marshes on the Mississippi River Delta at Golden Meadow, Louisiana. The project was implemented in 1985.

Volume

The access channel needed excavation to a depth of 2.4 m (8 ft) above a 25.4 cm (10 in) high-pressure gas transmission line buried 4 m (13 ft) deep along its 1,799 m (5,900 ft) length.

Equipment

The contractor used the Jet-Spray method of dredging and placed the excavated material in thin overlays over adjacent marshes.

St. Bernard Terrebone Parish Project, Louisiana

Place and Time

St. Bernard and Terrebone Parishes' projects were implemented in 1986.

Volume

The St. Bernard and Terrebone Parish projects included two parts. One was the Lake Coquille project that involved dredging a 149.4 m (490 ft) canal through saline marsh to access an open-water drilling location. About 8,028 m^3 (10,500 cy) of silty-clay material was excavated. The second part was the Terrebone Parish Wetlands project. It included dredging an existing oil/gas canal to a depth of 2.4 m (8 ft) and creating a new 149.4 m (490 ft) canal/slip. About 14,451 m^3 (18,900 cy) of silt-clay material was excavated.

Thickness and Width

In the Lake Coquille project, the silty-clay dredged material was placed in layer thickness varying from 18 to 38 cm (7.1 to 15 in) for distances up to 79.3 m (260 ft) from the canal edge. In the Terrebone Parish Wetlands project, the silty-clay dredged material was placed in layer thickness varying from 10 to 15 cm (4 to 6 in) for distances up to 70 m (230 ft) from the canal edge.

Equipment

The high-pressure spray technology was used through the saline marsh.

Vegetation

These two brackish marshes have *Spartina alterniflora, Salicornia spp.* (glassworts), and *distichlis spicata* (saltgrass). At both sites, placement of dredged material smothered existing vegetation. Limited recolonization by these species was evident after one growing season (8 to 14 months).

Mississippi Delta Rehabilitation Project, Louisiana

Place and Time

The project was implemented in 1991 in the Mississippi Delta, Louisiana. The purpose was to divert sediment laden Mississippi River water through a siphoning geotube from the elevated levee. The idea was to deposit 305,840 m^3/yr (400,000 cy/yr) to improve 17,000 acres of delta land with new sediment.

Volume

Approximately 38,230 m^3 (50,000 cy) of material was excavated by drag line to bury portions of the siphons to a depth of 1.2 m (4 ft) and dredge the discharge pond. Approximately 19,115 m^3 (25,000 cy) of material and pond bottom material was excavated.

Equipment

The Jet-Spray equipment was used for the outfall channels and deposited in a thin layer on adjacent marsh.

Vegetation

The aerially-projected material was sprayed in thin overlays that imitated the natural thin-flood deposits that invigorate, rather than smother marsh grass.

Atchafalaya Bay Maintenance Dredging

Place and Time

The location was the Atchafalaya River near Morgan City, Louisiana, which is an outlet to the Gulf of Mexico. The project began in 1991.

Volume

In the project, shoaling in the 6.7 m (22 ft) depth waterway requires about 1.53 to 2.29 mcm (2.0 to 3.0 mcy) of dredged material annually. The material was spread in thin lift at selected areas.

Equipment

The T. L. James & Company, Inc. used Jet-Spray equipment and a 61 cm (24 in) cutter suction dredge to maximize the distribution of the over 1.91 mcm (2.5 mcy) of dredged material and approximately 3,354 m (11,000 ft) of pipeline was used.

Nairn Wetland Nourishment/Creation Demonstration Project, Louisiana

Place and Time

The Nairn project site is located in Plaquemines Parish at the northern edge of a large area of concentrated wetland loss. The U.S. Environmental Protection Agency proposed this project in 1992 (USEPA, 1992) for purpose of marsh creation and restoration, but it was not initiated.

Volume

About 0.92 mcm (1.2 mcy) of sediment from the bed of the Mississippi River near Sixty-mile Point was to be dredged.

Equipment

A hydraulic dredge was to be used, and the sediment placement was to be accomplished by the Jet-Spray wide-area dispersal system. The system consists of manifold pipe and four stations spaced at 61 m (200 ft) intervals. Each station consisted of two electrically driven retraction reels, one on either side of the manifold pipe. One 305 m (1,000 ft) small diameter pipe was to extend into marsh from each retraction reel. At the end of the reel pipe was to be a semi-amphibious sled carrying an opposing pair of Jet-Spray nozzles. The line pressure spins the nozzles to sprinkle the sediment in a 30.5 m (100 ft) radius. Placement begins with the reel pipes fully extended, and as the reel retracts, the sleds are pulled back, covering their tracks. Damage to the marsh is minimized by “snaking” the manifold pipe into the marsh using a cable and a winch anchored to a “deadman.” The winch, anchors, reels, pipe and sleds can be placed in the marsh with marsh buggies using 1.8 m (6 ft) wide soft tires that produce very low-ground loading.

Thickness and Width of Placed Material

The 0.92 mcm (1.2 mcy) dredged material from the Mississippi River was to create approximately 204 acres of new salt marsh and restore an additional 459 acres that are currently deteriorating.

Portable Water Supply Project, the City of Savannah, Georgia

Place and Time

The project began in the fall of 1992 in the city of Savannah, Georgia. Its purpose was to dredge the water supply channel, Little Abercorn Creek.

Volume

The 57,345 m^3 (75,000 cy) of difficult material was removed from 3,963 m (13,000 ft) of creek channel.

Equipment

The dredging and placement of the material were completed with the use of Aztec Development Co.’s JET-SPRAY® dredge.

Thickness

The aerial placement of dredged material with thin-layer overlays was 7.6 cm (3 in) or less.

Vegetation

The dredged material was placed aerially over the top of a wall of hardwood trees.

Skidaway Inlet Dredging Project, Georgia

Place and Time

The Skidaway Inlet project was proposed in 1990 and the permitting process began in 1995.

Volume

This project involved dredging about 19,115 m^3 (25,000 cy) of material along a 1,037 m (3,400 ft) long section of the creek in order to deepen the Skidaway Inlet elevation to -1.5 m (-5 ft) MLW. The material consists mainly of organic silts.

Equipment

A hydraulic suction dredge with a Jet-Spray attachment designed to discharge the slurry material into the adjacent marsh in thin overlay was used in the project.

Thickness and Width

The thickness of placements was 5 cm (2 in) thin lifts. Two common types of natural disturbance, dunewash and crack deposition, are very similar to thin-layer disposal of dredged material and provided some insight into the long-term effects of these techniques. The thickness of the crack layer ranges from 20 to 30 cm (7.9 to 11.8 in).

Vegetation

Marsh vegetation was typically *Spartina paten* that was able to penetrate up to 33 cm (13 in) of material and *Spartina alterniflora* that was able to penetrate 24 cm (9.4 in) of material.

Potential Location's for Use of Thin-Layer Disposal along the Texas GIWW

Wetlands are often recognized as the best place for the application of thin-layer disposal. In these cases, the impacts of the dredged material disposal on the ecosystem are the smallest. Therefore, the wetlands along the Texas GIWW in which thin-layer disposal could be applied are identified. A series of maps were developed by the Texas General Land Office that show the Texas Gulf Intracoastal Waterway. The wetland area that has been identified for possible thin-layer disposal can be found in Map 3 (Barnett Lake – Entrance (East) to Galveston Bay, Figure 3-15), Map 5 (Galveston West Bay – Christmas Bay, Figure 3-16), Map 6 (San Bernard River – East Matagorda Bay, Figure 3-17), Map 7 (San Bernard National Wildlife Refuge, Big Boggy NWR, Figure 3-18), and Map 11 (Laguna Madre Potrero Granda to Port Mansfield Channel, Figure 3-19). In these maps the Texas GIWW is shown by a dashed line and the current confined disposal areas are the numbered shaded areas usually located on one side of the GIWW. It is suggested that the side opposite the CDFs can be considered for thin-layer disposal of the dredged material resulting from maintenance dredging of the GIWW.

The GIWW running from Barnett Lake through wetlands to the East Entrance of Galveston Bay is shown in Map 3 (Figure 3-15), and the distance along the waterway is approximately 51 km (32 mi). The numbered shaded areas are confined disposal areas that are located on the south side of the waterway. It is recommended that maintenance dredged material be used beneficially to renourish the open wetlands next to the waterway using thin-layer disposal techniques. These locations were selected by looking at the map to see if wetlands were paralleling the waterway. More physical and biological investigations are needed to determine the feasibility or desirability of using thin-layer disposal techniques to beneficially renourish the adjacent wetlands with dredged material from maintenance dredging of the GIWW.

Map 5 (Figure 3-16) shows the GIWW stretching through the Galveston West Bay to Christmas Bay. The confined disposal areas are located on the West Bay side of the GIWW and there is approximately 16 km (10 mi) of wetland area on the north side of the GIWW that could be considered for thin-layer disposal. There is another 16 km (10 mi) that are located on the north side of Bastrop and Christmas Bays. These areas are recommended for consideration in using GIWW maintenance dredged material to beneficially renourish the adjacent wetlands.

Next, the stretch of wetlands from the intersection of the Freeport Ship Channel and the GIWW to where the GIWW parallels East Matagorda Bay is illustrated on Map 6 in Figure 3-17. This is a stretch of approximately 71 km (45 mi) of waterway that runs through wetlands that include the San Bernard and Big Boggy National Wildlife Refuges. Again this area appears to be a possible location where thin-layer disposal may be considered for beneficially using GIWW maintenance dredged material for wetland renourishment.

Another possibility for thin-layer disposal is the area between the Colorado River and where the GIWW enters Matagorda Bay as shown in Map 7 (Figure 3-18). This distance is approximately 21.6 km (13.4 mi) with confined disposal areas number 107 to 112 located on the east Matagorda Bay side of the waterway. The wetland areas on the north side of the waterway should be considered for thin-layer disposal.

Finally, the 36 km (22 mi) distance from Potrero Granda to where the GIWW enters the Laguna Madre is shown in Map 11 (Figure 3-19). The waterway runs through submerged vegetation and mudflats, and this area is suggested as a possibility for applying thin-layer disposal to renourish the mud flats with dredged material from the GIWW. Again, it is emphasized that physical and biological considerations are needed to determine the feasibility and/or desirability of using thin-layer disposal for renourishing these areas.

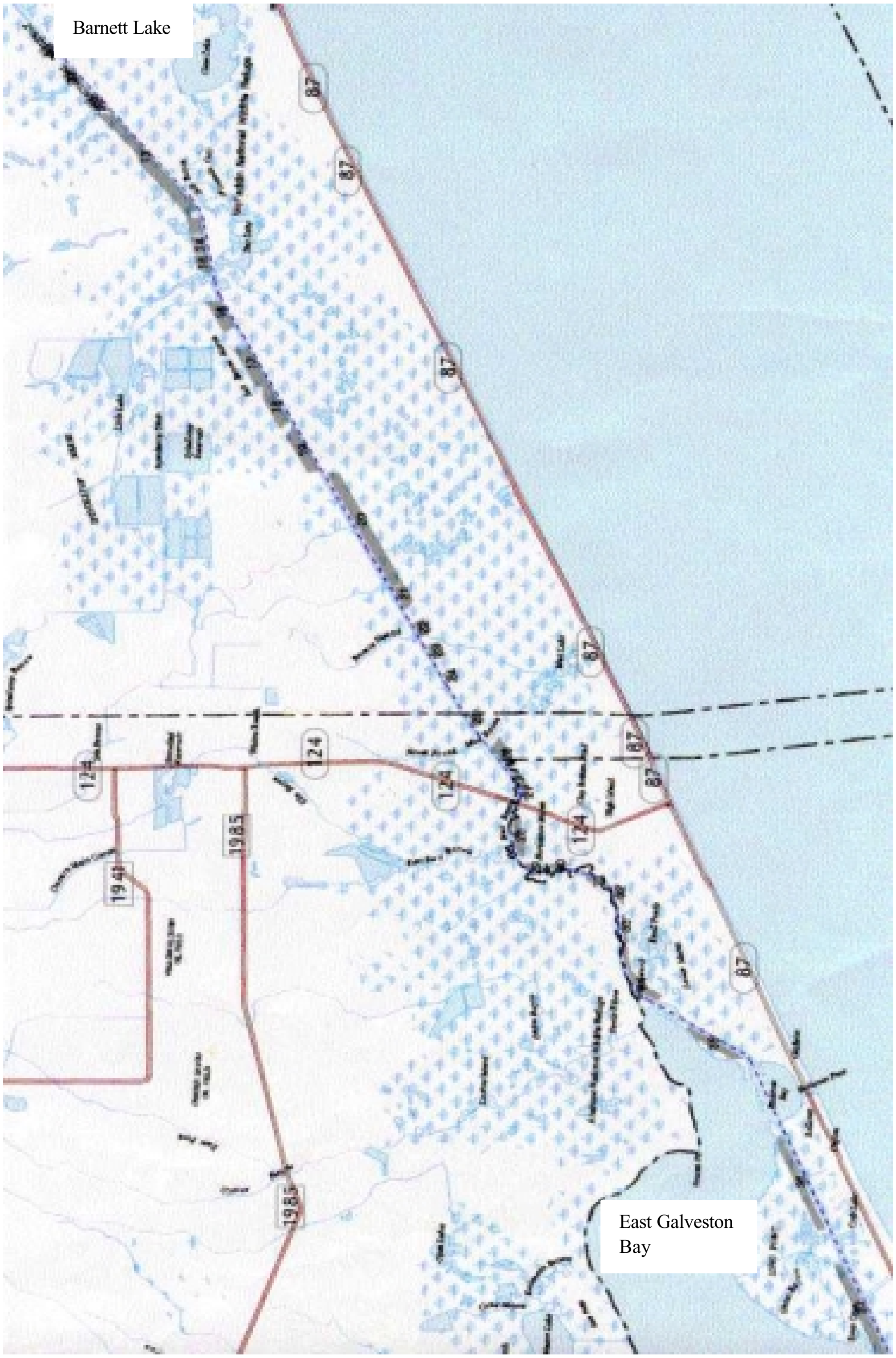


Figure 3-15. Map 3: Barnett Lake – Entrance (East) to Galveston Bay; McFadden NWR, Salt Bayou; Horseshoe Marsh, Anahuac NWR; Station Number: from 550+00 to 2360+00; Corresponding CDF Site Number: from 10 to 37.

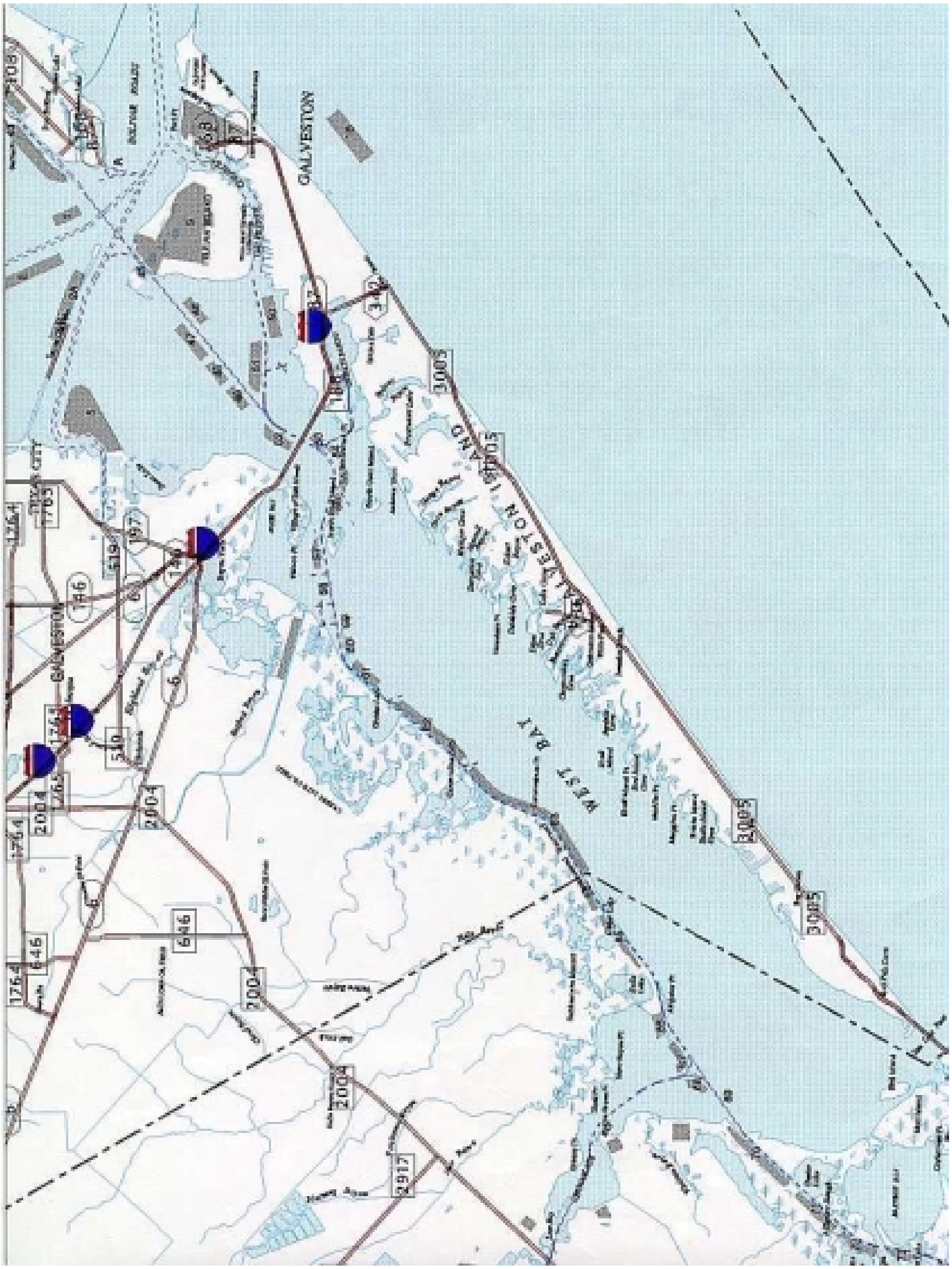


Figure 3-16. Map 5: Galveston West Bay – Christmas Bay, Greens, Vedar, Halls, Oyster, Alligator Lakes; Station Number: from 45+000 to 100+000; and from 120+000 to 156+000; Corresponding CDF Site Number: from 61 to 65 and from 70 to 72.

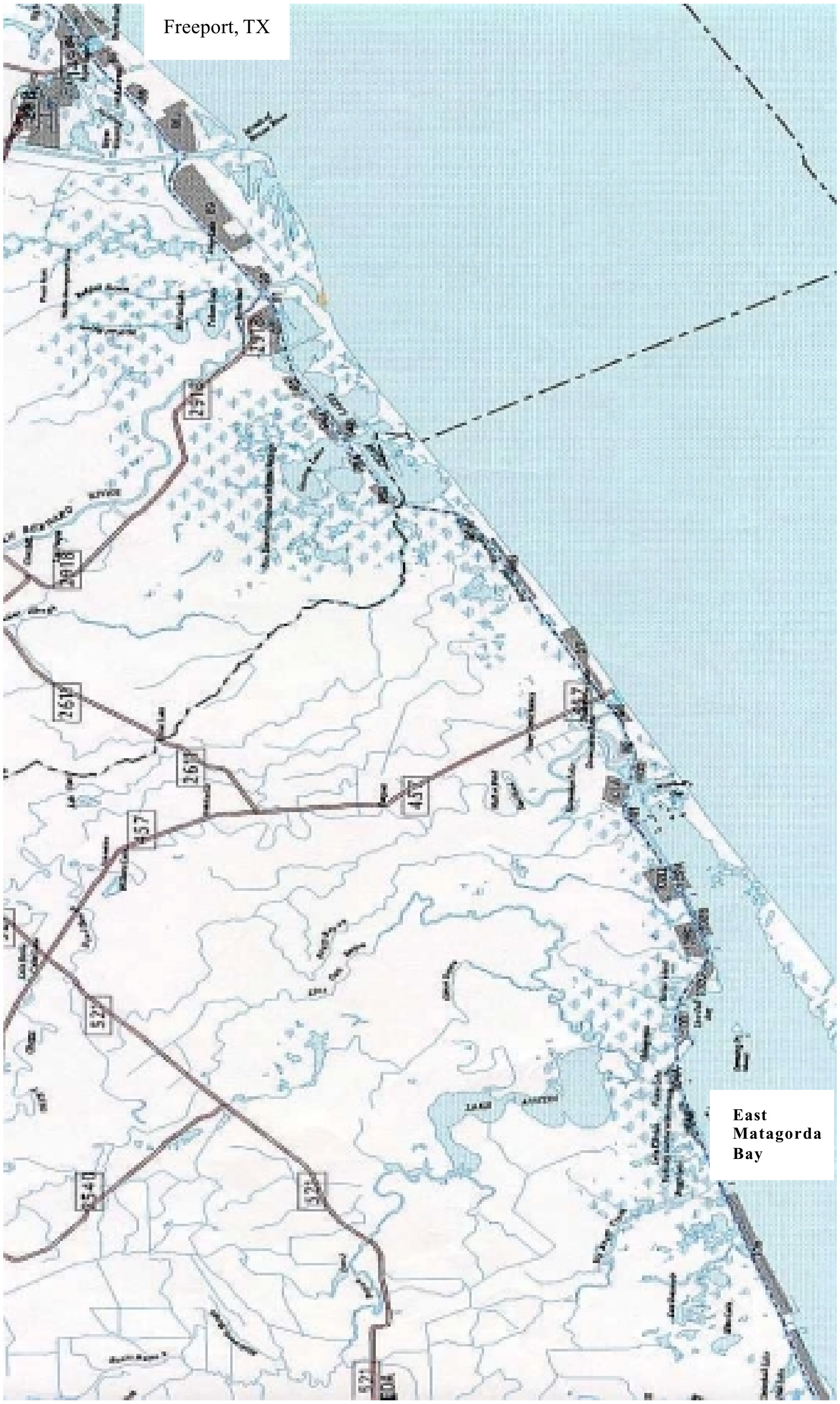


Figure 3-17. Map 6: Freeport Ship Channel, San Bernard River – East Matagorda Bay, San Bernard National Wildlife Refuge, Big Boggy National Wildlife Refuge; Station Number: 220+000 to 450+642; Corresponding CDF Site Number: 84 to 106.

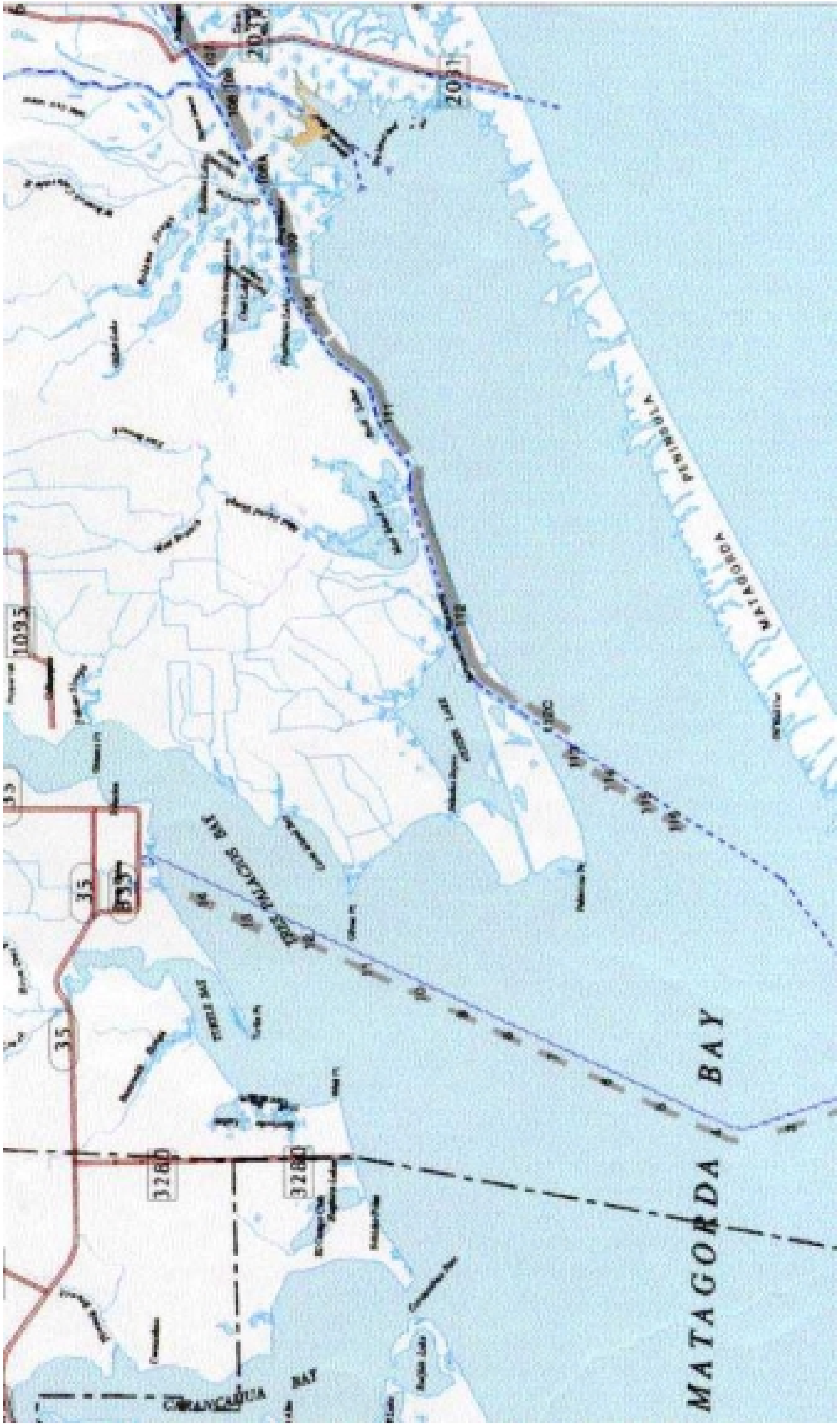


Figure 3-18. Map 7: San Bernard NWR, Big Boggy NWR; Station Number: from 451+000 to 34+000; Corresponding CDF Site Number: from 107 to 112.

Figure 3-19. Map 11: Laguna Madre Potrero Granda to Port Mansfield Channel; Station Number: 301+000 to 270+000; Corresponding CDF Site Number: 210 to 208.

Estimates of Thin-Layer Disposal Width and Thickness for Selected Texas GIWW Locations

The feasibility of thin-layer disposal along the Texas GIWW can be illustrated by assuming a volume of dredged material available from maintenance dredging for the purpose of spraying a thin layer of dredged material on the wetlands adjacent to the waterway. The distance along the waterway is taken as the distance between stations along the waterway as taken from Corps of Engineers dredging charts provided by the Galveston District (Baumer, 1997). For example, stations 120+000 to 145+000 represent 7,622 m (25,000 ft) along the waterway in the area of Galveston Causeway to Bastrop Bayou shown on Map 5 (Table 3-12 and Figure 3-20). A thin-layer thickness and dredged material volume were assumed and used along with the distance along the waterway to calculate the disposal width (distance normal to the GIWW). The required disposal widths were calculated for different thicknesses and dredged material volumes and presented in Figure 3-20 for the waterway along the Galveston West Bay between stations 45+000 and 72+000 which parallel the location of the confined disposal facilities numbered 61 and 63. For 382,300 m^3 (500,000 cy) of dredged material sprayed at a thickness of 10 cm, it would require a disposal width of 457.3 m (1,500 ft). Typical thin-layer disposal equipment is capable of a disposal width of 76.2 m (250 ft) without using reeled piping as discussed previously. Therefore special retraction reels and piping would be necessary to attain this disposal width. A 15 to 25 cm (5.9 to 9.8 in) thickness would require a 304.9 to 189.9 m (1000 to 600 ft) disposal width, respectively. If the amount of dredged material is greater than 382,300 m^3 (500,000 cy), then the thin-layer disposal would likely have to be augmented with discharge into the adjacent disposal sites.

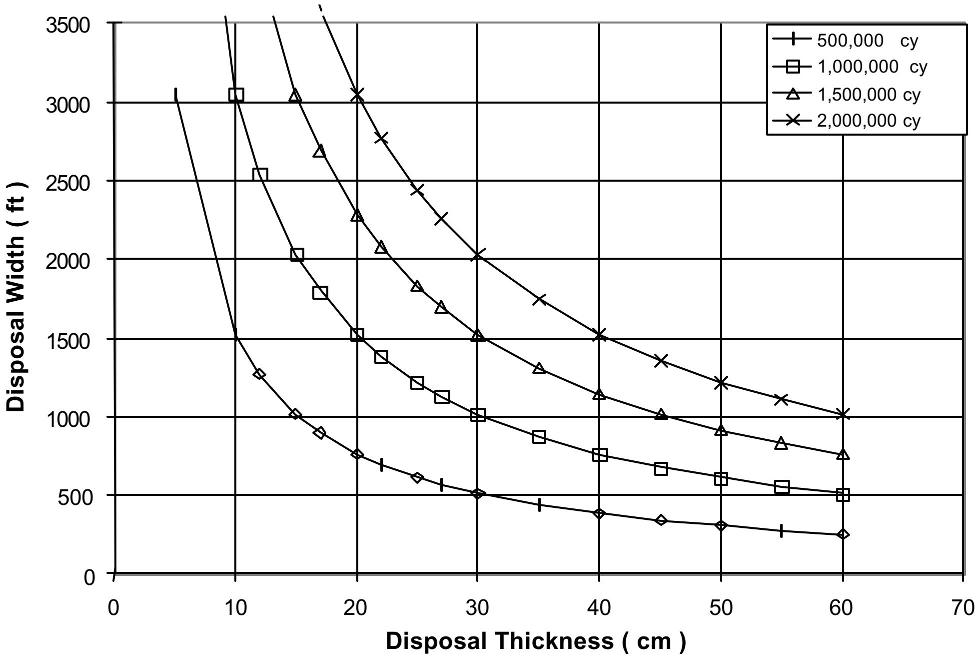


Figure 3-20. Estimation of Disposal Width for GIWW from Galveston Causeway to Bastrop Bayou (Map 5) in the Area of Disposal Sites 61 to 63, Station 45+000 to 72+000.

Disposal widths are calculated in a similar manner for the waterway between Freeport Harbor and Caney Creek shown on Map 6 (Figure 3-16), and the results are illustrated in Figure 3-21. In this case the waterway length is 73,000 ft and it is shown that the disposal width is 500 ft for a 10 cm thickness, 400 ft for a 15 cm thickness and 250 ft for a 25 cm thickness. For 1 million cy of dredged material the 10 cm thickness requires 1,100 ft of disposal width which would require the retractable reels and associated pipelines. The maintenance dredged material is also assumed to be evenly distributed along the waterway which may or may not be the case. For this example it appears that the thin-layer disposal is possible. It is also necessary to conduct further physical and biological investigations to determine the viability and desirability of this thin-layer beneficial use concept, but it does appear to be possible for this location.

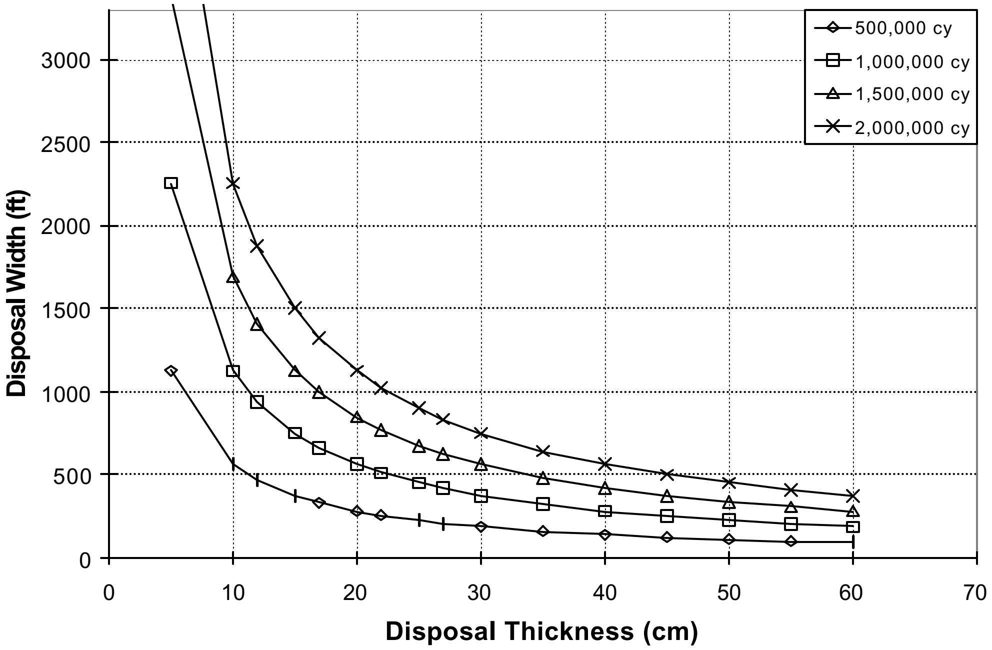


Figure 3-21. Estimation of Disposal Width for the GIWW in Vicinity of Freeport Harbor to Caney Creek (Map 6) in the Area of Disposal Sites 88 to 96B, Stations 244+000 to 317+000.

A third location from the Colorado River to Matagorda Bay is also illustrated in Figure 3-22 and the area is shown in the previous Map 7 (Figure 3-18). The waterway length is between stations 457+000 to 535+000 which represents a distance of 78,000 ft. It is shown that a 10 cm thickness requires 500 ft disposal width for the 500,000 cy of dredged material and 300 ft and 200 ft for the 15 cm and 25 cm thickness, respectively. This shows the thin-layer disposal concept is possible for the smaller dredged material volume (approximately 500,000 cy) and that larger volumes of one million or greater require additional inland piping or augmentation with another disposal option such as a nearby confined disposal site. From these illustrations, thin-layer disposal width and thickness can be determined for these specific dredging sites when the amount of dredged material is known.

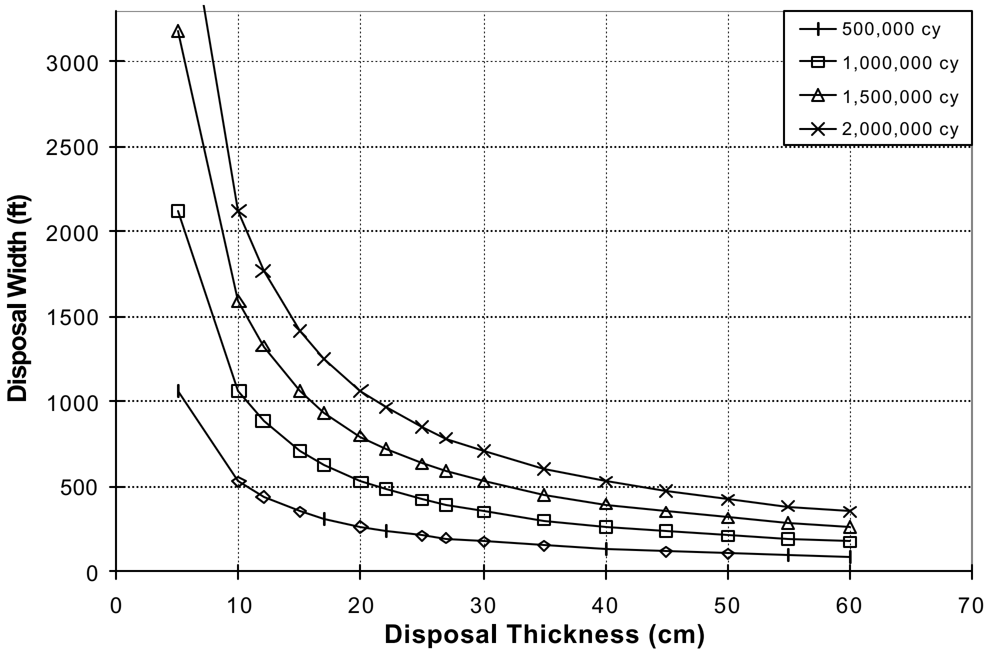


Figure 3-22. Estimation of Disposal Width for GIWW between Colorado River and Matagorda Bay (Map 7) in the Area of Disposal Sites 108 to 112, Stations 457+000 to 535+000.

Effect of Dredging Frequency upon Application of Thin-Layer Disposal

Maintenance dredging data from previous dredging projects in the Texas GIWW from 1986 to 1996 were used to estimate the thickness of the thin-layer disposal of the material dredged from the GIWW. These data were obtained from the Galveston District (Baumer, 1997) and include the dredged material volume, the station numbers of the dredged sections, the work completion date, downstream station, upstream station, channel section length, and the amount of dredged material from the section. Table 3-12 shows the data that corresponds to Map 5 for the area between Galveston West Bay and Christmas Bay. For example, 711,422 cy of material was dredged between Galveston Causeway to Bastrop Bayou and complete January 1, 1989, over a distance of 10,670 m (35,000 ft).

This information is used to determine the width and thickness of the dredged material from the GIWW using thin-layer disposal techniques. It is also used to determine the volume of the disposed dredged material and to investigate the effect of the frequency of dredging. This analysis is based on the assumption that the length of the thin-layer disposal area has the same length as the dredging area in the GIWW.

Table 3-12. Map 5: Galveston West Bay – Christmas Bay; Greens, Cedar, Halls, Oyster, Alligator Lakes; Disposal Site No.: 61 to 65; 70 to 72; The Corresponding Station No.: 45+000 to 100+000; 120+000 to 145+000.

Channel	Work Comp	DS Station	US Station	PresAct cy	OverAct cy	Section Total cy	Total cy	Section Length ft
Galv. Cswy. - Bastrop Byu.	1/1/89	45+000	50+000	83591	8666	92257		
Galv. Cswy. - Bastrop Byu.	1/1/89	50+000	55+000	126736	19006	145742		
Galv. Cswy. - Bastrop Byu.	1/1/89	55+000	60+000	73886	15845	89731		
Galv. Cswy. - Bastrop Byu.	1/1/89	60+000	65+000	102299	20771	123070		
Galv. Cswy. - Bastrop Byu.	1/1/89	65+000	70+000	71951	11956	83907		
Galv. Cswy. - Bastrop Byu.	1/1/89	70+000	75+000	80481	16496	96977		
Galv. Cswy. - Bastrop Byu.	1/1/89	75+000	80+000	63887	15851	79738	711422	35000
Galv. Cswy. - Bastrop Byu.	4/27/87	80+000	85+000	56341	19183	75524		
Galv. Cswy. - Bastrop Byu.	4/27/87	85+000	90+000	94709	18834	113543		
Galv. Cswy. - Bastrop Byu.	4/27/87	90+000	95+000	102132	16749	118881		
Galv. Cswy. - Bastrop Byu.	4/27/87	95+000	100+000	105871	14011	119882	427830	20000
Galv. Cswy. - Bastrop Byu.	4/27/87	120+000	125+000	84138	25103	109241		
Galv. Cswy. - Bastrop Byu.	4/27/87	125+000	130+000	40798	20064	60862		
Galv. Cswy. - Bastrop Byu.	4/27/87	130+000	135+000	46103	19982	66085		
Galv. Cswy. - Bastrop Byu.	4/27/87	135+000	140+000	28703	17596	46299		
Galv. Cswy. - Bastrop Byu.	4/27/87	140+000	145+000	24159	17101	41260	323747	25000

Note: DS means downstream; US means upstream; PresAct means present dredging action; OverAct means over dredging action; Work Comp means work that was completed on the given date.

The disposal thickness is limited in some environmentally sensitive areas, in order to prevent damage to the wetland. For example, initial smothering of vegetation may occur due to the large amount of water in the dredging process. In poorly drained soils, decomposition of organic matter may lead to hypoxic conditions that reduce plant growth. Significant changes in marsh elevation may alter vegetation patterns. Usually, the thin-layer disposal thickness is not expected to be over 25 cm (0.8 ft) in these environmentally sensitive areas.

Increasing the dredging frequency in a certain location could result in a reduced dredged material volume to be placed by thin-layer disposal. Then, the thin-layer disposal technique could be applied and the disposal thickness would be smaller. For the purpose of this report, the maintenance material in the GIWW is assumed to be distributed evenly along the waterway.

Table 3-13 shows the required thin-layer disposal thickness for the dredging sites long the Texas GIWW in Map 5 according to the previous dredging frequency which is approximately every 2 years. A disposal width of 400 ft was assumed and the resulting thin-layer thickness was 1.37, 1.44, and 0.87 ft. These values exceed the suggested maximum thickness of 25 cm (0.8 ft), and therefore the thin-layer disposal would have to be augmented with disposal in the confined disposal sites in addition to the thin-layer disposal. If the dredging frequency is doubled for these dredging sites, then the disposal thickness is reduced to an acceptable level of 0.65, 0.72, and 0.44 ft for those areas as illustrated in the far right-hand column in Table 3-14.

Table 3-13. Galveston West Bay – Christmas Bay; Greens, Cedar, Halls, Oyster, Alligator Lakes; Disposal Site No.: 61 to 65; 70 to 72; The Corresponding Station No.: 45+000 to 100+000; 120+000 to 156+000.

Channel	Work	DS	US	PresAct	OverAct	Section	Total	Section	Width	Thickness
	Comp	Station	Station	cy	cy	Total cy	cy	Length ft	Layer ft	Layer ft
Galv. Cswy. - Bastrop Byu.	1/1/89	45+000	50+000	83591	8666	92257			400	**1.37**
Galv. Cswy. - Bastrop Byu.	1/1/89	50+000	55+000	126736	19006	145742			400	**1.37**
Galv. Cswy. - Bastrop Byu.	1/1/89	55+000	60+000	73886	15845	89731			400	**1.37**
Galv. Cswy. - Bastrop Byu.	1/1/89	60+000	65+000	102299	20771	123070			400	**1.37**
Galv. Cswy. - Bastrop Byu.	1/1/89	65+000	70+000	71951	11956	83907			400	**1.37**
Galv. Cswy. - Bastrop Byu.	1/1/89	70+000	75+000	80481	16496	96977			400	**1.37**
Galv. Cswy. - Bastrop Byu.	1/1/89	75+000	80+000	63887	15851	79738	711422	35000	400	**1.37**
Galv. Cswy. - Bastrop Byu.	4/27/87	80+000	85+000	56341	19183	75524			400	**1.44**
Galv. Cswy. - Bastrop Byu.	4/27/87	85+000	90+000	94709	18834	113543			400	**1.44**
Galv. Cswy. - Bastrop Byu.	4/27/87	90+000	95+000	102132	16749	118881			400	**1.44**
Galv. Cswy. - Bastrop Byu.	4/27/87	95+000	100+000	105871	14011	119882	427830	20000	400	**1.44**
Galv. Cswy. - Bastrop Byu.	4/27/87	120+000	125+000	84138	25103	109241			400	**0.87**
Galv. Cswy. - Bastrop Byu.	4/27/87	125+000	130+000	40798	20064	60862			400	**0.87**
Galv. Cswy. - Bastrop Byu.	4/27/87	130+000	135+000	46103	19982	66085			400	**0.87**
Galv. Cswy. - Bastrop Byu.	4/27/87	135+000	140+000	28703	17596	46299			400	**0.87**
Galv. Cswy. - Bastrop Byu.	4/27/87	140+000	145+000	24159	17101	41260	323747	25000	400	**0.87**

Note: DS means downstream; US means upstream; PresAct means present dredging action; OverAct means over dredging action; Work Comp means work that is completed on the date shown.

Table 3-14. Disposal Thickness after Adding One Dredging Time in the Middle of Previous Dredging Interval.

Channel	DS Station	US Station	PresAct cy	OverAct cy	Section Total cy	Total cy	Section Length ft	Width Layer ft	Thickness Layer ft
Galv. Cswy. - Bastrop Byu.	45+000	50+000	41796	4333	46128.5			400	0.65
Galv. Cswy. - Bastrop Byu.	50+000	55+000	63368	9503	72871			400	0.65
Galv. Cswy. - Bastrop Byu.	55+000	60+000	36943	7922.5	44865.5			400	0.65
Galv. Cswy. - Bastrop Byu.	60+000	65+000	51150	10385.5	61535			400	0.65
Galv. Cswy. - Bastrop Byu.	65+000	70+000	35976	5978	41953.5			400	0.65
Galv. Cswy. - Bastrop Byu.	70+000	75+000	40241	8248	48488.5			400	0.65
Galv. Cswy. - Bastrop Byu.	75+000	80+000	31944	7925.5	39869	355711	35000	400	0.65
Galv. Cswy. - Bastrop Byu.	80+000	85+000	28171	9591.5	37762			400	0.72
Galv. Cswy. - Bastrop Byu.	85+000	90+000	47355	9417	56771.5			400	0.72
Galv. Cswy. - Bastrop Byu.	90+000	95+000	51066	8374.5	59440.5			400	0.72
Galv. Cswy. - Bastrop Byu.	95+000	100+000	52936	7005.5	59941	213915	20000	400	0.72
									0.44
Galv. Cswy. - Bastrop Byu.	120+000	125+000	42069	12551.5	54620.5			400	0.44
Galv. Cswy. - Bastrop Byu.	125+000	130+000	20399	10032	30431			400	0.44
Galv. Cswy. - Bastrop Byu.	130+000	135+000	23052	9991	33042.5			400	0.44
Galv. Cswy. - Bastrop Byu.	135+000	140+000	14352	8798	23149.5			400	0.44
Galv. Cswy. - Bastrop Byu.	140+000	145+000	12080	8550.5	20630	161874	25000	400	0.44

Note: DS means downstream; US means upstream; PresAct means present dredging action; OverAct means over dredging action; Work Comp means the work that is completed on the date shown.

Another example is for the area from the San Bernard River to East Matagorda Bay that is shown on Map 6 (Figure 3-17) adjacent to disposal sites 84 to 106. At the current dredging frequency and for a disposal width of 400 ft, the thin-layer thickness is 1.7 and 1.2 ft which exceeds the limit of 25 cm (0.8 ft) as shown in Table 3-15. After one more dredging time is added in the middle of the previous dredging interval and linear sediment accumulation in the GIWW are assumed in the dredging intervals, the disposal thickness is tabulated in Table 3-16. By doubling the dredging frequency to approximately every year, the thin-layer thickness is reduced to 0.85 and 0.6 ft that is near or below the suggested maximum thickness as illustrated in Table 3-16.

The dredging history in the selected areas of the GIWW that have been analyzed show that the volume of dredged material required to be disposed would result in thin-layer thickness greater that the 25 cm (0.8 ft) suggested maximum. In order to use thin-layer disposal, the results indicate that the dredging would have to be augmented by additional disposal into existing confined disposal sites or by increasing the dredging frequency such that the volume of maintenance material does not exceed the amount required to keep the thin-layer thickness within acceptable limits. The technology and equipment are available for thin-layer disposal and there have been many successful thin-layer disposal operations in areas outside of Texas and the GIWW. However, physical and biological investigations of the proposed thin-layer disposal areas need to be conducted to determine the desirability and/or acceptability of thin-layer disposal for the Texas GIWW.

Table 3-15. Map 6: San Bernard R.–E. Matagorda Bay; San Bernard NWR, Bay Boggy NWR; Disposal Site No. 84 to 106; Corresponding Sta. No. 220+00 to 450+642.

Channel	Work Comp	DS Station	US Station	PresAct cy	OverAct cy	Section Total cy	Total cy	Section Length ft	Width of Layer ft	Thickness Layer ft
FreePt. Hbr. - Caney Cr.	3/28/90	225+000	230+000	107900	23100	131000			400	1.7
FreePt. Hbr. - Caney Cr.	3/28/90	230+000	235+000	107900	23100	131000			400	1.7
FreePt. Hbr. - Caney Cr.	3/28/90	235+000	242+100	145200	29800	175000	437000	17100	400	1.7
FreePt. Hbr. - Caney Cr.	3/28/90	244+800	250+000	65600	24400	90000			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	250+000	255+000	78500	18500	97000			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	255+000	260+000	113900	23100	137000			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	260+000	265+000	109900	23100	133000			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	265+000	270+000	59700	21300	81000			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	270+000	275+000	52900	23100	76000			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	275+000	279+000	42500	18500	61000			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	279+000	280+000	5600	23000	28600			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	280+000	285+000	73900	23100	97000			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	285+000	290+000	94900	23100	118000			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	290+000	295+000	84900	23100	108000			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	295+000	300+000	84900	23100	108000			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	300+000	305+000	46700	24300	71000			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	305+000	310+000	20200	20800	41000			400	1.2
FreePt. Hbr. - Caney Cr.	3/28/90	310+000	317+000	33600	30400	64000	1310600	73000	400	1.2

Note: DS means downstream; US means upstream; PresAct means present dredging action; OverAct means over dredging action; Work Comp mean work that is completed on the date shown.

Table 3-16. The Disposal Thickness after Adding One Dredging Time in the Middle of the Previous Dredging Interval.

Channel	DS Station	US Station	PresAct cy	OverAct cy	Section Total cy	Total cy	Section Length ft	Width of Layer ft	Thickness Layer ft
FreePt. Hbr. - Caney Cr.	225+000	230+000	53950	11550	65500			400	0.85
FreePt. Hbr. - Caney Cr.	230+000	235+000	53950	11550	65500			400	0.85
FreePt. Hbr. - Caney Cr.	235+000	242+100	72600	14900	87500	218500	17100	400	0.85
FreePt. Hbr. - Caney Cr.	244+800	250+000	32800	12200	45000			400	0.6
FreePt. Hbr. - Caney Cr.	250+000	255+000	39250	9250	48500			400	0.6
FreePt. Hbr. - Caney Cr.	255+000	260+000	56950	11550	68500			400	0.6
FreePt. Hbr. - Caney Cr.	260+000	265+000	54950	11550	66500			400	0.6
FreePt. Hbr. - Caney Cr.	265+000	270+000	29850	10650	40500			400	0.6
FreePt. Hbr. - Caney Cr.	270+000	275+000	26450	11550	38000			400	0.6
FreePt. Hbr. - Caney Cr.	275+000	279+000	21250	9250	30500			400	0.6
FreePt. Hbr. - Caney Cr.	279+000	280+000	2800	11500	14300			400	0.6
FreePt. Hbr. - Caney Cr.	280+000	285+000	36950	11550	48500			400	0.6
FreePt. Hbr. - Caney Cr.	285+000	290+000	47450	11550	59000			400	0.6
FreePt. Hbr. - Caney Cr.	290+000	295+000	42450	11550	54000			400	0.6
FreePt. Hbr. - Caney Cr.	295+000	300+000	42450	11550	54000			400	0.6
FreePt. Hbr. - Caney Cr.	300+000	305+000	23350	12150	35500			400	0.6
FreePt. Hbr. - Caney Cr.	305+000	310+000	10100	10400	20500			400	0.6
FreePt. Hbr. - Caney Cr.	310+000	317+000	16800	15200	32000	655300	73000	400	0.6

Note: DS means downstream; US means upstream; PresAct means present dredging action; OverAct means over dredging action; Work Comp mean work that is completed on the date shown.

Actually, the added dredging times are not restricted to the middle of the previous dredging intervals. The added dredging action can be added at any time during the previous dredging intervals. After that, a new dredging time schedule can be arranged in order to arrive at the limiting thin-layer disposal thickness.

Conclusions

There are some dredging sites along the Texas GIWW that the thin-layer disposal method can be applied. The dredging locations have been identified in this report as possible candidates for thin-layer disposal include Galveston Causeway to Bastrop Bayou, Freeport Harbor to Caney Creek, and San Bernard River to Matagorda Bay. For the specific dredging site, the thin-layer disposal width and thickness can be predicted by knowledge of the dredged material type (sands, silts and clays) and volume. Disposal thickness and width versus thickness curves have been presented and discussed in this chapter.

When the thin-layer disposal thickness exceeds the desired thickness limit (currently 15 to 25 cm is the limit for no impact on existing vegetation) for a specific dredging site, then increasing the dredging frequency and changing the dredging time schedule should be considered in order to apply the thin-layer disposal at this location. Another possibility is to augment the thin-layer disposal by discharging the excess dredged material into current confined disposal facilities.

Experiences with thin-layer disposal have been documented at many sites outside of Texas and thin-layer disposal techniques and existing equipment have been described. Many thin-layer beneficial use projects have been successful and it appears there are opportunities for this relatively new technique to be used for the benefit of the operation of the Texas GIWW. Additional physical and biological investigations are needed to further evaluate the acceptability of thin-layer disposal for the Texas GIWW.

USE OF GEOTUBES AS A BENEFICIAL USE

Introduction

Certain areas along the GIWW are currently widening due to erosion, and the loss of wetlands has become another concern. As long as there is no protection of the wetlands and erosion continues, the GIWW will continue to widen and inundate the wetlands in these areas along the GIWW. A potential solution to the problem is to use dredged material from the GIWW to fill geotubes and place them in eroding areas. These structures can prevent the inundation into the wetlands and provide long-term management of dredged material. By using geotubes, it is likely that the frequency of dredging could be reduced, thus decreasing the need for more CDFs. Therefore, by placing dredged material-filled geotubes along the GIWW, the actual material will be used beneficially, erosion of the wetlands can be reduced and the amount of material to be dredged is expected to decrease.

Objective

Even though there are many ways to beneficially use dredged material, the use of geotubes is relatively new along the GIWW. Few geotubes have been placed along waterways and pilot studies are still in progress by the Corps of Engineers. This section of the report discusses geotubes, the design process of a geotubes (including current software), how to install such a system, case histories, cost analysis (including a cost estimating spreadsheet for geotube applications), and recommendations.

Geotubes

A geotube is a coastal structure made from high-strength synthetics that act as a form to hold in soil and create a solid elongated structure to control or prevent erosion. It consists of two or more 4.57 m (15 ft) wide geotextile sheets (industry standard) sewn together to form a shell similar to that of a pillowcase (Wickoren, 1998). An example of a geotube is shown in Figure 3-23. The most common geotube is a 9.14 m (30 ft) circumference geotube that usually yields a 1.83 m (6 ft) height and a 2.74 m (9 ft) width. A geotube of this magnitude holds about 1.53 cubic meters (2 cubic yards) of dredged material per linear foot of the geotube (Wickoren, 1998).

Brief History

Due to the fact that traditional coastal structures have become increasingly expensive to construct and maintain and a scarcity of natural rock, the need for a more cost effective coastal structure (geotubes) has been developed in the later half of this century. The first use of a geosynthetic system was in the 1950s. The early 1970s brought rapid developments to these systems.

Figure 3-23. Example Geotube System (courtesy of Synthetic Industries).

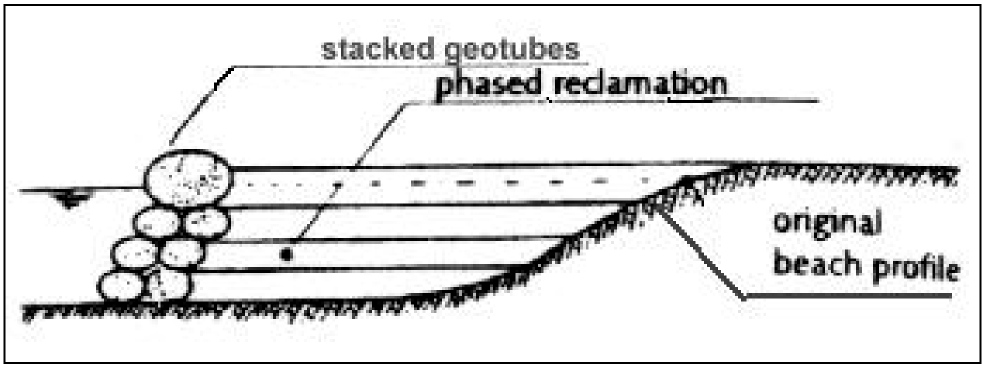
Since then, geotubes have been used successfully all over the world, such as: Europe, Mexico, Australia, Japan, and the United States (Pilarczyk, 1994). For example, the U.S. Army Corps of Engineers (USACE) placed a geotube along the Texas GIWW at West Bay Galveston in the late 1970's and it remains in place to date.

The early geotubes were made from 1380 to 2760 kPa (200 to 400 psi) woven material, usually polyester or polypropylene, and had dimensions up to 0.91 m (3 ft) high, 1.22 m (4 ft) wide and 3.66 m (12 ft) long. These early geotubes were usually filled with sand or mortar and were not filled hydraulically. The first experimentation of dredged filled geotubes was in the 1980's in Brazil for a reclamation project to create land for housing. Also in 1989, the direct filling of the geotubes from a suction dredge was successful off the coast of Germany in the North Sea (Sprague, 1993). The early 1990's brought tensile strengths of 2760 to 6900 kPa (400 to 1000 psi) and placement of geotubes by the USACE for erosion control and evaluation (Davis and Landin, 1996). Today, materials of up to 8280 kPa (1200 psi) strengths are being used with dimensions of a 13.7 m (45 ft) circumference and over 610 m (2000 ft) long. These strengths have enabled the geotubes to be filled hydraulically with dredged material directly from the dredge. There have been recent success stories with dredge-filled geotubes in Destin, Florida; Mobile, Alabama, and Galveston, Texas.

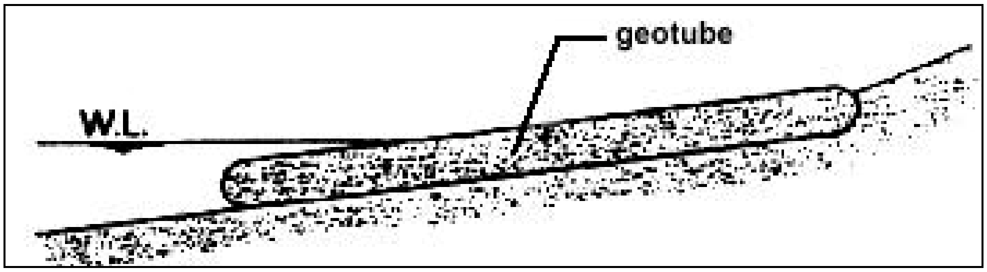
As described by Pilarczyk (1994), there have been many uses for geotubes, which include the following:

- reclamation works,
- containment dikes,
- offshore breakwaters,
- dune reinforcement, and
- revetments.

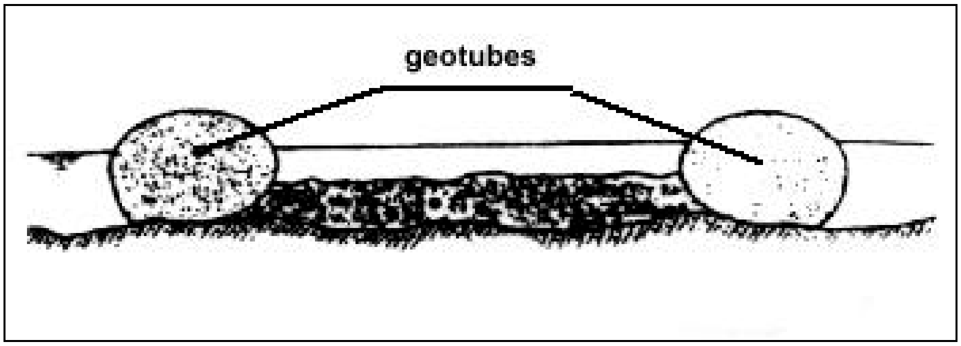
Figure 3-24 shows illustrations of possible uses of geotubes.



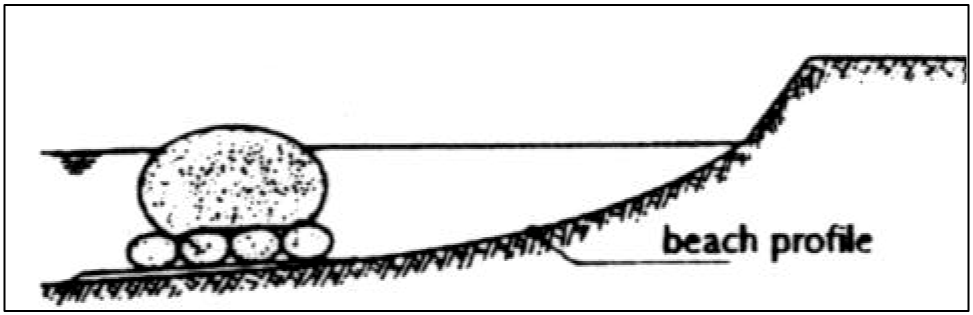
Reclamation Works



Groin

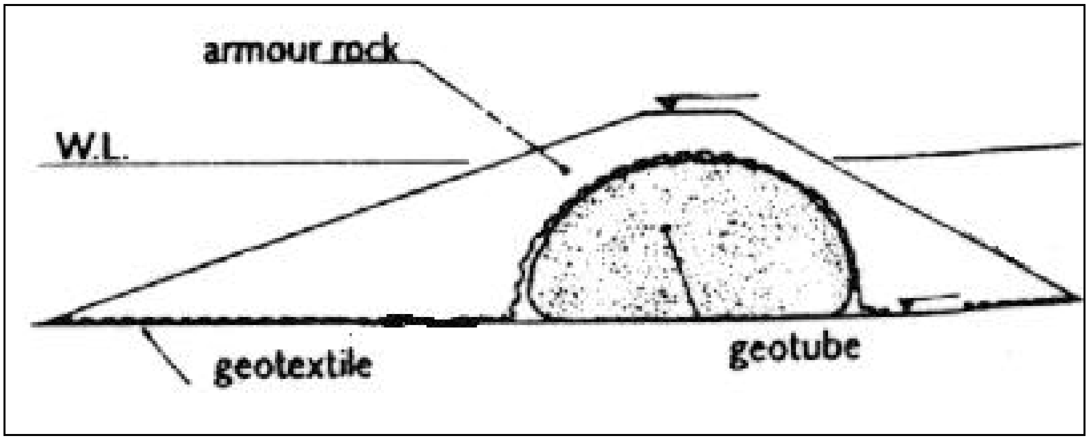


Contaminant Dike

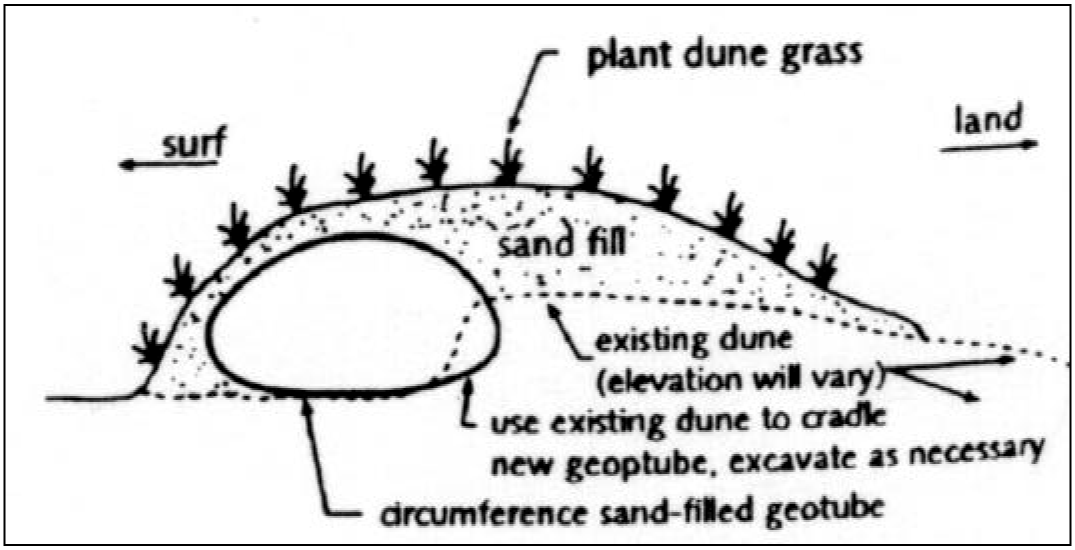


Offshore Breakwater

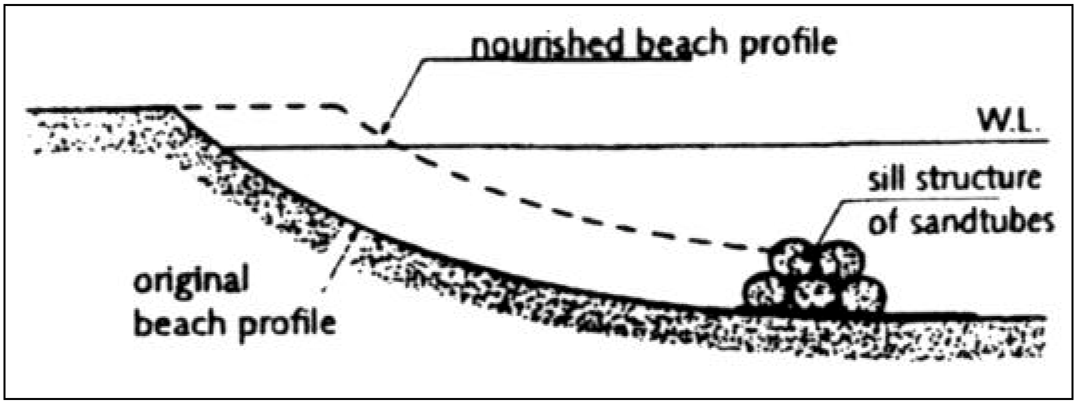
Figure 3-24. Example Geotube System Uses (Pilarczyk, 1996).



Core for a Breakwater



Dune Reinforcement



Perched Beach

Figure 3-24. Example Geotube System Uses (Pilarczyk, 1996), Continued.

Advantages of Geotubes

There are many advantages of using geotubes as coastal structures rather than the more conventional ones such as concrete revetments or bulkheads. The first is the basis for this study; dredged material can be beneficially used instead of being placed in a CDF. Another advantage, which is also important, is that the cost is considerably less than conventional coastal structures. Along the same lines, there is a major reduction in construction time to install the structure. The use of local materials is another advantage of using geotubes because concrete forms or other materials and equipment do not need to be shipped in from great distances. In most cases, all materials needed for these structures are likely found locally. Finally, the use of low-skilled labor is another advantage of using geotubes (Pilarczyk, 1994).

Possible Limitations of Geotubes

As described by Davis and Landin (1996), the following are possible limitations of geotubes:

- The resistance to punctures in the fabric of the geotubes is relatively low. Though it is not necessarily easy to puncture the material with a blunt object, it can be done with an object such as a knife. This leads to the conclusion that vandalism could be a possible problem if placed in a public area. Also, debris from the surrounding body of water, including boats, could cause punctures in the fabric. However, it has been observed in field that the geotube remains intact beyond the puncture area.

- Fabric degradation, due to UV (ultra violet rays from the sun) exposure, is another concern for geotubes. Although laboratory tests show the fabric to be resistant, the tests are inconclusive. Some suggest the life expectancy can be up to 50 years, while others suggest only 10 years, depending on exposure.

- Placement and alignment of geotubes can also cause a possible limitation. This is due to the fact that it depends on the skill of the contractor and the environmental conditions. For example, if waves and currents are present, then the geotube can twist, which causes it to move from its aligned position. However, the skills of contractors are improving, but a "best" method has yet to be determined.

- Variation in the height along the geotube usually occurs. This is caused by stopping the filling process before the geotube is full, which causes the sediments (when mostly sand) to stabilize and the geotube to flatten. There is also usually a difference in height near the fill holes. Therefore, a variation occurs in height along the geotube.

- Finally, there is only limited guidance for the design and installation of the geotubes.

Design of Geotubes

A geotube should be designed such that it has sufficient permeability, the dredged material is contained, the geotube is able to survive the pressures of filling, and it resists erosion once filled (Sprague, 1993). Soil testing of the dredged material being placed in the geotube should be conducted to determine the grain size statistics and fall velocities.

Material

The material used is usually a woven geosynthetic fabric, where two sheets are sewn together to create an envelope. The material chosen should be resistant to UV rays as well as oils and chemicals that could be found at the particular site. Most fabrics used are either polyester or polypropylene. Polyesters have a higher strength and better resistance to chemicals and creep, but they can be sensitive to high pH levels (Wickoren, 1998). Polypropylenes are cheaper, lighter in weight, and have a high degree of chemical inertness but are susceptible to some petroleum chemicals (Wickoren, 1998). Both types retain their original dry strength in water and are woven geotextiles that are resistant to abrasions (Koerner, 1990).

The American Society for Testing and Materials (ASTM) has developed tests that should be considered in designing a geotube. Table 3-17 lists these tests.

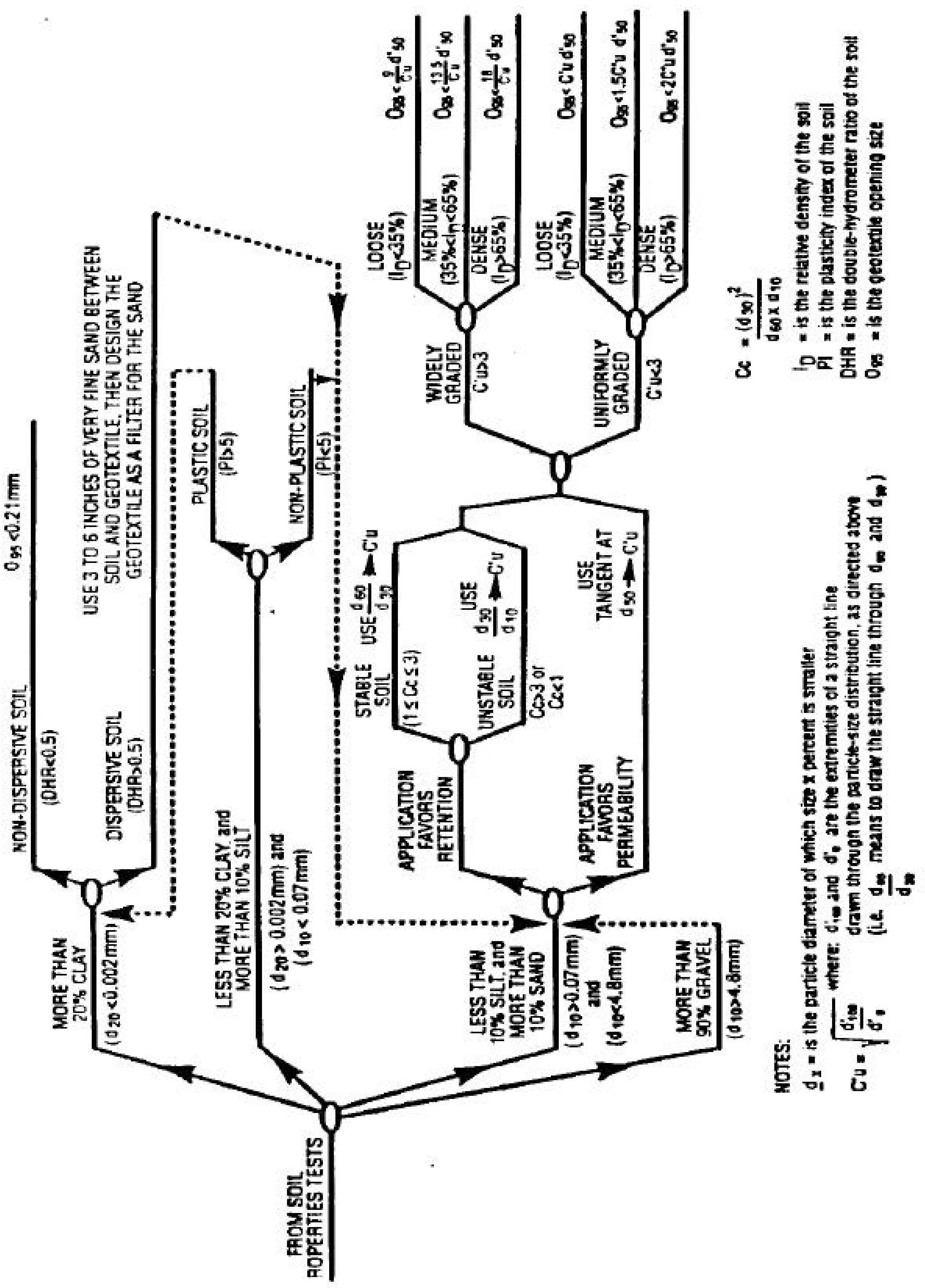
Table 3-17. ASTM Geotextile Property Tests.

Test	Property
ASTM D4595-94	Tensile Strengths
ASTM D4833	Puncture Strength
ASTM D4884	Seam Strength
ASTM D3786-90	Mullen Burst
ASTM D4355-92	UV Resistance
ASTM D5322-92	Chemical Degradation
ASTM D4751-93	Apparent Opening Size
ASTM D5262-92	Creep
ASTM D5101, 1987-91	Clogging

Material selection is mainly based on the size of the fill material particles. This means that the filtration properties of the fabric or the size (O_{95}) of the openings in the fabric must retain the fill and allow the geotube to dewater. ASTM test 4751 gives the apparent opening size (AOS) needed based on soil testing. The American Association of State Highway and Transportation Officials (AASHTO) recommends the following:

- For soil with $\leq$ 50% passing sieve #200: AOS $\geq$ sieve #30, ($O_{95} < 0.59$ mm)
- For soil with > 50% passing sieve #200: AOS $\geq$ sieve #50, ($O_{95} < 0.30$ mm)

Figure 3-25, from Sprague (1993), shows the opening characteristics based on the fill material properties. The material strength must be large enough so that the geotube does not rupture during filling and installation.



NOTES:

d_x = is the particle diameter of which size x percent is smaller

$C'u = \sqrt{\frac{d'_{100}}{d'_0}}$ where: d'_{100} and d'_0 are the extremities of a straight line drawn through the particle-size distribution, as directed above (i.e. $\frac{d_{60}}{d_{30}}$ means to draw the straight line through d_{60} and d_{30})

$Cc = \frac{(d_{30})^2}{d_{60} \times d_{10}}$

I_D = is the relative density of the soil

PI = is the plasticity index of the soil

DHR = is the double-hydrometer ratio of the soil

O_{95} = is the geotextile opening size

Figure 3-25. Opening Characteristics of Geosynthetic Material (Sprague, 1993).

Inlet/Outlet Spacing

The spacing of the inlet/outlet holes on the geotube depends solely on the soil characteristics of the fill material. The first requirement is that the fill material be transportable as a slurry. In most cases, if a predominantly sand slurry is used, the spacing of the inlets should be relatively close together due to the fact that sand settles relatively quick, thus creating a blockage if the spacing is not close together. For well-graded sands, a 7.62 m (25 ft) spacing is usually sufficient. If the material is a silty clayey mixture, spacing of up to 152 m (500 ft) may be used.

The fill material settling characteristics is determined to aid in the design of the inlet/outlet spacing. Figure 3-26 shows a section of a geotube with inlet/outlets labeled A through E. Notice there are two angles, one being very steep and the other a milder slope. This shows that if the soil has a high rate of settling (sandy slurry), the steep angle should be used to determine spacing. In this case port holes A through E should be used to fill the geotube. On the other hand; if the settling of the soil is much less, as depicted by the flatter angle, openings B and E are sufficient to fill the geotube.

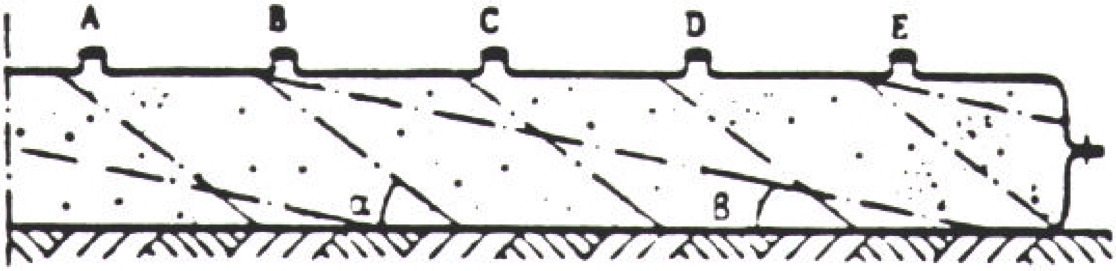


Figure 3-26. Inlet Spacing Based on Fall Velocity (Sprague, 1993).

Also, to aid in determining the spacing of the inlet/outlets, an equation can be used from Sprague (1993). This equation is a function of the volumetric flow rate of the slurry, the width of the flow, and the settling velocity of the soil sediments.

$$L = Q / (W \times V_f) \qquad \textbf{(3-5)}$$

where:

L = inlet/outlet spacing (m, ft),
Q = flow rate of slurry (m^3/s, ft^3/s),
W = width of the flow (m, ft), and
V_f = fall velocity of soil sediments (m/s, ft/s).

There are empirical formulas to determine the fall velocity based on the sediment grain sizes. The Shore Protection Manual (USACE, 1984) describes empirical formulas, by Hallermier, to find the fall velocity of natural grains. The value of d_{50} is determined by conducting a sieve analysis on the soil sample. The formulations are as follows:

$$V_f = (\gamma_s / \gamma - 1)\, g\, d^2_{50} / 18\nu, \text{ for } B<39$$

$$V_f = [(\gamma_s / \gamma - 1)\, g]^{0.7}\, d^{1.1}_{50} / 6\nu^{0.4}, \text{ for } 39 < B < 10^4 \tag{3-6}$$

$$V_f = [(\gamma_s / \gamma - 1)\, g\, d_{50} / 0.91]^{0.5}, \text{ for } 10^4 < B,$$

where:

B = $[(\gamma_s / \gamma - 1)\, g\, d^3_{50} / \nu^2]$,
γ_s = specific gravity of the solid,
γ = specific gravity of the fluid,
d_{50} = median grain size (m),
g = gravitational acceleration (9.81 m/s^2), and
ν = fluid kinematic viscosity (m^2/s).

Similarly empirical formulas can be derived by equating the drag and buoyant forces with the weight of a particle (Herbich, 1992). For small particles (d_{50} < 0.15 mm) laminar conditions dominate and Stoke's Law applies:

$$V_f = \frac{g d_{50}^2}{18\nu}\left(\frac{\rho_s - \rho_w}{\rho_w}\right) \tag{3-7}$$

For intermediate grain sizes (0.15 mm < d_{50} < 1.5 mm) and a Reynolds number between 10 and 1,000, the fall velocity can be calculated using the following expression where V_f is given in mm/s and d_{50} is input in mm:

$$V_f = \frac{8.925}{d_{50}\left[\sqrt{1 + 95(SG - 1)d_{50}^3} - 1\right]} \tag{3-8}$$

An experimental value ***c*** is used in the following formula when the grain size is larger than 1.5 mm:

$$V_f = c\sqrt{d_{50}\frac{(\rho_s - \rho_w)}{\rho_w}} \tag{3-9}$$

Another method to determine the fall velocity comes from Goldman (1986), which is a graphical method based on grain size and water temperature as shown in Figure 3-27.

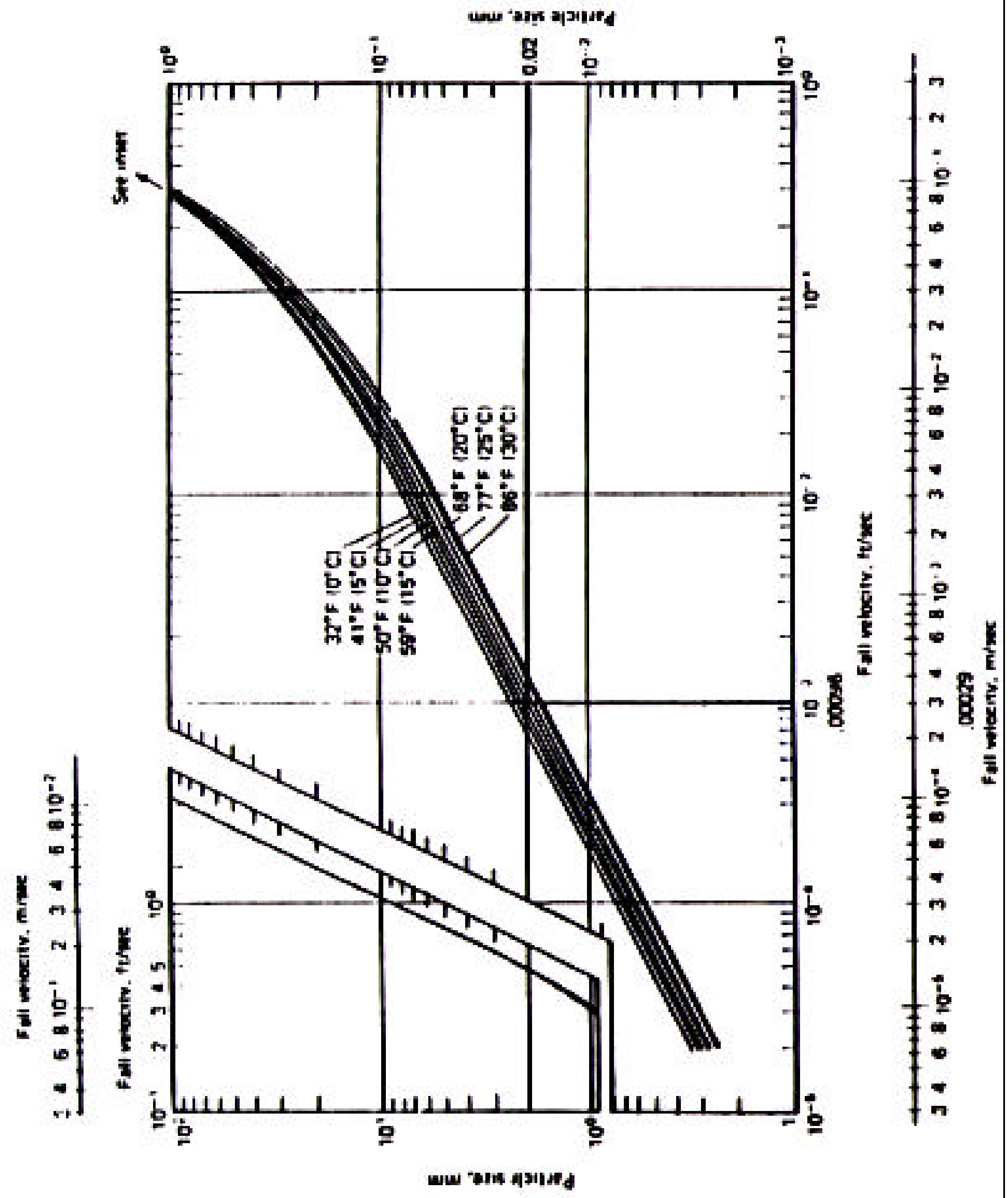


Figure 3-27. Fall Velocity (Goldman, 1986).

Stability

Stability of the filled geotube is essential. To achieve this, a high unit weight for the geotube is necessary to resist the hydrodynamic forces encountered in the coastal environment. This implies that the geotube should be filled enough to achieve a unit weight sufficient to resist the forces such as drag, lift, and inertial forces caused by waves and currents.

There have been several experiments to determine the stability of single geotubes and multiple geotube systems as reported by ACZ Marine (1990) and Pilarczyk (1994). These experiments consisted of sandbags and multiple geotube systems; however, there is a need for more experimental testing to determine stability criteria (similar to the Hudson equation that is used to calculate the stability for breakwater armor units).

However, a general criteria for stability of sand-filled geotubes has been formulated by Pilarczyk (1996). This states the following relationship can be used when the geotube is placed parallel to the wave crests.

$$H_s / B = 1 \tag{3-10}$$

where B is the horizontal width and H_s is the significant wave height. For example, if the significant height of the waves created by boat traffic is 0.91 m (3 ft) (Herbich, 1992) and the width of a 9.14 m (30 ft) circumference geotube is 2.74 m (9 ft), the ratio between the two is one-third. Since this number does not exceed 1.0, the geotube is considered stable.

For placement along the GIWW, stability due to waves is a minimal concern since the smallest geotubes will most likely be 9.14 m (30 ft) in circumference and the wave climate is that from tugs, barges, and boats. A single geotube of this magnitude, once filled, should have a unit weight large enough to withstand this wave climate. However, if smaller geotubes are used singularly or stacked, a closer look at the stability should be conducted.

GeoCoPS (Geosynthetic Confined Pressurized Slurry)

Another aspect of design is the shape of the geotube once in place and filled with dredged material. A program has been developed that predicts the shape of a filled geotube given the unit weight of the slurry. This program was developed for the USACE Waterways Experiment Station (WES) as part of the Construction Productivity Advancement Research (CPAR) program. GeoCoPS also aids in the design of the material needed to withstand the pressures of filling. The following is a summary of GeoCoPS from the Supplemental Notes for Version 1.0 of the program (Leshchinsky et al., 1996).

There are four assumptions that govern the formulation for the program:

- The problem is two dimensional, which means for a long geotube each cross section is identical.
- The shell (geosynthetic material) is thin and flexible and its weight is negligible.
- The fill material is a slurry, thus a hydrostatic state of pressure exists inside the geotube.
- Shear stresses do not exist between the slurry and the shell.

Calculations

GeoCoPS begins with the force equilibrium equation of a small section of the geotube, as shown in Figure 3-28.

$$r(x) = \frac{T}{p(x)} \tag{3-11}$$

where r(x) = radius of curvature at any location x, T = tensile force, and p(x) = hydrostatic pressure at any location x.

This equation is valid anywhere along the geotube from the top center down to where the geotube meets the ground, as seen in Figure 3-28. This equation expresses the complete solution. Using differential calculus and substitution, the equation takes on the form

$$\mathrm{T}y'' - (\mathrm{p}_\mathrm{o} + \gamma x)\left[1 + y'^2\right]^{2/3} = 0 \tag{3-12}$$

where y is the geometry (location of the point in question) of the geotube.

This equation has no closed form solution and must be solved numerically. As seen from the equation, there is a relationship between the geometry of the geotube, the circumferential tensile force, pumping pressure (p_o) and the unit weight of the slurry (γ), and the height of the geotube (h). This can be written as

$$y = f(x \mid T, p_o, h, \gamma) \tag{3-13}$$

Since the unit weight of the slurry is known, the equation simplifies to one independent variable x, and three parameters T, p_o, and h. Since the geometry is to be determined, then one of the three remaining parameters is given by the operator such as the desired height of the geotube, the pumping pressure, or a specified tensile strength. Then, the other two parameters are determined numerically. In order to solve for the other parameters, constraints must be imposed.

One constraint is the geometric boundary condition at point O (refer to Figure 3-28). This states that the slope at point O must be zero:

$$\frac{1}{y'(0)} = 0 \tag{3-14}$$

The other constraint is the flat base length b where equations for b and W (weight of slurry per unit length) combine to yield the following:

$$\mathrm{b} = \frac{2\gamma}{\mathrm{p_o} + \gamma \mathrm{h}} \int_0^{\mathrm{h}} \mathrm{y(x)dx} \tag{3-15}$$

Now the three equations can be solved for a single given design parameter that results in a geotube circumference (L). Since L is known, then b can be determined and for a given circumference, the third equation becomes:

$$L = b + \int ds \tag{3-16}$$

The final calculation is for the axial force, which is not always needed since the circumferential stress dominates most design criteria. This axial stress is simply the force carried by the geotube in the axial (z) direction and is equal to the force divided by the circumference, which yields the axial stress per unit length. Figure 3-29 shows axial and circumferential stresses in a geotube.

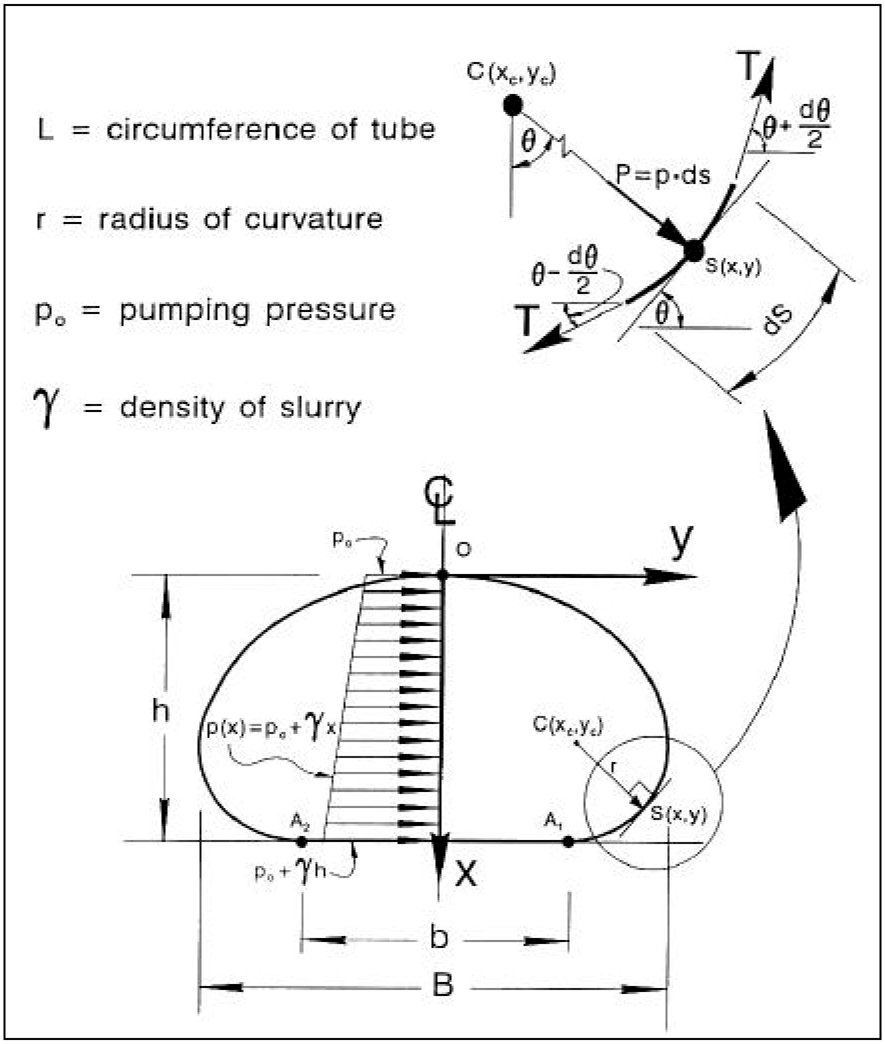


Figure 3-28. Geotube Cross Section (Leshchinsky et al., 1996).

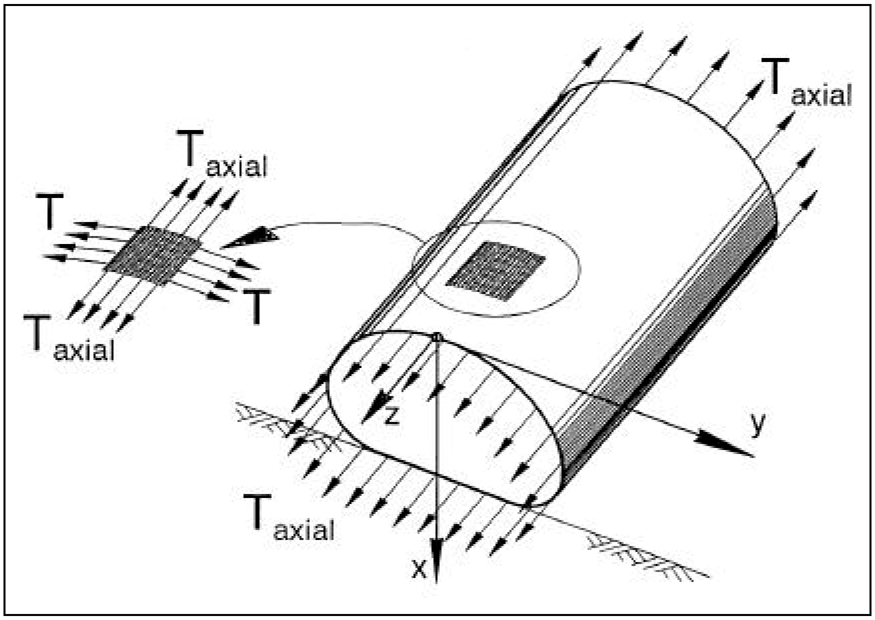


Figure 3-29. Stresses of a Geotube (Leshchinsky et al., 1996).

Verification

GeoCoPS predicts the shape, pressures, heights, and stresses to a comparable standard against other empirical formulations and experimental methods. Leshchinsky gives a verification of the programs performance in the supplemental notes and in a technical paper (Leshchinsky et al., 1996). Only a small percent difference exists between GeoCoPS and the methods by Sylvester (1986), Liu (1981) and Kazimierowicz (1994) for the height, width, and tensile strength.

Sensitivity

In order to show the sensitivity of the parameters to the geotube, Leshchinsky conducted a parametric study. Figures 3-30 through 3-33 show how the parameters effect the tensile force (T_{ult}), geometry (including height) of the geotube, and the pumping pressure. As seen from Figure 3-30, higher tensile forces require larger pumping pressure to obtain a greater height. Figure 3-31shows the effects of the height on the geometry of the geotube (smaller heights yield a flatter geotube and require lower pumping pressure). Likewise, Figure 3-32 shows how the pumping pressure effects the geometry of the geotube. These figures demonstrate that the geometry of the geotube is highly sensitive to the parameters of the problem. Finally, Figure 3-33 shows the influence of pumping pressure on the height of the geotube. Note that in order to reach a height of a theoretical circle, the pumping pressure, as well as the strength of the material (tensile force), approaches infinity.

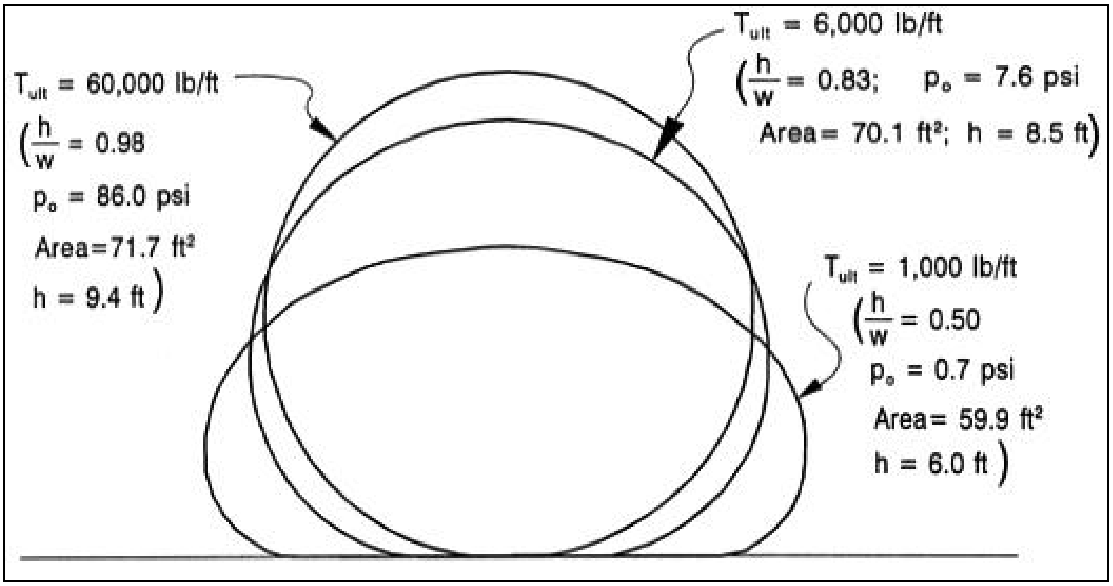


Figure 3-30. Effects of T_{ult} on the Geometry of a Geotube (Leshchinsky et al., 1996).

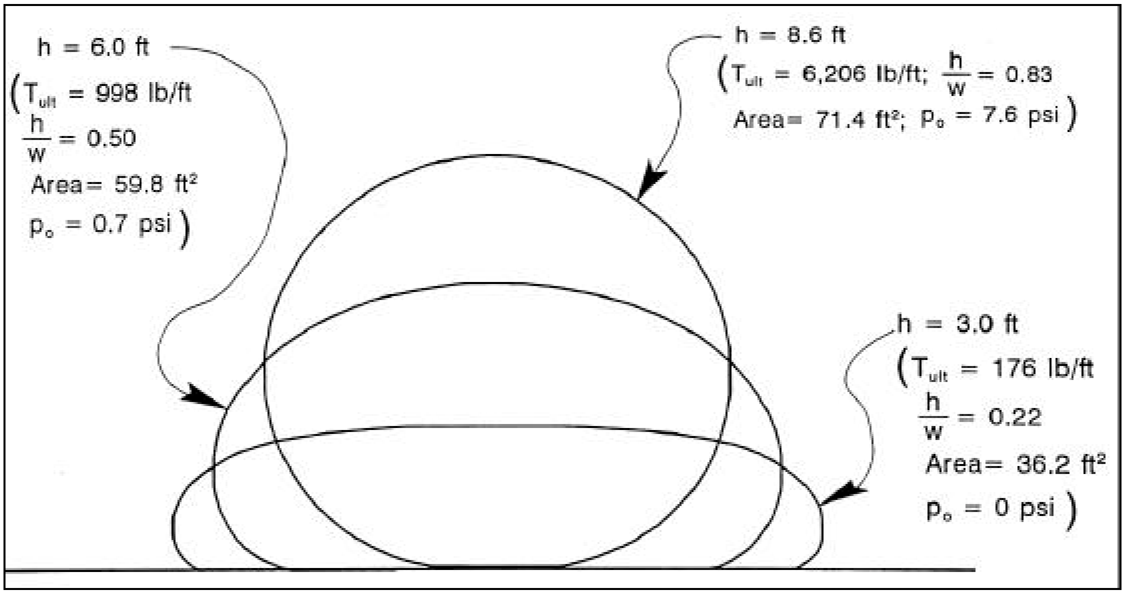


Figure 3-31. Effects of Height on the Geometry of a Geotube (Leshchinsky et al., 1996).

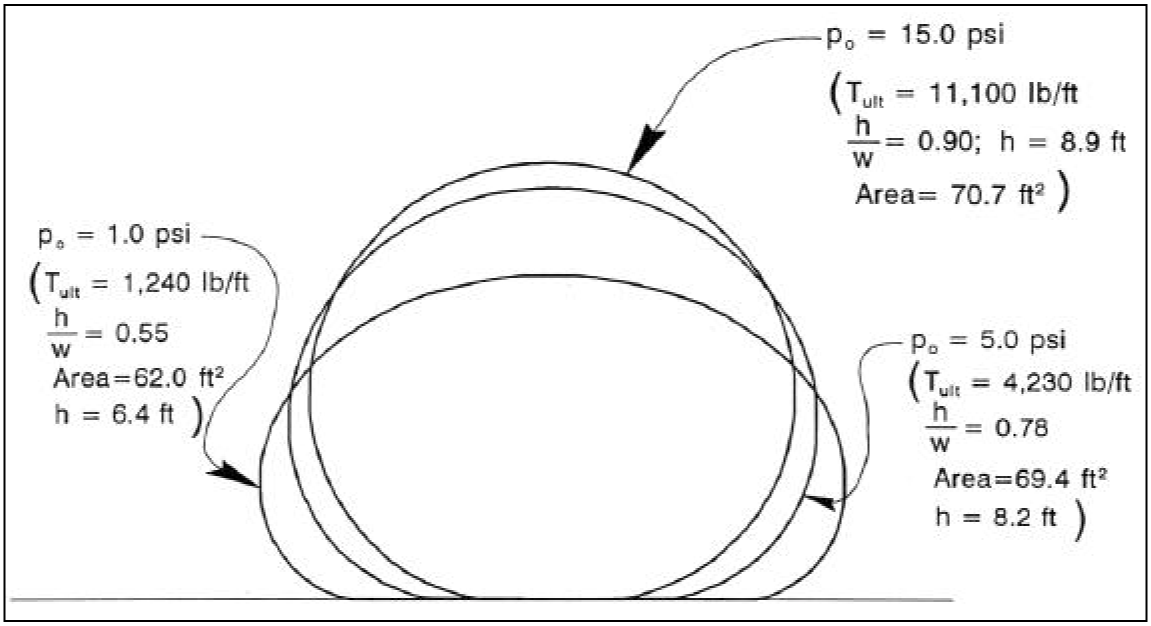


Figure 3-32. Effects of Pumping Pressure on the Geometry (Leshchinsky et al., 1996).

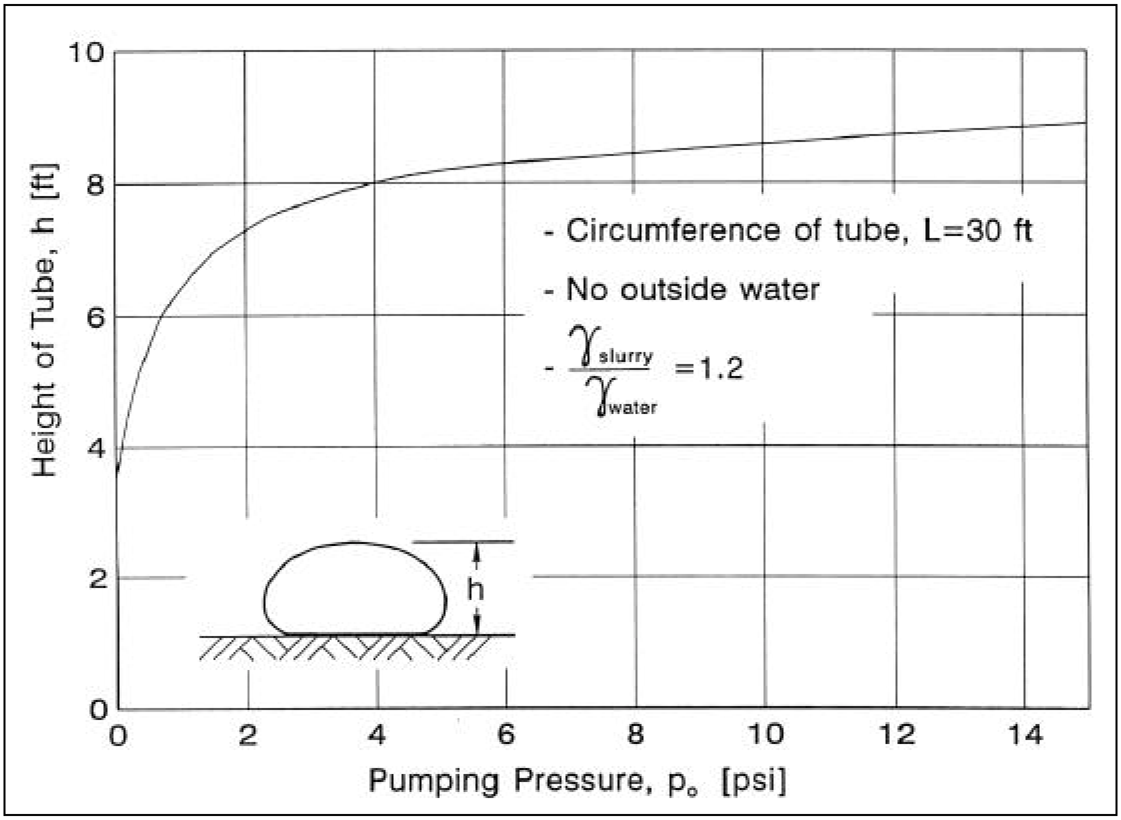


Figure 3-33. Height of Geotube versus Pumping Pressure (Leshchinsky et al., 1996).

Safety Factors

GeoCoPS contains the option of adding a factor of safety in the program to obtain the ultimate tensile strength (T_{ult}). The following shows the factors of safety and gives the recommended values.

$$T_{ult} = T \cdot (F_{s\text{-}id} \cdot F_{s\text{-}cd} \cdot F_{s\text{-}bd} \cdot F_{s\text{-}cr} \cdot F_{s\text{-}ss}), \qquad \textbf{(3-17)}$$

where $F_{s\text{-}id}$ = factor of safety for installation damage (1.3),

$F_{s\text{-}cd}$ = factor of safety for chemical degradation (1.0),

$F_{s\text{-}bd}$ = factor of safety for biological degradation (1.0),

$F_{s\text{-}cr}$ = factor of safety for creep (1.5), and

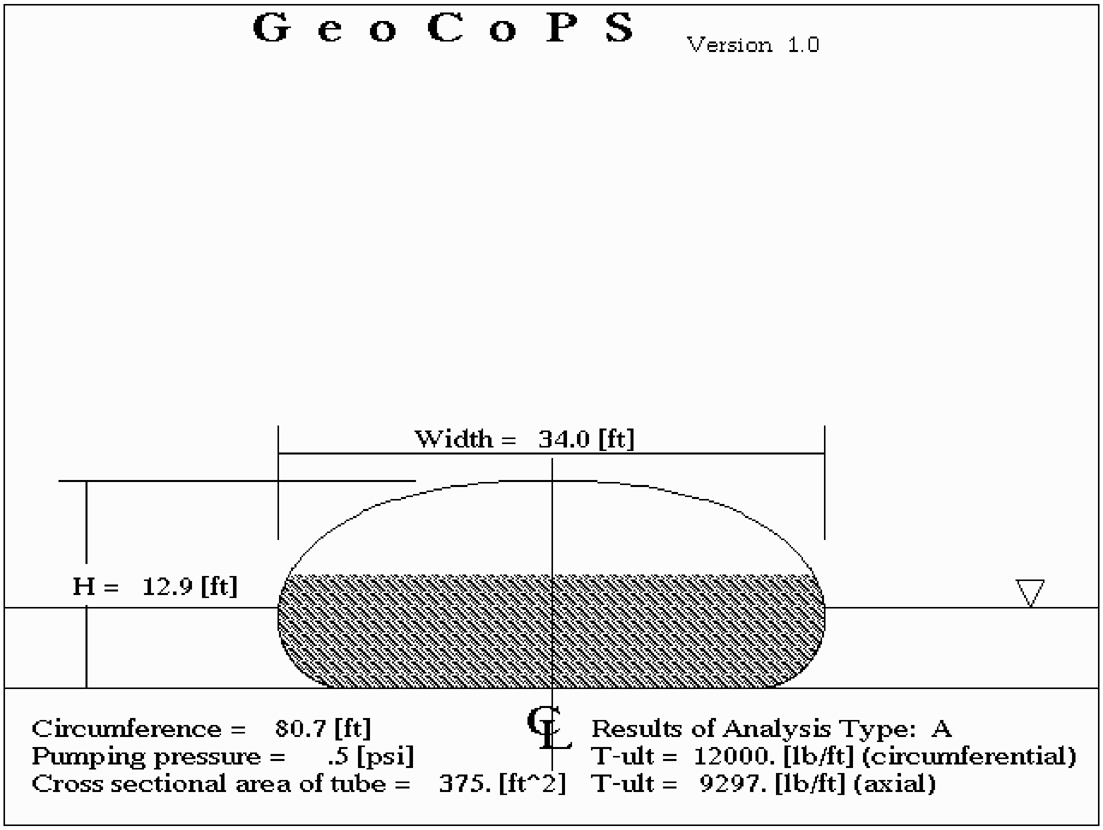
$F_{s\text{-}ss}$ = factor of safety for seam strength (2.0).

GeoCoPS

GeoCoPS is a verified engineering tool that can be used in the design and installation of geotubes to obtain material criteria, pumping pressures, and geometry of the geotube. It uses its three basic input formats that depend on the project and these formats are:

- Type A – input the tensile force and circumference; calculate height, pumping pressure, and geometry.
- Type B – input the height and circumference; calculate tensile force, pumping pressure, and geometry.
- Type C – input the pumping pressure; calculate the tensile force, height, and geometry.

Figure 3-34 is an example of the output for format Type A from GeoCoPS.



```
Circumference =    80.7 [ft]                 Results of Analysis Type:  A
Pumping pressure =     .5 [psi]              T-ult =  12000. [lb/ft] (circumferential)
Cross sectional area of tube =    375. [ft^2]  T-ult =   9297. [lb/ft] (axial)
```

Figure 3-34. Example Output from GeoCoPS.

Scour

One problem that arises with the use of geotubes is scour. Scour is caused when sediments become suspended and are then transported by waves or currents from the foundation of a structure. The problem arises with geotubes because the shape of the geotube amplifies the velocities and increases the shear stress between the fluid and soil, thus removing sediments from the underside of the geotube. This phenomenon is called undercutting and can cause the structure to fail if the scour is severe enough to cause the structure to twist or fall into a scour hole.

For long geotubes, such as those for the application to the GIWW, scour becomes a problem more at the ends of the geotube rather than along the edges; especially when a scour pad (apron) is used. When scour occurs at the end, the structure sinks into the scour hole and fails, thus damaging the integrity of the entire structure. It has been shown by field observations that backside scour occurs due to down draft (displacement of water caused by barges draft) of passing barges along the GIWW (Murphy, 1998).

Scour Apron

Instead of using a method such as riprap, which could be an excessive cost, a standard practice is to use a scour apron. A scour apron prevents the undermining of the geotube thus preventing the geotube from falling into a scour hole or rolling and failing. Scour aprons are made from a woven geotextile similar to that of the geotubes. They are usually a 2760 kPa (400 lb/in) polypropylene material and cost less than the material for the geotubes.

Presently, there are no criteria for calculating the width of the scour apron. However, a common practice is to make the apron as wide as the circumference of the geotube. If there is exposure to hydrodynamic action on both sides of the geotube, a larger apron should be considered (Wickoren, 1998).

Figure 3-35 shows how a scour apron works. The edges of the apron are weighted by one of the following methods:

- Sandbags can be tied to the edge of the apron in a spacing of about every 0.61 to 1.52 m (2 to 5 ft) along the length of the geotube. This method utilizes the entire width of the apron and is the easiest to install.
- Pockets are sewn into the end of the apron and sandbags are placed in the pockets.
- A seam along the entire length of the apron can be sewn to form a small geotube. This small geotube can then be filled similar to the geotube itself. This method also uses some of the width but creates a large area of anchoring the apron.

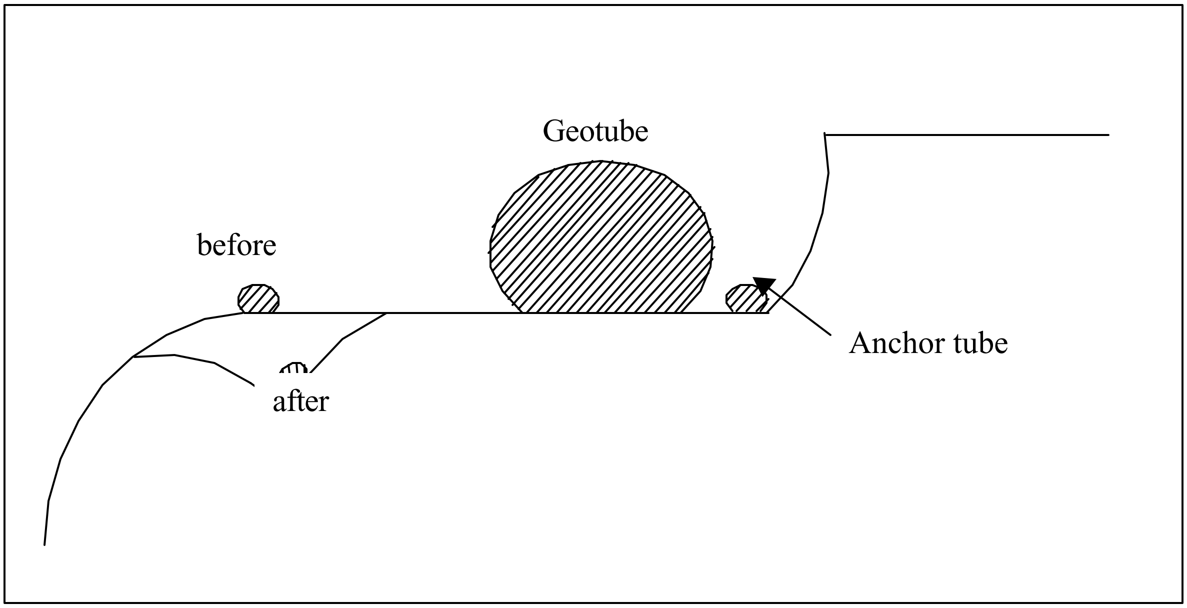


Figure 3-35. Illustration of a Scour Apron.

These three methods of anchoring the apron have been used and have been successful. Due to the ease of installation, the contractors most likely prefer the first two methods. Once the edge of the apron is anchored, undermining may occur at the edge and the weighted apron edge can fall into the scour hole and pull the apron tight. Once the scour hole reaches a certain depth, a state of equilibrium is reached as shown in Figure 3-35. There is a need for laboratory testing and field studies to determine the width of the scour apron, prevent backside erosion (undercutting), and scour at the end of the geotubes.

Installation

Site Investigation

Installation begins with a site investigation to determine factors that influence the operations of an installation. First, the site must be evaluated to determine what equipment is needed to complete the installation. If the location is not accessible by large land-based equipment or marsh buggies, a barge must be used to hold the necessary equipment for filling the geotube. Also, the amount of pipe needed to transport the slurry from the dredge to the geotube must be determined. It is determined at this time if any special equipment is needed in the operations, such as a mini barge, crane, or marsh buggy. A site investigation determines the optimum time of day to begin the site preparation in regards to tides, currents, and waterway traffic (it will be less difficult at low tide with less traffic). Finally, all environmental concerns are determined through the site investigation.

Site Preparation

Preparing the site for a geotube installation begins with assembling the proper equipment as predetermined by the site investigation. Some sites require leveling the area (dry land) or digging a trench to aid the stability of the geotube during filling. Site preparation includes installing the scour apron as discussed previously. Stakes may be used to hold the apron in place until it is anchored by one of the techniques described earlier. Stakes may also be put into place at this time to hold the geotube in place before and during the filling procedure. Once the scour apron is in place and anchored, the geotube is then laid out and stabilized by the stakes. The apron and geotube are usually on a spool and are rolled into place using a mini barge (Figure 3-36), crane, or marsh buggy. Once the apron and geotube are in place and stabilized, filling can begin.

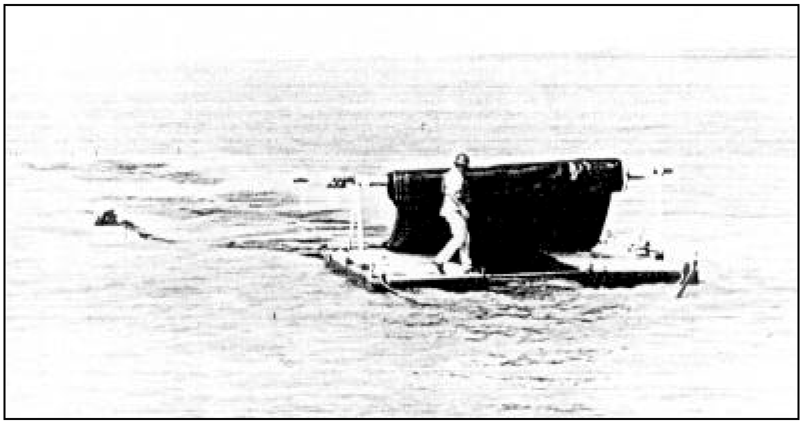


Figure 3-36. Installation of a Scour Apron Using a Mini-Barge (Murphy, 1998).

Transporting the Slurry

There are two basic methods to transport the slurry to fill the geotube. The first method uses a small dredge just for filling the geotube and the discharge pipeline is connected directly to the geotube. The second method is to use the normal dredge (from GIWW maintenance dredging) and utilize a split pipe technique to fill the geotube as seen from Figure 3-37. The split pipe technique allows normal GIWW dredging operations to continue during the installation of the geotube. A ball valve can be used to control the slurry pressure into the geotube. If this method is used, careful attention to the velocities must be considered to prevent the pipes from clogging. Both methods have been used and have been successful. The determining factors for selecting which method to use are economics and the size of the dredging project. The basic idea is to beneficially use a portion of dredged material from the project along the GIWW by using the same dredge to fill the geotube or to dredge a small part of the project with a small dredge that can be directly connected to the geotube.

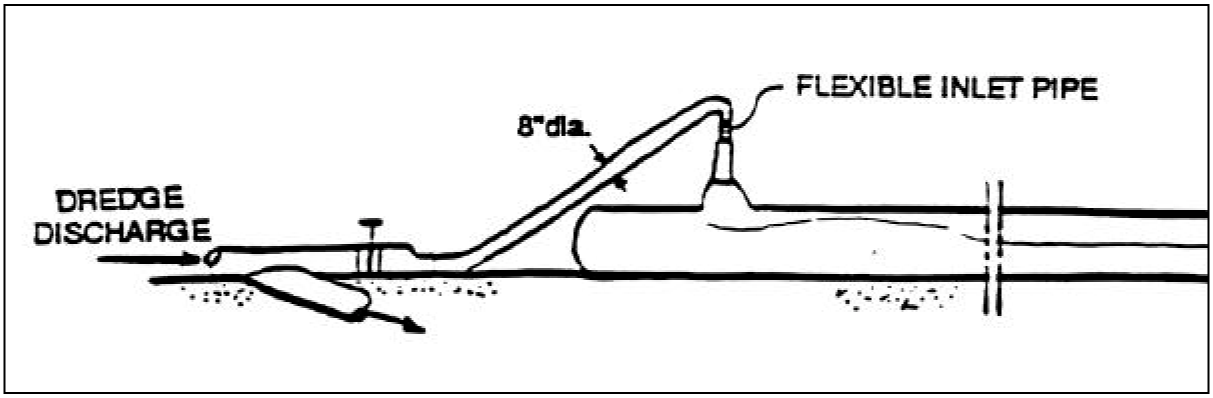


Figure 3-37. Split Pipe Method (Sprague, 1993).

Filling

Once the method of dredging and transporting the slurry is determined and the site has been prepared, then filling the geotube can begin. As stated earlier, the geotube must be restrained while filling because it will take some time for the solids to accumulate inside the geotube. Once there is enough buildup of solids accumulation, then the geotube will stabilize itself. However, even though one end of the geotube is stable, it still may be necessary to restrain the empty end because it may twist and roll.

Depending on the dredge, it may be necessary to hold the discharge pipe with a frame, backhoe, or crane near the filling port for support. With a small dredge, the discharge line can usually be directly connected to the fill port. A pressure gauge can be used to monitor the pressure inside the geotube as illustrated in Figure 3-38.

Using GeoCoPS can aid in the filling procedure by determining the pumping pressure needed to obtain a specific height of a geotube. However, some contractors do not use pressure gauges and operate solely by experience. It is important not to overpressurize the geotube during filling for obvious reasons. This is achieved by watching the pressure and leaving the fill holes open to allow the water to escape more rapidly.

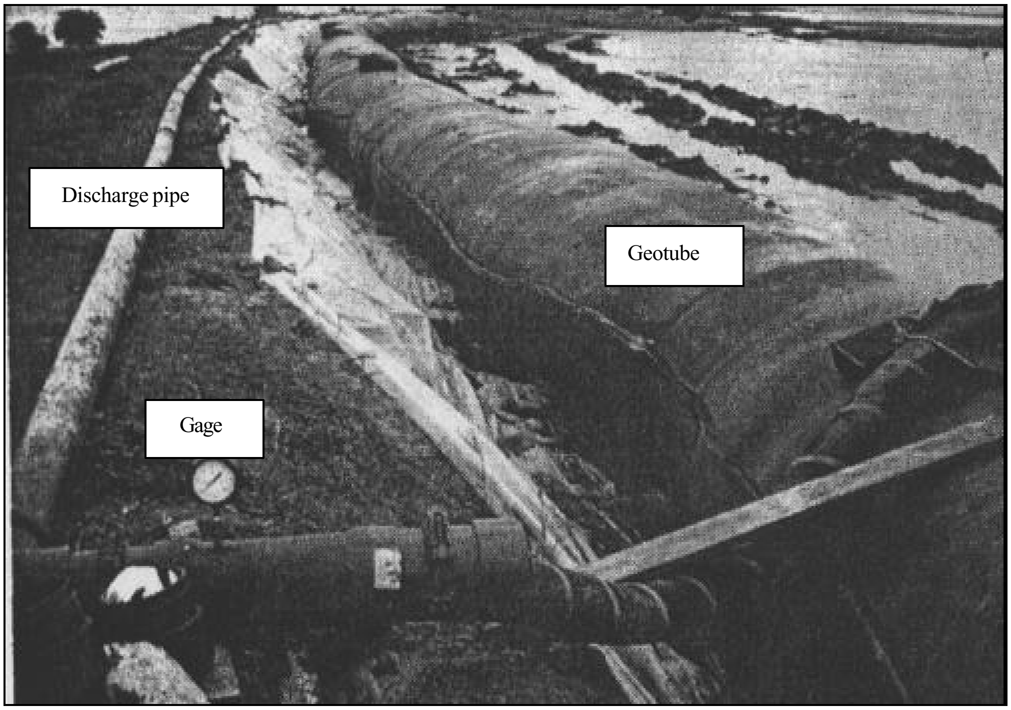


Figure 3-38. Pressure Gauge Connected to Inlet (Leshchinsky et al., 1996).

The dredge material also effects the filling procedure. If the sediments are mostly sand, pumping one time is usually the only chance the contractors will get (because a sand slurry dewaters almost immediately), except to add sand to the fill holes to level off the geotube. With fine-grained sediments or a fluid mud, it may be necessary to pump a few times to obtain a full geotube. This is because the water takes longer to escape from the sediments.

Dewatering

Dewatering depends on the fabric of the geotube and the material being pumped inside the geotube. With sand slurry, dewatering is not a problem and takes a relatively short period of time. However, if the sediments are fines (silt or clay), this process may require a few days.

Dewatering is also affected by the specifications of the job. There is a difference in creating clean runoff and separating the sediments from the slurry. For example, if contaminated sediments are pumped into the geotube, all sediments must be retained by the geotube and would take longer to dewater. This aspect should be considered in the design of the geotube and the site investigation.

There is no standard method for hydraulically filling geotubes since this is a relatively new concept. Installation techniques may vary with each contractor, thus experience of the contractor is a key to a successful installation.

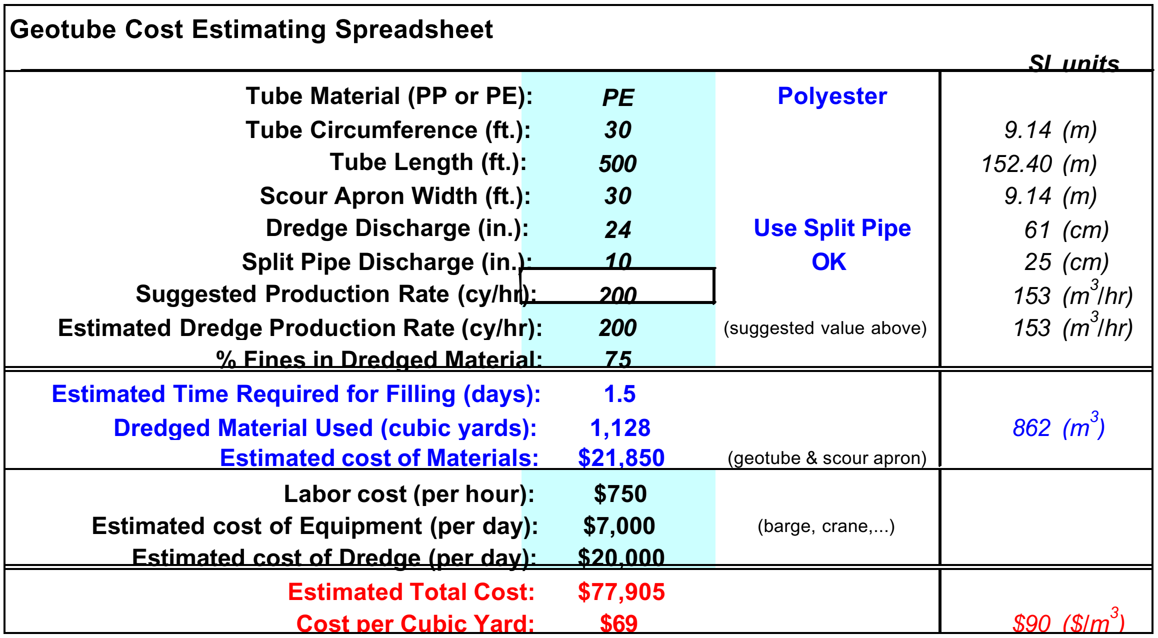
Cost Analysis

As with all beneficial uses, it costs more to beneficially use dredge material than to simply place the material in a disposal area. The question then becomes, "is the extra cost feasible and valid?" The cost of installing a geotube, as a beneficial use of dredged material, is feasible and valid because the geotube contains a percentage of the dredged material and it protects the wetland environment from further erosion. Geotubes can also aid in stabilizing the waterway from further expansion.

There are many ways to view the cost of installing a geotube along the GIWW. One way, as with other beneficial uses, is to estimate the price per cubic yard of material beneficially used. Another method is to price the installed geotube per linear foot. Finally, an overall view of a scheduled dredging project can be used. For example, if an upcoming dredging project for a certain amount of material uses 15% of the material to install a geotube, the total cost of the project will increase only by the amount of materials and labor to install the geotube. Furthermore, the price per cubic yard of the entire project only increases by a small factor.

The cost of any project can be broken down into different categories such as labor, equipment, materials, and consumables. Labor of course is the cost of the personnel, usually a small field crew and a supervisor. Equipment includes the dredge, barges needed, cranes, marsh buggies, backhoes, and any other special equipment. The materials consist of the geotube itself, scour apron, and any materials needed to install the geotube (stakes, ropes, etc.). Finally, consumables are the fuels and any item that no longer exists when the project is completed. The following spreadsheet (Figure 3-39) may be used as a guide to estimate the cost of a geotube project.

There are certain factors that can significantly effect the cost of a geotube project. One factor is the percentage of fines in the dredge material. If the material contains a large amount of fines, the cost could increase greatly due to the fact that the time to install the geotube could double or triple. With a large percent of fines, the geotube takes much longer to clog and start to retain sediments. The geotube also takes much longer to dewater, and multistage pumping is necessary. Another factor, determined by the site investigation, is the accessibility to the site for the equipment. For example, if a barge is needed, the cost for equipment will increase. Finally, the cost of mobilization also can vary with each project and is not always a clear-cut number. However, using the split pipe method to install the geotube could decrease mobilization costs because the cost of mobilization would most likely be in the dredging project, not the geotube project.



Geotube Cost Estimating Spreadsheet			SI units
Tube Material (PP or PE):	PE	Polyester	
Tube Circumference (ft.):	30		9.14 (m)
Tube Length (ft.):	500		152.40 (m)
Scour Apron Width (ft.):	30		9.14 (m)
Dredge Discharge (in.):	24	Use Split Pipe	61 (cm)
Split Pipe Discharge (in.):	10	OK	25 (cm)
Suggested Production Rate (cy/hr):	200		153 (m^3/hr)
Estimated Dredge Production Rate (cy/hr):	200	(suggested value above)	153 (m^3/hr)
% Fines in Dredged Material:	75		
Estimated Time Required for Filling (days):	1.5		
Dredged Material Used (cubic yards):	1,128		862 (m^3)
Estimated cost of Materials:	$21,850	(geotube & scour apron)	
Labor cost (per hour):	$750		
Estimated cost of Equipment (per day):	$7,000	(barge, crane,...)	
Estimated cost of Dredge (per day):	$20,000		
Estimated Total Cost:	$77,905		
Cost per Cubic Yard:	$69		$90 ($/m^3)

Figure 3-39. Geotube Cost Estimation Spreadsheet.

Case Histories

Destin Harbor (Sprague and Fowler, 1994)

Old Pass Lagoon is the only passage for boat traffic to enter the Gulf of Mexico from Destin Harbor. It was dredged in 1991 but needed additional dredging just three weeks later due to accelerated erosion of Norriego Point. This erosion was causing sediments to be deposited in Old Pass Lagoon, and if the erosion continued it would have prevented boat passage to the ocean. The city of Destin and the USACE developed a sand bypass system along with dredge-filled geotubes to stabilize the situation. The geotubes were used as groins to prevent the sediments from traveling to the lagoon.

The equipment and materials for the construction of the geotubes were:

- Jetel Pump portable dredge: The discharge of the dredge was 8.71 to13.25 cubic meters (2,300 to 3,500 gallons) per minute. Likewise, the production rate was 122 to 284 cubic meters (159 to 372 cubic yards) per hour (SG = 2.65), and 132 to 307 cubic meters (172 to 401) cubic yards per hour (SG = 1.5). The discharge diameter of the dredge was 20.3 cm (8 in).

- Geotube: The geotubes used were constructed from two materials, one for a strengthened outer shell and the inside layer for soil retention. The flat geotube width was 284 cm (112 in), filled width was 203 cm (80 in), and the height once filled was 152 cm (60 in). The length of the geotubes was 30.5 m (100) ft with inlets every 15.2 m (50 ft).

- Scour Apron: The scour apron was a filter weave 15.2 m (50 ft) wide and 30.5 m (100 ft) in length. A 61 cm (24 in) hem was sewn around the edge to be filled like the geotube or slit to place sandbags, as described earlier, to anchor the apron.

The installation of the geotubes began by constructing a sand platform to fit the dimensions of the scour apron. The scour aprons were then placed into position and anchored down with sandbags for the first two geotubes, and the third geotube was anchored by filling the seam. The geotubes were then unrolled from the spool and placed in position. The discharge pipe was then connected to the first inlet. Finally, the dredged material was pumped into the geotubes to a sufficient pressure to obtain the design height of 152 cm (60 in).

The following observations were made once the geotubes were installed:

- Final design of the geotubes depends on pumping pressures, capacity, and the characteristics of the dredged material.
- The inlet design is critical to obtain the maximum pressure inside the geotube.
- Greater pressures inside the geotube produce a higher profile.
- A gradual reduction in discharge, perhaps by using a valve, can help insure a uniform cross section near the end of pumping.

This system proved to be successful in that the geotubes have prevented buildup of material in the lagoon.

Gaillard Island (Sprague and Fowler, 1994)

Gaillard Island is a man-made island in Mobile Bay and is used as a disposal area for dredged material from the Mobile Ship Channel. In 1991, the Mobile District wanted to increase the capacity of the island by using dredged material-filled geotubes as the perimeter. This method would increase the height of the island in a shorter period of time and reduce the amount of material to be moved. In 1992, a trial section of 610 m (2,000 ft) was constructed.

The equipment and materials for the project were:

- Dredge: The dredge used was a self-propelled cutterhead suction dredge. The production rate was 2,294 to 2,676 cubic meters (3,000 to 3,500 cubic yards) per hour with specific gravities of 1.29 (in situ) and 1.16 (slurry).
- Geotube: Four geotubes of 152 m (500 ft) length were constructed for this project. Three geotubes had a flat geotube width of 300 cm (118 in) and the fourth geotube was 457 cm (180 in). The widths of the first three geotubes once filled were 203 cm (80 in) with heights of 152 cm (60 in). The final geotube had filled dimensions of 229 cm (90 in) width and 168 cm (66 in) height. Each geotube was 152 m (500 ft) in length with fill ports every 30.5 m (100 ft) and the apparent opening size was 210 mm.

The design of the geotubes was based on gradation and weight properties of the organic silts and clays in the dredged material as well as the anticipated filling pressures during installation. The design balanced the need for soil retention and fabric permeability.

The installation began by deploying a 20.3 cm (8 in) diameter branch line with an in-line valve from the dredge discharge line placed adjacent to the geotube. The branch line was constructed with 6.1 m (20 ft) joints of schedule 80 PVC pipe and fitted with quick connects to relocate the flexible hose as the geotube was being filled. Next, a shallow, level trench was excavated to the approximate width of the geotube to stabilize the geotube during installation. An impermeable material was then placed along the trench to prevent the water from eroding the soil underneath the geotube during installation. The geotube was then rolled into position and the inlet hose was connected to the first inlet of the geotube. After several hours of pumping dredged material into the geotube, the filling was complete. The pressures during filling were controlled by the valve at the main-line connection. Once filling was completed, the hose was disconnected and the ends of the geotube were tied off to prevent the material from escaping.

The following observations were made once the project was completed:

- The design of the geotubes produced acceptable retention of solids, little permeability, and adequate seam strength.
- The inlet design is critical to obtain maximum pressures in the geotube.
- Greater pressures in the geotubes produce higher profiles.
- Better design of the inlets is needed to improve the appearance of the geotube and reduce the time required to connect/disconnect the filling hose.

This geotube system successfully demonstrated that geotubes can be filled with dredged material and can then be used to retain dredged material on an island.

Suggested GIWW Geotube Beneficial Use Pilot Projects

Freeport Harbor to Brazos River

The GIWW from Freeport Harbor to the Brazos River has a historical dredging frequency of two years. This section of the GIWW consists of a 7.62 m (25 ft) depth and 38.1 m (125 ft) width to be maintained. The estimated quantity dredged per cycle is 650,000 cubic meters (850,000 cubic yards) of material. Proposed placement areas are CDFs 86, 87, and 89 as shown in Figure 3-40.

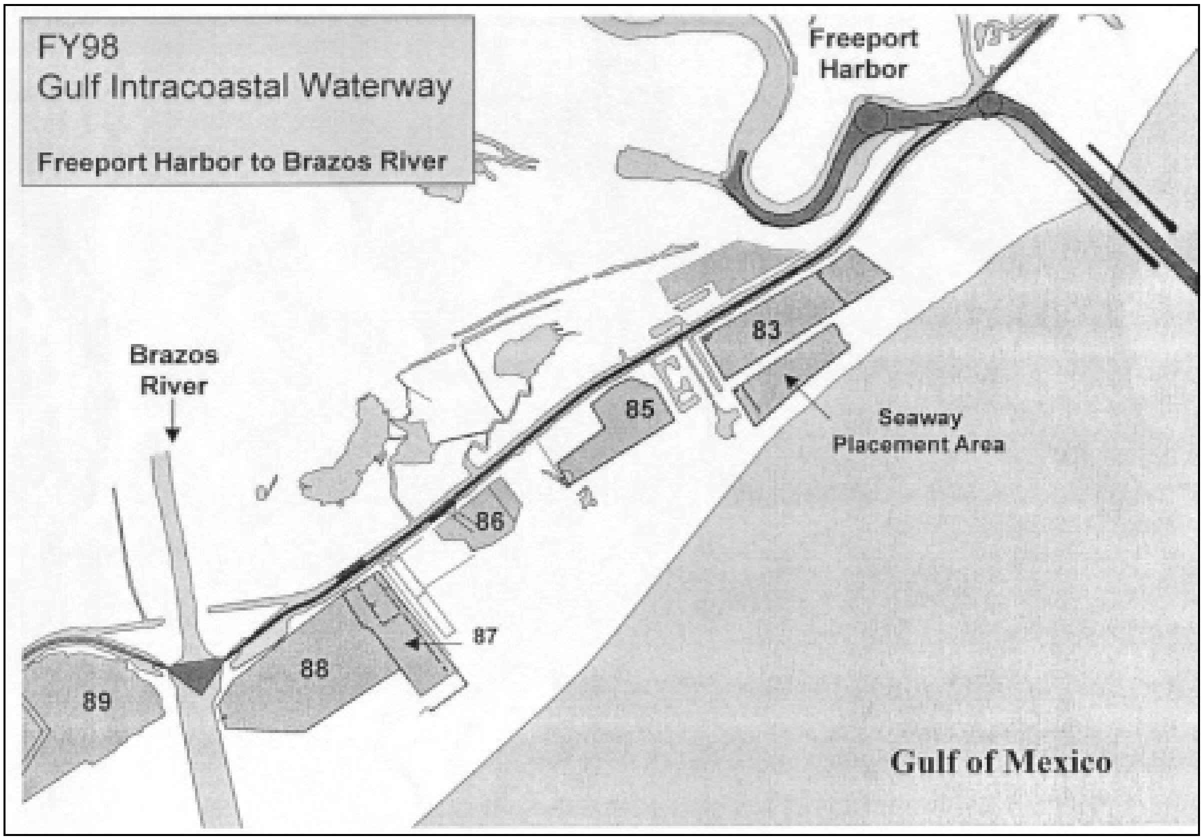


Figure 3-40. GIWW, Freeport Harbor to Brazos River (USACE, 1997).

Example specifications for the application of geotubes are as follows:

- Five geotubes placed along the landward side of the GIWW opposite CDF's 85, 86 and 87.
- Each geotube is 305 m (1,000 ft) long and consists of a 9.14 m (30 ft) circumference constructed from 5516 kPa (800 lb/in) polypropylene.
- Scour aprons are constructed to a 13.7 m (45 ft) width.
- The design of the geotube is consistent with the information supplied by this report (using d_{50} of 0.07 mm and 75 percent passing #200 sieve).
- The method of installation is the small dredge technique (115 cubic meters {150 cubic yards} per hour, 20.3 cm {8 in} dredge).

Table 3-18 summarizes results from the design.

Table 3-18. Suggested Freeport Harbor Geotube Design Parameters.

Parameter	Method	Result
Apparent Opening Size (AOS)	AASHTO	$O_{95} < 0.30$ mm
Fall Velocity	Herbich, 1992	0.0113 ft/s
Inlet / Outlet Spacing	Sprague, 1993	120 ft
Height	GeoCoPS	7.2 ft max
Width	GeoCoPS	11.1 ft max
Pumping Pressure	GeoCoPS	1.8 psi

Table 3-19 shows the results from the geocost spreadsheet. Note that the estimated amount of dredged material used is over 8,410 cubic meters (11,000 cy), which is about 1.5 percent of the material dredged from the GIWW. The cost per cubic yard is estimated at \$102/m^3 (\$78/cy).

Table 3-19. Suggested Freeport Harbor Geotube Project Cost Estimate.

Geotube Cost Estimating Spreadsheet			*SI units*
Tube Material (PP or PE):	***PP***	**Polypropylene**	
Tube Circumference (ft):	***30***		*9.14 (m)*
Tube Length (ft):	***5000***		*1524.00 (m)*
Scour Apron Width (ft):	***45***		*13.72 (m)*
Dredge Discharge (in):	***8***	**OK, skip next line**	*20 (cm)*
Split Pipe Discharge (in):		**OK**	*0 (cm)*
Suggested Production Rate (cy/hr):	***140***		*107 (m^3/hr)*
Estimated Dredge Production Rate (cy/hr):	***150***	(suggested value above)	*115 (m^3/hr)*
% Fines in Dredged Material:	***75***		
Estimated Time Required for Filling (days):	**20.4**		
Dredged Material Used (cubic yards):	**11,279**		*8624 (m^3)*
Estimated cost of Materials:	**\$169,625**	(geotube & scour apron)	
Labor cost (per hour):	**\$750**		
Estimated cost of Equipment (per day):	**\$10,000**	(barge, crane,...)	
Estimated cost of Dredge (per day):	**\$15,000**		
Estimated Total Cost:	**\$882,407**		
Cost per Cubic Yard:	**\$78**		*\$102 (\$/m^3)*

Main Channel in Matagorda Bay

The GIWW along the main channel of Matagorda Bay has a one-year frequency of dredging. The estimated amount of material dredged is 153,000 cubic meters (200,000 cubic yards). Placement areas, shown in Figure 3-41, for this project are 116B, 117A, and 116A. This section of the GIWW is maintained at a 3.66 m (12 ft) depth and 38.1 m (125 ft) width.

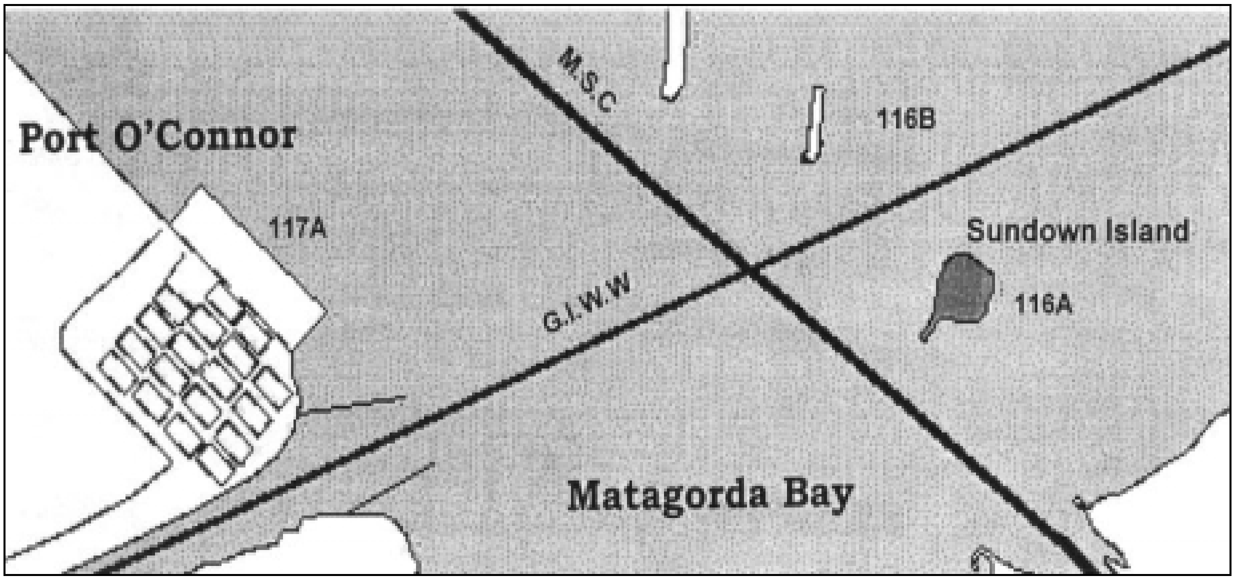


Figure 3-41. Main Channel Matagorda Bay (USACE, 1997).

Specifications for this example are as follows:

- Four geotubes placed along the landward side of the GIWW near the Port O'Connor entrance to the bay and one on the seaward side to stabilize the entrance.
- The landward geotubes are to be 152 m (500 ft) long and the seaward geotube is 305 m (1,000 ft) long. All geotubes consist of a 9.14 m (30 ft) circumference constructed from 6895 kPa (1,000 lb/in) polyester.
- Scour aprons are constructed to a 9.14 m (30 ft) width.
- The design of the geotube is consistent with the information supplied by this report (using d_{50} of 0.35 mm and 25% passing sieve #200).
- The method of installation is the split pipe technique (460 cubic meters {600 cubic yards} per hour).

Table 3-20 summarizes the results of the design.

Table 3-20. Suggested Matagorda Bay Geotube Design Parameters.

Parameter	Method	Result
Apparent Opening Size (AOS)	AASHTO	$O_{95} < 0.59$ mm
Fall Velocity	Herbich, 1992	0.171 ft/s
Inlet/Outlet Spacing	Sprague, 1993	32 ft
Height	GeoCoPS	7.9 ft max
Width	GeoCoPS	10.7 ft max
Pumping Pressure	GeoCoPS	3.4 psi

This example uses the split pipe method and has an estimated cost $\$95/\text{m}^3$ (\$73/cy) as shown in Table 3-21. Nearly 5,400 cubic meters (7,000 cy) of material is used, which is almost 3.5 percent of the dredged material.

Table 3-21. Suggested Matagorda Bay Geotube Project Cost Estimate.

Geotube Cost Estimating Spreadsheet			***SI units***
Tube Material (PP or PE):	***PE***	**Polyester**	
Tube Circumference (ft.):	***30***		*9.14 (m)*
Tube Length (ft.):	***3000***		*914.40 (m)*
Scour Apron Width (ft.):	***30***		*9.14 (m)*
Dredge Discharge (in.):	***20***	**Use Split Pipe**	*51 (cm)*
Split Pipe Discharge (in.):	***8***	**OK**	*20 (cm)*
Suggested Production Rate (cy/hr):	***140***		*107 (m^3/hr)*
Estimated Dredge Production Rate (cy/hr):	***175***	(suggested value above)	*134 (m^3/hr)*
% Fines in Dredged Material:	***75***		
Estimated Time Required for Filling (days):	**10.5**		
Dredged Material Used (cubic yards):	**6,768**		*5174 (m^3)*
Estimated cost of Materials:	**\$131,100**	(geotube & scour apron)	
Labor cost (per hour):	**\$750**		
Estimated cost of Equipment (per day):	**\$5,000**	(barge, crane,...)	
Estimated cost of Dredge (per day):	**\$20,000**		
Estimated Total Cost:	**\$492,437**		
Cost per Cubic Yard:	**\$73**		*\$95 (\$/m^3)*

Summary

Placement of geotubes along the GIWW is a method for combating the erosion loss of wetlands as well as providing a beneficial use of dredged material. Geotubes can provide protection against erosion and provide long-term management of dredged material. Geotubes have been used in many applications such as groins, revetments, contaminant dikes, breakwaters, reclamation works, dune reinforcement, and can be used along the GIWW. Advantages of using geotubes include providing a beneficial use for dredged material, lower cost compared to traditional coastal erosion structures, decrease in work volume, use of local materials and lower skilled labor. On the other hand, resistance to punctures, fabric degradation, placement, variation in height, and limited guidance are possible limitations of using geotubes.

Geotubes placed along the GIWW should be designed to withstand the pressures of filling, provide sufficient permeability, contain the dredged material, and resist erosion once in place. Soil properties of the fill material must be found in order to select the material and calculate spacing for the inlets. The size of the geotextile mesh openings should be such that the material is contained and the tube is allowed to dewater. Recommendations by AASHTO and a soil testing flowchart method from Sprague (1993) are suggested for determining the mesh opening size. The material used should be a high-strength geosynthetic that is resistant to ultraviolet rays, oils, and chemicals that may be found along the GIWW. The spacing of the inlets is based on the fall velocity of the sediments and increases as the mean sediment size decreases. A design tool, GeoCoPS is a verified tool that can predict the dimensions of a filled geotube and can be used in selecting geotextile material based on the filling pressures.

Scour is a problem that must be addressed before a geotube can be installed. Scour aprons can be installed using sandbags, sewn pockets, or a continuous seam that keeps the leading edge from floating. Scour aprons are a standard method to prevent scour. However, there are no criteria for calculating the width of the apron, and current practice suggests that the circumference of the tube as the scour apron width.

Two installation methods have been described. One method is called the small dredge method and the other is the split pipe method. The small dredge method utilizes a small dredge that is directly connected to the filling tube. The small dredge is only used until the tube is filled. The split pipe method uses the same dredge that is doing the maintenance dredging in the GIWW, and a branched pipe from the discharge line of the dredge is connected to the geotube for filling.

Conclusions and Recommendations

A geotube can be designed for placement along the GIWW and provide a beneficial use of dredged material while preventing further inundation of wetlands due to erosion. Geotubes for this application consist of a circumference of approximately 9.14 m (30 ft) and contain about 1.53 cubic meters (2 cubic yards) of dredged material per linear foot. Case studies described in this study demonstrate that geotubes have been successfully filled hydraulically and used as coastal protection structures. Geotubes, designed to contain dredged material and protect further erosion of the GIWW, are more economical when installed in conjunction with maintenance-dredging projects. The more cost-efficient installation method is the split pipe method because mobilization costs are much less. As shown by the cost-estimating spreadsheet, the cost per cubic yard (approximately \$60 to \$80) is much greater than placing the material in a CDF, but over time it is expected to reduce dredging frequency and wetland loss, which is an excellent beneficial use for the dredged material.

It is recommended that pilot studies, such as the examples described in this report, be conducted to determine the effectiveness of long-term dredge material management using geotubes. These pilot studies should be conducted parallel with a dredging project and monitored to report the condition of the geotubes and their effectiveness in preventing further erosion. The geotubes for these studies are recommended to be approximately 9.14 m (30 ft) circumference, 152 to 305 m (500 to 1,000 ft) in length, filled directly from a small dredge or branch pipe, and have a minimum scour apron width of 9.14 m (30 ft). It is also recommended that further studies be conducted regarding scour and the width of the scour aprons to maximize the structure's effectiveness against erosion and undercutting.

CHAPTER 4 IDENTIFY SEPARATION TECHNIQUES APPLICABLE TO GIWW DREDGED MATERIAL (TASK 3)

INTRODUCTION

Each year the state of Texas dredges over 7.7 mcm (10 mcy) from the Gulf Intracoastal Waterway (GIWW) in addition to nearly 15.3 mcm (20 mcy) from other waterways and ports. The U.S. Army Corps of Engineers (USACE) assists local and state governments with the maintenance of the states' navigation channels. The majority of the dredged material from these channels is placed in upland disposal areas, or confined disposal facilities (CDFs). The USACE and the Texas Department of Transportation (TxDOT), the local sponsor responsible for the maintenance of the GIWW, are concerned with the amount of dredged material placed into CDFs each year.

There are three primary reasons for using separation techniques with dredged material. The first is to remove contaminated materials, generally silt, from larger, clean sands. Contaminates in the sediments "attach" themselves to smaller fine-grained particles. Separation techniques are particularly suited for this application and most research in this area has demonstrated this use. The second purpose is to extract sand, or beach quality material (BQM), for use in beach renourishment or construction projects. Mining and minerals processing industries have used separation techniques for years to mine aggregates. The third reason to use a mechanical separator is to dewater the dredged material in order to reduce the volume of material placed into a CDF or upland disposal area.

As dredged material is placed in a CDF, it begins to settle. The heavier particles will fall out of the water column first, then the smaller particles. The CDF consolidates as water is removed from the system. The settling rate in these facilities ranges anywhere from one to five years, and maintenance dredging is often performed every two or three years. Since it is not advised to place new dredged material in a disposal area until the sediment has settled, disposal areas are only available every few years. Although the area inside a disposal area can be increased by increasing the dike height, this is only a temporary solution. Eventually the CDF will reach capacity. Alternatives such as restricting the use of a CDF for storage of only the most contaminated sediments are being considered in many places.

At the present time, the shortage of disposal areas is not a problem for the Texas GIWW. The large amount of time it takes for the CDFs to dewater before the next dredging project can be a problem. Decreasing the settling times would help. The dredge slurry pumped into a disposal area is at least 50 percent water. By removing the water before the dredged material is placed in the CDF, the volume placed in the CDF can be reduced and the settling time decreased. In order to further increase the capacity of the disposal area, the dredged material could also be separated into different fractions, not just dewatered before being placed in the disposal area. By separating the materials into fractions of sands and silty material, the different fractions can be used for different purposes. The intended use of the material and where the material will be placed will determine the required sediment size. Sediments that are coarse grained have the highest potential for beneficial uses. For example, it is known that dredged material should be considered a resource, and that the separation of coarser sand material could be used for beach renourishment and construction material. The fine particles, with a high organic content, could be used for marsh creation and rehabilitation.

Background

Many diverse industries have separation methods. Initially used by the mining and mineral processing industry, separation technologies are now used in chemical and petrochemical industries, power generation, the textile industry, and metal working (Svarovsky, 1984). Although separation techniques have not been used by the dredging industry in the maintenance of navigation channels in the U.S., they have been used by U.S. mining and minerals processing industries and by dredging industries in Europe.

The mining and minerals processing industries use a wide variety of separation techniques to isolate desired minerals from other materials. For example, separators are used with shore-based commercial sand mining dredges for mining construction material. Material is excavated from an area by clamshell dredge and combined with groundwater to form a slurry. The material is passed through a hydrocyclone or other separation device and the sand is separated from the finer grained material (Heible et al., 1994).

Objective

The objective of this study is to identify separation techniques that could be utilized to reduce the amount of dredged material placed in CDFs. A pilot study, based on dredging projects, pilot tests, and feasibility studies performed by the USACE and port districts is discussed. The purpose of the pilot study is to determine the applicability and feasibility of this technology for use in Texas and the GIWW.

Typically the cost of separation has been considered too high and not cost effective. It is cheap and easy to dispose of dredged material in a CDF. Policy constraints dictate the use of the least cost, most environmentally acceptable disposal alternative. The mining industry finds it worthwhile to dredge sand in some areas of the country. Sand is a natural resource and should not be “thrown away” into a CDF or other disposal area. The additional cost associated with adding the cyclone technology to the existing system must be subsidized by non-federal interests (Heible et al., 1994). When evaluating the economics of sediment recovery one must address the long-term perspective.

IDENTIFY SEPARATION TECHNIQUES

There are several separation methods that can be applied to the dredging industry. In addition to dividing the dredged material into different components based on grain size (i.e., sand and silt), separation techniques may also be used to separate contaminants from clean materials and to dewater the dredged material. A list of the types of separation techniques available for separating and dewatering is shown in Table 4-1.

Table 4-1. Separation Techniques.

Clarification Filters	Thin Layer Filters
Centrifugation	Sedimentation Processes
Ancillary Processes	Less Common Separation Processes

Clarification filters include screens and strainers. There are also several types of filters available: edge, bag, and sheet. Centrifugation can be divided into two categories, sedimenting and filtering. Ancillary processes are flocculation and coagulation that produce a cake material. Thin layer filters involve cross flow filtration and dynamic filters and result in cake formation. Sediment processes include thickeners and clarifiers, hydrocyclones, and sediment washing. Some of the less common separation processes include: floatation, magnetic, electrical, and sonic separators. Many of these technologies are only applicable to certain industries. Even with modifications, very few of these technologies can be used in the dredging industry. Operating parameters such as production rate and sediment separation size also prevent the use of many of these technologies in the dredging industry.

Separation equipment can be categorized into two broad areas, mechanical or chemical, based on the method of separation. Mechanical separators are typically used in the mining and minerals processing industry, whereas chemical separators are used in most petroleum and chemical industries. Overall, the efficiency and success rate of all separation processes are based on the particle properties such as size, density, and surface chemistry.

Mechanical

Table 4-2 is a list of the common mechanical separation systems.

Table 4-2. Mechanical Separation Techniques.

Attrition Scrubber	Filters/Screens
Centrifuge	Hydrocyclone
Dense Media Separator	Inclined Plates
Dewatering Wheel	Rotary Trommel
Diffusers	

- Attrition scrubbers separate fine-grained sediments from the larger material using a series of impellers that force sediment particles to rub against one anther.

- A centrifuge separates solids from liquids in a slurry using the centrifugal force principle.

- Dense media separator (DMS) separates organic materials from dense media sediments by washing in a tall, rectangular, or cylindrical tank.

- Dewatering wheels are large bucket wheels that separate sand from coarse-grained aggregates. The capacity ranges from 7.2 to 59.4 m^3/min (1,900 to 15,700 gpm).

Dewatering wheels are used extensively in the mining industry, and they appear appropriate for the dredging industry due to their high capacity.

- Diffusers reduce turbulence and distribute the feed slurry evenly over a distance and area larger than the discharge pipe. Multiple ports in the diffuser have a cross-sectional area greater than that of the discharge pipe. The diffusers may be aligned for radial, vertical, or horizontal flows.

- Filters and screens are often the first step in removing large sediments and debris, such as tree limbs and rocks. In many separation systems, filters and screens are used in conjunction with other separation techniques as the first step or process.

- A hydrocyclone is used for the separation of different density materials within a slurry. The operation of a hydrocyclone is similar to a centrifuge and based on the centrifugal force principle without the moving parts. Capacities range around 9.1 m^3/min (2,400 gpm). Hydrocyclones are well established in the mining and mineral industry as are dewatering wheels and filter systems.

- Inclined plates are used to enhance the settling velocity of slurry mixes. The plates provide additional surface area and a boundary for the slurry. The solids settle out and form a boundary layer on the top of the upward facing plate. Denser material drives the liquid upward on the underside of the downward facing plate.

- The rotary trommel is similar to a centrifuge with a rotating cylinder with lifter bars. A filter screen with washing and sizing zones separates the coarse and fine-grained sediments in the slurry.

Chemical

Table 4-3 is a list of the chemical separation techniques or methods currently in use.

Table 4-3. Chemical Separation Techniques.

Desiccation
Flocculation
Polymers
Sediment Washing

- Desiccation – Plants are used to remove or separate unwanted chemicals from sediments. In addition, the evaporation or transpiration by plants promotes the dewatering of the material. Current issues such as using plants to remove heavy metals and other contaminants from soils are being researched.

- Flocculation – Chemicals are added to promote the settling of fine-grain particles in a mixture or slurry. By attaching themselves to small silts and clays, chemicals can assist in increasing the settling time and removing contaminants from the water column.

- Polymers – There are three types of synthetic polymers used based on their ionic charge. Anionic, nonionic (zero charge), and cationic polymers are mixed with the sediment to increase settling time. Typical costs are $15,000 to $30,000 per 76,460 m^3 (100,000 cy) not including labor.

- Sediment Washing – This approach is a very common method of cleaning, or separating contaminated materials from clean sands. The contaminated sediments are mixed with a stream of water to separate the contaminated particles from the feed slurry. This method can prove to be expensive since both the remaining contaminated material and wash water must be purified before disposal.

TECHNIQUES APPLICABLE TO TEXAS GIWW

Hydrocyclone

The hydrocyclone is a "static separator based on centrifugal separation in a vortex generated within a cone-cylindrical body" (Svarovsky, 1984). Figure 4-1 shows a diagram of the hydrocyclone.

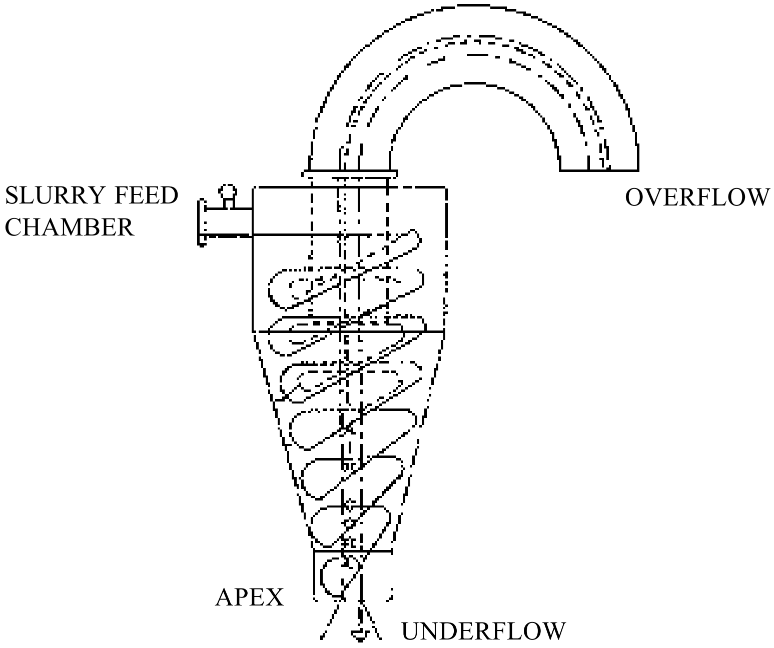


Figure 4-1. Hydrocyclone (Heible et al., 1994).

The primary use of a hydrocyclone is for the separation of different density materials within a slurry. The hydrocyclone operates based on the centrifugal force principle. Little energy is required and maintenance is low because there are no moving parts within a hydrocyclone.

Although this technology has not been applied to maintenance dredging of navigation channels, it has been used on shore-based commercial sand mining dredges. In these instances, the material is excavated from an area and combined with groundwater to form a slurry. The material is passed through a hydrocyclone or other separation device and the sand is separated from the finer-grained material.

Operation of a Hydrocyclone

Slurry enters tangentially into the upper cylindrical part of the cyclone where it transverses along the outer wall. As the slurry increases in angular velocity, a centrifugal force causes the coarser and larger particles to migrate along the outer wall. The larger particles exit at the apex as the "underflow." The lighter and smaller particles are forced to the middle of the hydrocyclone due to a low-pressure vortex caused by the circular motion of the fluid. The small particles, as well as the majority of the water, exit as the overflow. The particle size at which separation occurs is dependent on the upper cylindrical part of the hydrocyclone.

Table 4-4 shows hydrocyclone sizes and operational parameters. Manufactured sizes vary from 7.6 to 91 cm (3 to 36 in) in diameter. Separations from 10 to 100 microns can be achieved. The general rule is the larger the hydrocyclone, the larger the cut size. The maximum capacity is about 15.1 m^3/min (4000 gpm) for a 0.91 m (36 in) diameter hydrocyclone. With no moving parts a hydrocyclone requires little energy and low maintenance.

Table 4-4. Hydrocyclone Operational Parameters.

Size* (cm)	Size* (in)	Capacity (L/s)	Capacity (gpm)	Inlet Feed Pressure (kPa)	Inlet Feed Pressure (psi)	Separation (Micron)
7.6	3.0	0.3-2.2	5-35	68.9-482.6	10-3325	10-40
10.2	4.0	1.3-5.7	20-90	68.9-413.7	10-2850	10-40
15.2	6.0	2.5-12.6	40-200	68.9-344.7	10-2375	15-40
20.3	8.0	5.7-18.9	90-300	34.5-275.8	5-1900	20-44
30.5	12.0	12.6-50.5	200-800	34.5-206.8	5-1425	30-44
45.7	18.0	18.9-94.6	300-1500	34.5-179.3	5-1235	44-53
61.0	24.0	50.5-151.4	800-2400	34.5-172.4	5-1188	53-74
76.2	30.0	94.6-220.8	1500-3500	34.5-172.4	5-1189	74-100
91.4	36.0	113.6-252.4	1800-4000	34.5-137.9	5-950	100-149

*Sizes are defined by the diameter of the feed chamber. Values are approximate ranges from each size and depend on the sediment characteristics/distribution, suspended solids ratio, and specific gravity of the solids in the feed. (Met Pro Supply, Inc., 1995)

Operating Constraints

Heible et al. (1994) have identified several operational constraints and characteristics of hydrocyclones and show that hydrocyclones operate best at constant pressures and flowrates. In addition, the slurry concentration should be between 5 and 50 percent solids by weight. The hydrocyclone will operate most efficiently around 20 percent solids concentration. Direct feed from a pipeline dredge is not recommended due to several factors including varying percent solids, varying flowrates, and clogging due to debris (Heible et al., 1994). These factors may result in increased expenses due to dredging downtime. The operation of a hydrocyclone from a work barge or mobile shore-based trailer is recommended unless a filter or screen system is implemented. A hydraulic underloader may be used to pump the slurry from the barge to the shore for separation. In controlled plant applications, hydrocyclones can achieve silt removal rates of 95 to 99 percent. In field applications the efficiency is decreased (Williams, 1994). A further discussion on the operational constraints and other potential problems of the hydrocyclone can be found later in the discussion entitled "Feasibility of Applicable Techniques."

Recent developments to address the problem of varying percent solids include the maximum density separator (MDS). The MDS is a modification of a conventional hydrocyclone where constant high percent solids are produced from variable solids percent (Met Pro, 1995). Using the MDS, the slurry is kept under negative pressure (suction) resulting in a constant percent solids product (underflow) instead of the normal constant volume (Granat, 1997).

To achieve a desired separation and production rate, hydrocyclones can be stacked and sized accordingly. A careful design to take into account the size and production rate of various hydrocyclones can result in both required production rates and cost effectiveness.

Dewatering Wheel

Dewatering wheels are used extensively in the mining industry to classify aggregates. Figure 4-2 shows a typical dewatering wheel. Dewatering wheels are classified according to their wheel diameter.

Operation of a Dewatering Wheel

Wheel size and speed of rotation depend on the inflow of slurry. The slurry is fed to a bin through which a bucket wheel rotates. Each of the buckets on the wheel has a screen the size of the cut desired. In some cases, a vacuum chamber is used with the dewatering wheel. A suction pressure is applied to remove water and fines through the screen leaving the coarse fraction in the bucket. As the bucket rotates, the coarse fraction is removed (Enviro, 1994).

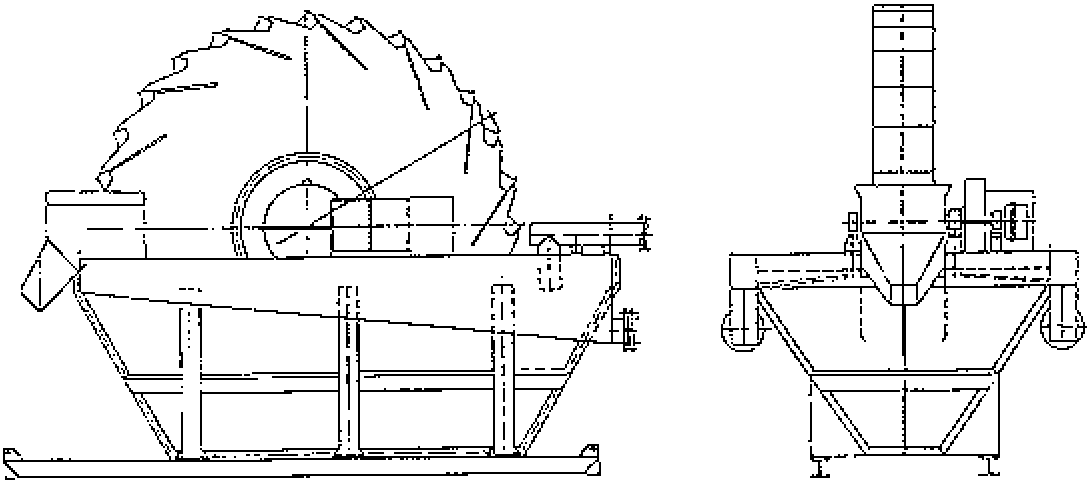


Figure 4-2. Dewatering Wheel (Williams, 1994).

Table 4-5 shows a sample of the dewatering wheel sizes and the corresponding operational parameters. Manufactured sizes vary from 2.44 to 10.1 m (8 to 33 ft) in diameter and mesh sizes for separation range from the #16 to the #250. The capacity of the dewatering wheel ranges from 7.6 to 56.8 m^3/min (2,000 to 15,000 gpm). The low rotational speed, 0.5 to 2.0 rpm, of the wheel produces little wear and the energy required can vary between 1.5 to 6 kW depending on the size.

Table 4-5. Dewatering Wheel Operational Parameters.

Diameter (ft)	Capacity (gpm)	Capacity (L/s)	Wheel RPM	Operating HP	Weight (tons)
7.9[b]	1862	117	2.19	5.4	6.6
9.8[a]	1004	63	0.86	1.6	7.2
10.0[b]	2560	162	2.15	9.3	8.8
11.5[a]	1120	71	0.80	2.0	8.3
11.5[b]	3320	209	1.22	8.7	17
13.1[b]	3680	232	1.21	11.9	19.8
16.4[b]	5040	318	1.15	20.0	30.8
21.3[a]	4850	306	1.40	30.0	35.3
26.3[a]	10000	631	1.12	48.6	64.5
32.8[a]	15700	991	1.23	107.5	86.5

[a] Dewatering wheel with narrow slurry basin.
[b] Dewatering wheel with wide slurry basin. (Enviro, 1994)

There are a limited number of dewatering wheels currently in use with dredging operations for mineral mining in the U.S. (Enviro, 1994). Friese Materials in Atmore, Florida, has been using a 5 m (~ 16.4 ft) wheel for dewatering and mineral recovery. In Flint, Michigan, the Kurtz Gravel Company has been using a 4 m (~13.1 ft) wheel since 1988.

Others Separation Techniques

Inclined Plates

Figure 4-3 shows an inclined plate and illustrates the process. As solids settle out and form a boundary layer on the top of the upward facing plate, the denser, sludge layer drives the liquid upward on the underside of the downward facing plate.

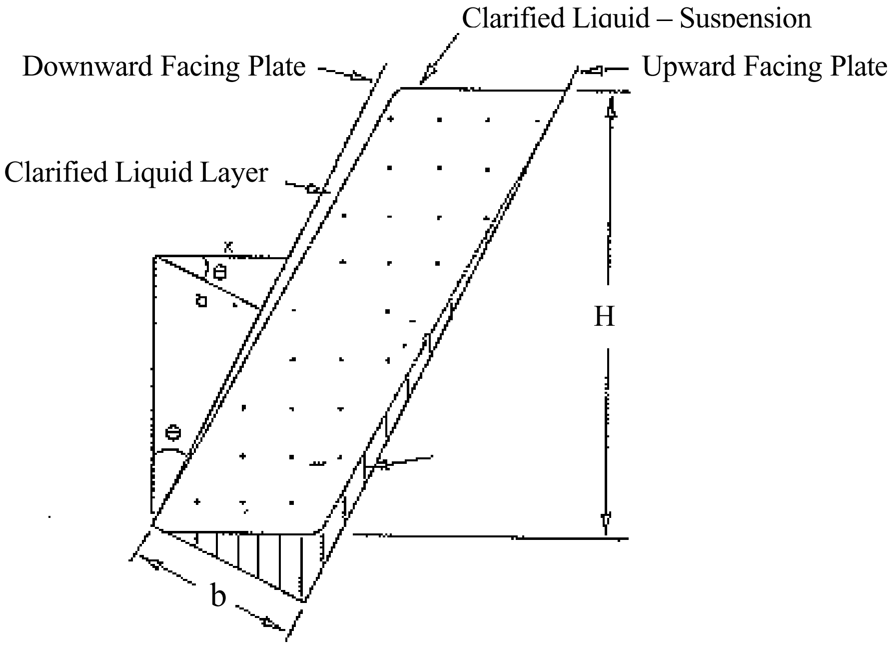


Figure 4-3. Inclined Plate Separator (Scott et al., 1992)

In 1992 physical model tests were conducted for some of the separation techniques (Scott et al., 1992). They noted that the efficiency of the inclined plate could be increased by:

- increasing the plate angle - an angle which is too large may interfere with the movement of the sludge layer and an angle which is too small may cause instability of the surface interface leading to entrainment of sediment,
- increasing the suspension height and/or the overflow times,
- decreasing the spacing between plates or adding more plates, and
- decreasing the slurry density and/or the flowrate.

Centrifuge

A typical centrifuge dewatering project flow diagram is presented in Figure 4-4. The dashed lines represent alternative pathways. A picture of the centrifuge is located in Figure 4-5.

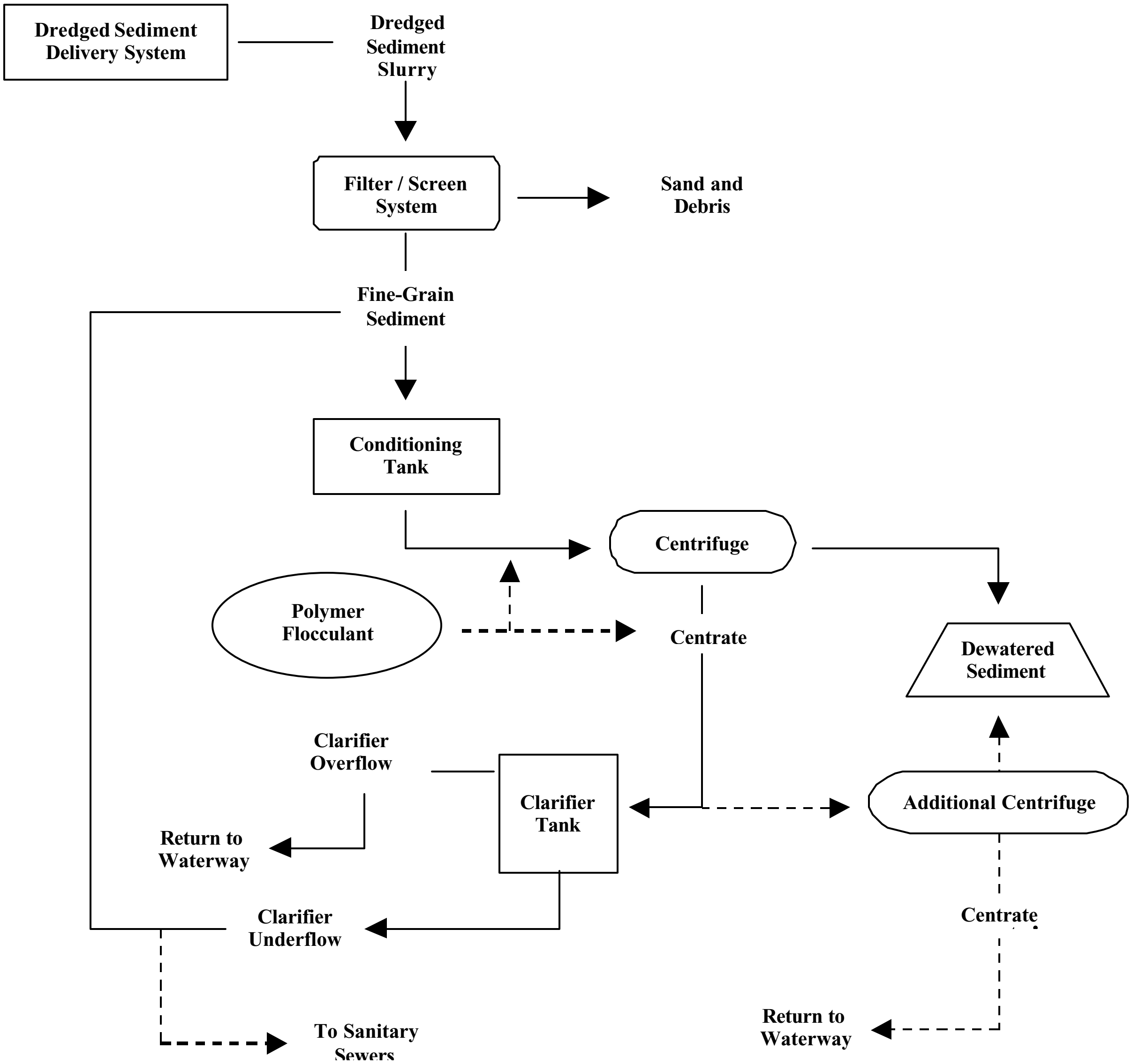


Figure 4-4. Typical Centrifuge Dewatering System (Case, 1996).

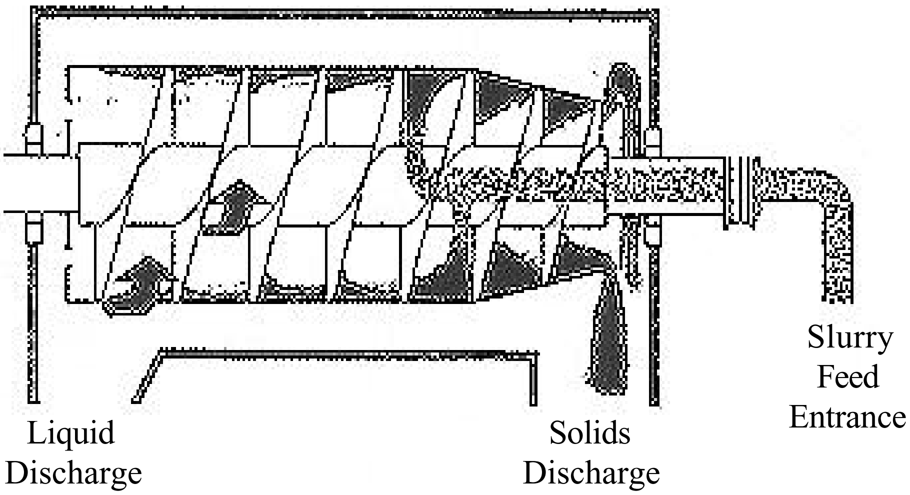


Figure 4-5. Centrifuge (Case, 1996).

CURRENT/PREVIOUS DREDGING PROJECTS OR PILOT TESTS

Miami River Project

The Jacksonville District USACE investigated the potential of using hydrocyclone technology for separating contaminates from dredged material from the Miami River (Granat, 1997). The contaminated sediments in the Miami River contain toxic heavy metals. The primary goals of this study were to determine (1) the feasibility of separating the sand and silt, (2) whether the underflow would be clean, and (3) the course of action for the "toxic" overflow.

As of May 1997, a pilot demonstration project was planned for the Miami River (Granat, 1997). A 12 in MDS will process 2.1 m^3/min (550 gpm) at 20 percent solids. It is estimated that 0.19 m^3/min (50 gpm) underflow of 70 percent solids and 1.9 m^3/min (500 gpm) overflow of approximately 12 percent solids will be produced. A storage capacity of 1912 m^3 (2,500 cy) per 16 hr day would be required. A 2294 m^3 (3,000 cy) scow or barge could be used as this storage. The pilot project could be scaled up with a larger hydrocyclone. A 61 cm (24 in) MDS could process 9.1 m^3/min (2,400 gpm) at 40 to 50 percent solids.

Canaveral Harbor, FL

In January 1994, the Jacksonville District USACE hosted a meeting to review the feasibility of using hydrocyclone technology to extract beach quality material (BQM) from a maintenance dredging project to renourish the beach environment. Representatives from the Florida Department of Environmental Protection (FDEP), the Canaveral Port Authority, the USACE, and hydrocyclone and dredging industries were present (Heible et al., 1994).

Maintenance dredging produced 1.3 mcm of material from 1986 to 1994. Of that amount, approximately 0.4 mcm or 30 percent is placed in a Nearshore Dredged Material Disposal Site (NDMDS) where the material is returned to the littoral system (Heible et al., 1994).

It was determined that hydrocyclones work best with constant pressure and flow rates. These requirements can be achieved by placing hydrocyclones in parallel. Typical dredging projects at Canaveral use clamshell dredges due to the presence of sea turtles. For this case, a scow and hydraulic unloader was used in conjunction with the clamshell dredge. It was estimated that twenty 61 cm (24 in) hydrocyclones would be required to handle a 61 cm (24 in) pipeline dredging operation. A feasibility plan was developed for the meeting and a pilot project was discussed. Funding for the project was not received and many issues such as costs and environmental constraints concerning the fine-grained overflow material remain unaddressed (Granat, 1997).

Washington State Lakes

Two pilot scale centrifuge dewatering projects were performed on two different dredged sediments (Case, 1996). The project at Lake Lawrence called for the dredge material to be dewatered with a centrifuge and the centrate returned to the lake. The sediment was a fine-grained organic material. The second project site was located at Capital Lake where the dredged material was mechanically dewatered and hauled off the site. The sediment at Capital Lake was a silty sand. The sediments in both cases were dredged hydraulically using a 15.2 cm (6 in) line and dewatered using a mobile mechanical dewatering system developed by Global Dewatering, Ltd. of Edmonton, Canada.

The major problem was the low production rate for both pilot studies. Slurry production rates for the centrifuge were between 45.9 to 58.1 m^3/hr (60 to 76 cy per hr). The overall production rate for the dredge slurry was 130 and 250 gpm for Lake Lawrence and Capital Lake, respectively. Due to the low production rates, Case suggests that this technology should be applied to small boat marinas or lake dredging projects with fine grain sediments (1996). As a result of this study, Lake Lawrence decided to proceed with a large scale dewatering project of 91,752 m^3 (120,000 cy) in situ at a cost of approximately \$13 per m^3 (\$10 per cy) in situ.

Saginaw River

In 1991 and 1992 a pilot scale test using sediment washing for contaminated sediments was performed at Saginaw River to evaluate the effectiveness of removing contaminants (Galloway and Snitz, 1994). The demonstration was conducted on dredged material with a 70 percent sand content. The system components included: a grizzly screen, a rotary trommel, three hydrocyclones, a Dense Media Separator (DMS), an attrition scrubber, and a dewatering screen. The system was effective in separating the coarse-grained particles from the large proportion of fine and organic materials within the dredge slurry. Nearly 80 percent of the dredged material was recovered. The capacity of the system was 45 metric tons per hr (49.6 ton/hr). Cost estimates for a small 8,000 m^3 (10,500cy) and large 80,000 m^3 (105,000 cy) prototype plant were \$70 and \$30 per m^3 (\$54 and \$23 per cy), respectively. One of the problems encountered was the formation of clay balls with large amounts of sand in the output stream.

Other Sites

In 1992, the Detroit District USACE performed a trial separation test in Grand Haven Harbor in Grand Haven, Michigan. The purpose of the study was to evaluate the feasibility of recovering the sand fraction for use as construction fill in order to reduce the volume to be placed in a CDF. The goal was to separate 76,000 m^3 (99,400 cy) of dredged material annually. Typically, an average of 20 to 25 percent of the Erie Pier dredged material is removed each year and used as construction fill. A 25.4 cm (10 in) dredge was used with a 10.2 cm (4 in) line that was split from the discharge line to a hydrocyclone (USACE, 1992).

FEASIBILITY OF APPLICABLE TECHNIQUES

Hydrocyclone

There are several anticipated problems, or barriers that must be addressed for the use of hydrocyclone technology in the dredging industry. Most of these problems are typical of all maintenance dredging operations. In addition, several unforeseeable problems specific to a particular site exist. These potential problems will only be realized during pilot studies. A flow diagram of the available options concerning the implementation of the hydrocyclone into a dredging system is shown in Figure 4-6.

One of the anticipated problems with using a hydrocyclone is that of attaching a device to the end of the discharge line that could shut down, or impede production. There are several alternatives to this.

Solution A – The first option is to use a hopper or clamshell dredge to place material in a barge. A hydraulic unloader could be used to forward the material through a hydrocyclone. Since most dredging projects along the Texas GIWW involve hydraulic dredges, the dredged material from a hydraulic dredge could also be placed on a barge. This option has several advantages. The flowrate through the hydrocyclone must be constant for higher efficiencies, and is less than the production flowrate from the dredge. Therefore, the fluctuating production rate in the discharge line would not affect the hydrocyclone and the production rate of the dredge would not be compromised. In addition, a filter screen could be used on the barge to reduce the amount of miscellaneous materials and clay balls sent to the hydrocyclone. One of the primary concerns with this solution is the difference between the production rate of the dredge, the rate the material is placed on the barge, and the rate of the unloading.

Solution B – Another option would be to place the hydrocyclones in a bank or parallel system directly from a hydraulic dredge. By maintaining a bank of hydrocyclones, the clogging of one cyclone would not impair the production, as another cyclone would take its place. The number of hydrocyclones would depend on the production rate of the dredge.

The greater the difference between the production rates of the dredge and the hydrocyclone, means that more reserve units are necessary.

Another anticipated problem concerns the overflow material. The overflow material contains the fine-grained particles. Due to water quality requirements, the discharge of the overflow material back into the waterway will be restricted.

Solution A – There are few options of how to address this situation. First, the overflow could be passed through another series of hydrocyclones to further purify the water. The second overflow material could then be returned to the water body.

Solution B – Another option is to place only the overflow material in a CDF. The coarse or sandy fraction of the dredged material (underflow) would be used for some beneficial purpose.

Estimated Costs

The addition of a hydrocyclone or a bank of hydrocyclones to a dredging operation requires the consideration of several additional costs. Extra scows, hydraulic unloaders, booster pumps, and extra personnel are needed. In addition, the energy required to raise or develop the inlet pressure for the hydrocyclone must be determined (Heible et al., 1994). The number of hydrocyclones required is dependent on the method of dredging in addition to the production rate. Whether the separation system operates directly from a dredge or from a scow or barge, the controlling factor is the production rate of the dredge.

The estimated price of a hydrocyclone is approximately \$8,000. Tankage, piping, structure, and components require an additional \$7,000 to \$10,000 (Heible et al., 1994). The total for a single hydrocyclone installation will range from \$15,000 to \$18,000 not including pumping costs. For a bank system, or multiple hydrocyclones, the piping, structure, and component will only add an additional \$7,000 to \$10,000 to the total cost. For example, the application of a hydrocyclone system that requires a capacity of 113.6 m^3/min (30,000 gpm) would result in an estimated cost of \$130,000. This would include fifteen 61 cm (24 in) hydrocyclones at 7.6 m^3/min (2,000 gpm) capacity at a cost of \$8,000 each and \$10,000 for piping and structural components.

Additional labor costs for manpower and operation of the unloader systems must also be considered. These costs are in addition to the standard costs of a dredging operation when determining the overall cost of the project. Since hydrocyclones have no moving parts, the long-term wear is minimized and the capital costs can be shared by many projects over the years.

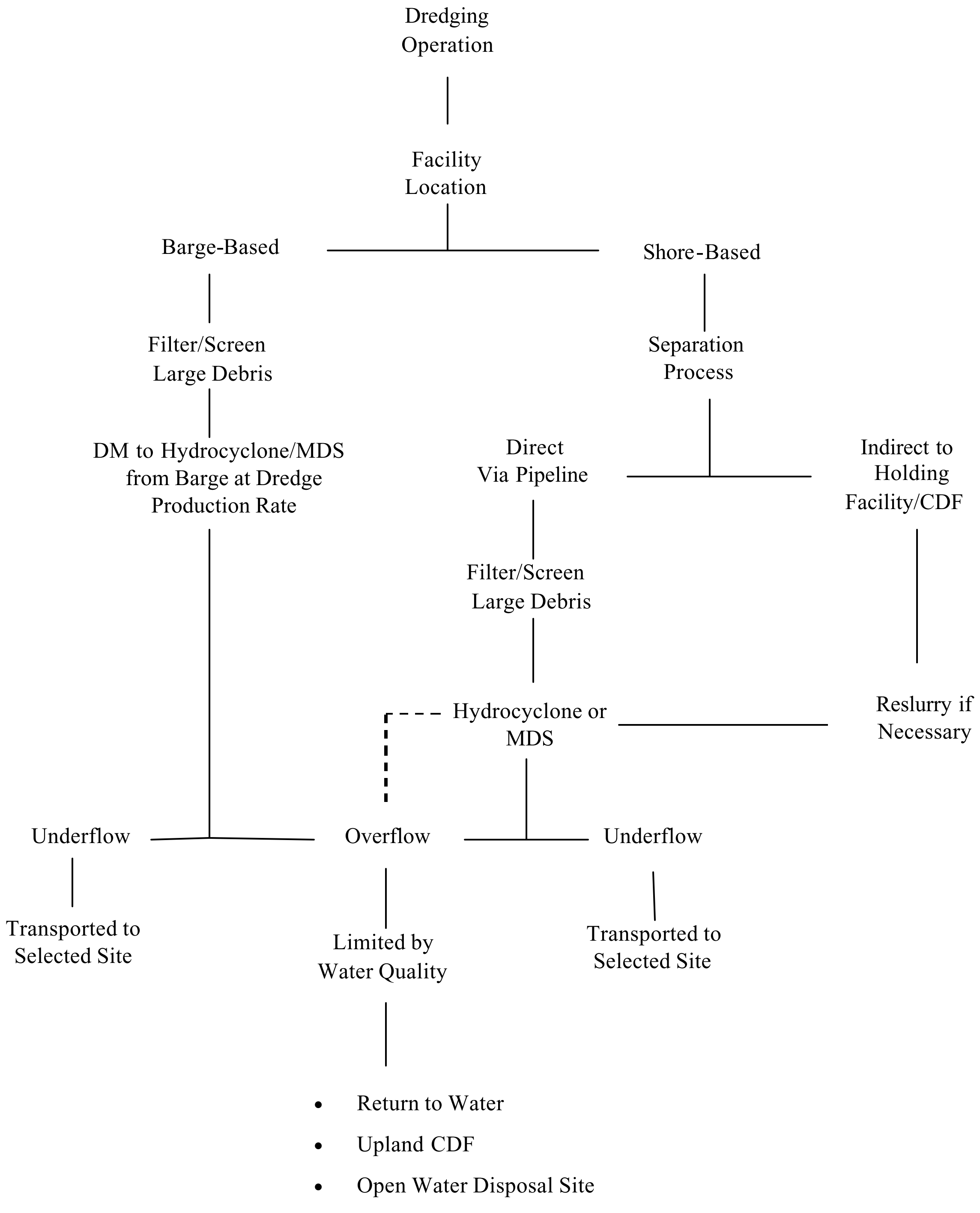


Figure 4-6. Flow Diagram of Hydrocyclone Options.

Dewatering Wheel

Dewatering wheels have been used on the West Coast in conjunction with dredges in the mining industry. Since many dredgers are familiar with dewatering wheels, they are more likely to accept this technology. Dewatering wheels are capable of variable RPMs to coincide with dredging production rates. In addition, clogging by large particles will not be a concern since the particles will be scooped into the bucketwheel and placed with the large fraction. Capital costs for a large dewatering wheel to be used in a dredging operation is approximately $600,000 not including operating costs such as fuel and labor.

PILOT STUDY FOR TEXAS GIWW

Example System

The material will be dredged from the site using either a clamshell dredge or a hydraulic suction dredge. The dredge slurry can be placed either in a nearby scow or hydraulically pumped to a bank of hydrocyclones on the nearby shore. If the slurry is placed in a barge or scow, a hydraulic unloader may be used to slurry the dredge material from a scow. There are two options concerning the underflow depending on the location of the hydrocyclone.

- For a barge-based hydrocyclone the resulting underflow can be placed into a shallow draft scow and transported to the site, or reslurried and transported via pipeline to an upland site.

- For a shore-based hydrocyclone the resulting underflow can be hauled by truck to the site.

The overflow is dependent on initial sediment characteristics and the degree of separation. The selected action for the overflow is dependent on environmental constraints. This can be a significant factor in the operation. In addition, the overflow may be passed through an additional hydrocyclone for further clarification and returned to the water body, or pumped to an upland CDF.

CONCLUSIONS AND RECOMMENDATIONS

The separation of sands and silts and the dewatering of dredged material can extend the life of a CDF by reducing the volume of disposed material. In addition, separated material like sand can be used for beneficial purposes such as beach renourishment.

While many separation techniques are not applicable to the high volumes associated with dredging operations, the dewatering wheel and hydrocyclone have been identified as two potential dewatering mechanisms for use in the GIWW. Both these technologies have been used in the mining and mineral processing industries. Limited use in the dredging industry includes West Coast mining operations using the dewatering wheel and trial tests in Michigan using the hydrocyclone. Further investigation into the operation of sand mining companies will assist in determining the operating constraints and potential problems of the dewatering wheel.

Separation techniques can also be applied to contaminated sediments. Contaminants attach themselves with clays and organic materials. If the dredged material could be divided into sand and silt fractions, the amount of contaminated material to be treated or disposed of could be decreased. While the proposed hydrocyclone pilot study for Miami River involves contaminated material, the actions and results of this pilot study should be studied for potential use as a separator of large particles.

Further research and pilot tests should be conducted to evaluate the effectiveness of either of these technologies in dredging operations.

CHAPTER 5 DEVELOPMENT OF COMPUTER SOFTWARE FOR EVALUATING THE COST OF PUMPING DREDGED MATERIAL THROUGH LONG PIPES (TASK 4)

INTRODUCTION

In order to assess the economic implications of long distance pumping in the GIWW, spreadsheet software has been developed to estimate the costs of dredging projects in which the dredged material must be pumped a long distance. The program is not limited to long distance pumping projects, but is applicable to all cutter suction dredging operations regardless of the distance. Development of such a program presents an interesting dilemma in that the estimate must be as accurate as possible, but the input must be simple and generalized. The data accessed by the individual and entered into the program are generally restricted to the following:

- volume of sediment to be dredged,
- distance from the site to the nearest available disposal area,
- sediment characteristics,
- depth of the cut to be made, and
- size of dredge likely to be used.

Many generalizations must be made, with some being very critical to the final cost. Two of the most difficult and potentially expensive generalizations to make are (1) mobilization and demobilization costs and (2) dredge production rates. These two factors contribute heavily to the total cost, and they both vary substantially from contractor to contractor and job to job.

PREVIOUS RELATED RESEARCH

Cost estimation methods have been in existence since the early days of the dredging business. Dredging contractors conduct most of the research, and they tend to keep their findings within the company. However, some research has been conducted by outside sources as well. Bray, Bates, and Land (1997) present a useful outline for developing a cost estimating program. Huston (1970) also gives some general guidelines for cost estimating. Herbich (1992) has obtained some information on typical crew sizes, dredge operating time, and other useful data on typical dredging projects. Another important contribution is Herbich's research in using nondimensional pump characteristics curves. The United States Army Corps of Engineers (USACE, 1988) has done extensive research on the cost estimation procedures. USACE has developed their own program, but this is not available to the public. However, many of the procedures used in the program are published. Turner (1996) has conducted much research in the area and presents some practical ideas. There has been much more research conducted in the area of sediment transport in pipelines and production of dredge pumps. Wilson et al. (1997) describes methods for calculating friction losses and critical velocities in pipelines that are widely accepted in the dredging industry. Contractors in the development of their cost estimation programs have used much of this research, but as yet there exists no independent programs that make use of this information for the purpose of cost estimation.

“CSDCEP” PROGRAM

Organization

The Cutter Suction Dredge Cost Estimation Program (CSDCEP) incorporates both the theory and practical ideas described earlier in Chapter 2 to create the most accurate and simple-to-use cost estimation software possible. A flowchart of the CSDCEP program is shown in Figure 5-1. The software is in a spreadsheet format, using Quattropro as the platform. There are four main components to the program:

(1) User input and program data. Three pages in the spreadsheet are devoted to data input and data access, and these pages are the main input page, the defaults page, and the database page. The main input and output page is the primary input area and display of the program results. The defaults page consists of typical values of variables used in the program, and the user can change these values if it is known that the default value is not the best value for the project under evaluation. The database page contains data on labor rates, crew sizes, and equipment costs that are accessed by the program.

(2) Mobilization and demobilization page. The costs are calculated on this page for the process of preparing and transporting the dredging equipment to and from the job site.

(3) Project execution page. This component is one page of the spreadsheet that calculates all the costs of equipment and labor, as well as any additional costs that the user enters.

(4) Production page. There are three pages in CSDCEP devoted to the production estimate, and these pages are the critical velocity determination, head loss determination, and the actual production estimation page.

Main Input and Output Page

The main page is divided into two areas called the “Main Input” area (Figure 5-2) and the “Cost Estimate Results” or “Main Output” (Figure 5-3). The user enters the basics of the dredging project through the main input section.

Dredge Size

The dredge size used on the project is defined by the diameter of the discharge pipeline in inches. This number is used in all areas of the program and is the basis for determining crew sizes, dredge production rates, and equipment costs.

Quantity to Be Dredged

The volume in cubic yards of material to be removed is used to define the quantity to be dredged. It is assumed that the pay for the dredging project is based upon the volume of material removed from the channel, not the volume placed in the disposal area.

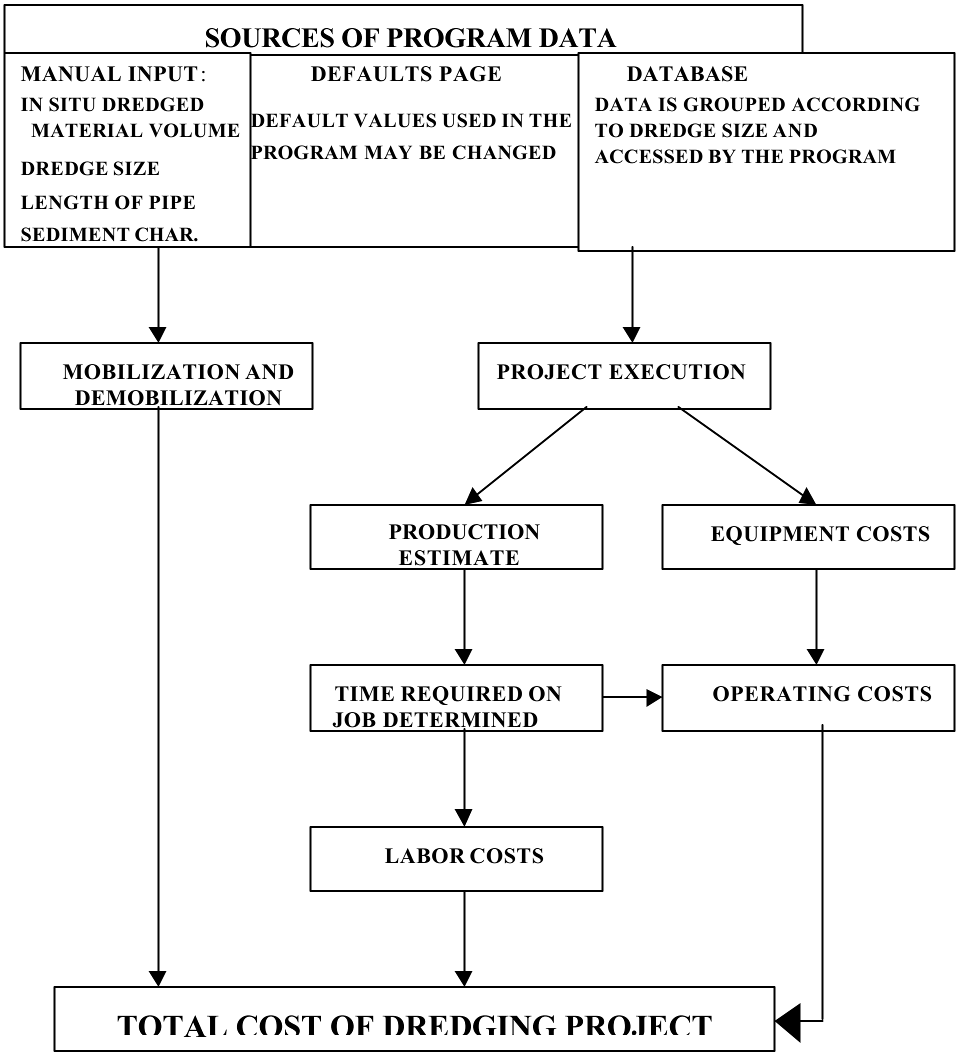
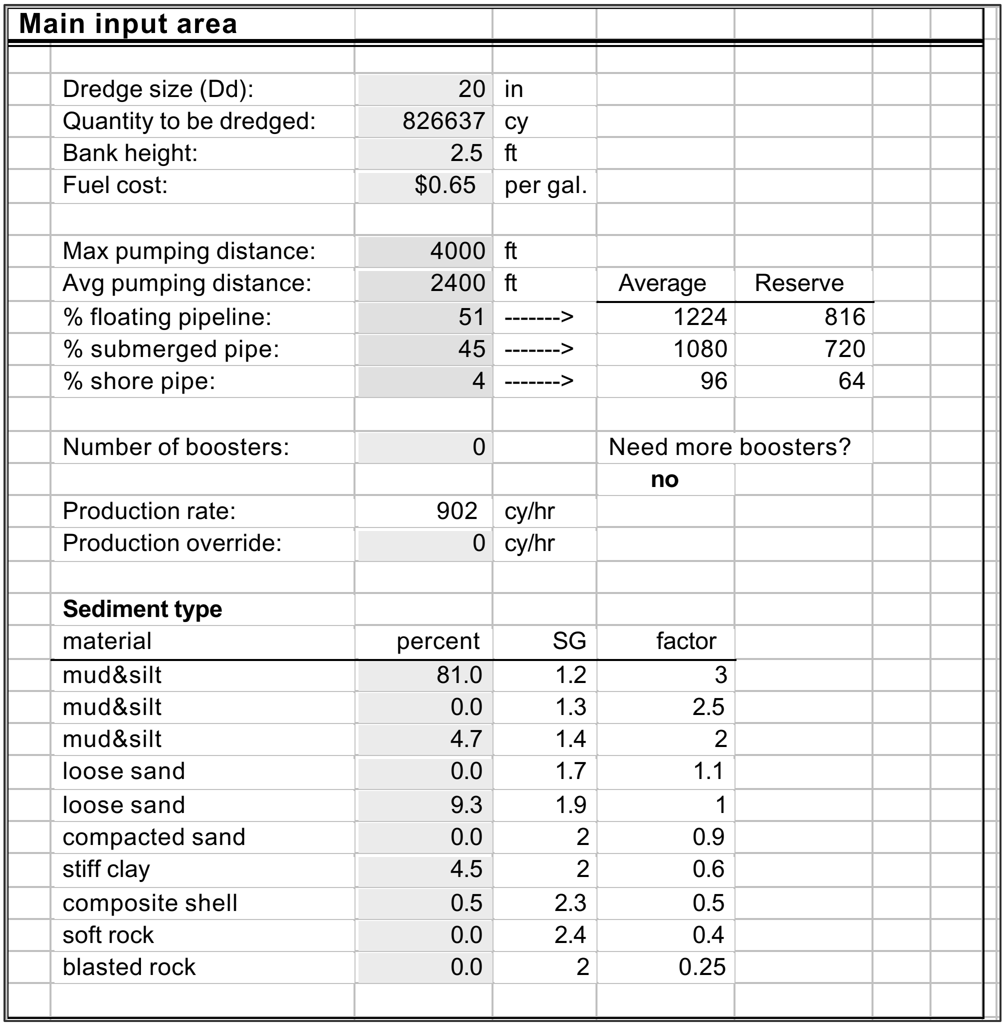


Figure 5-1. Flowchart of the CSDCEP Program.



Main input area

Dredge size (Dd):	20	in		
Quantity to be dredged:	826637	cy		
Bank height:	2.5	ft		
Fuel cost:	$0.65	per gal.		
Max pumping distance:	4000	ft		
Avg pumping distance:	2400	ft	Average	Reserve
% floating pipeline:	51	------->	1224	816
% submerged pipe:	45	------->	1080	720
% shore pipe:	4	------->	96	64
Number of boosters:	0		Need more boosters?	
			no	
Production rate:	902	cy/hr		
Production override:	0	cy/hr		
Sediment type				
material	percent	SG	factor	
mud&silt	81.0	1.2	3	
mud&silt	0.0	1.3	2.5	
mud&silt	4.7	1.4	2	
loose sand	0.0	1.7	1.1	
loose sand	9.3	1.9	1	
compacted sand	0.0	2	0.9	
stiff clay	4.5	2	0.6	
composite shell	0.5	2.3	0.5	
soft rock	0.0	2.4	0.4	
blasted rock	0.0	2	0.25	

Figure 5-2. CSDCEP Main Input Page.

Bank Height

The bank height is the average depth of the cut to be made in the channel. This number is used to determine the “bank factor” that is a factor applied to the dredge production based on the ratio of the cutter head diameter to the bank height. If the bank height is equal to or greater than the cutter diameter, optimum cutting efficiency is achieved, and the factor is approximately equal to one. However, if the cutter diameter is greater than the bank height, the cutter does not take in as much material as it is capable of doing, and a factor of less than one is applied to the estimated production rate.

Fuel Cost

The current price of bulk fuel per gallon.

Average Pumping Distance

This is the average length of pipe through which the dredged material is pumped to the containment area. This value is used to determine production rates, the need for booster pumps, cost of pipeline wear, and preparation time for mobilization and demobilization.

Maximum Pumping Distance

This is the maximum length of pipe used on the job. This number is not as significant as the average distance, but it does add to the cost as a result of pipeline on standby and preparation time for mobilization and demobilization.

Percent Floating Pipe, Percent Submerged Pipe, and Percent Shore Pipe

This is the percent of the total line length of each respective type of pipeline. It impacts the final cost based on the fact that floating pipe is more expensive than shore pipe and submerged pipe is the most expensive.

Number of Boosters

The number of booster pump stations is defined for the desired pipeline. A booster pump must be added if the pipeline is too long for the chosen dredge pump to maintain the necessary velocity. The program determines if this step is necessary in the production estimation routine. If another pump is required, it is shown to the right of the input box. Also, it may be desirable to have more booster pumps than are necessary in order to increase dredge production and lower the total cost. The optimum number of boosters can be determined by varying the number entered here and observing the effect on the total cost.

Production Override

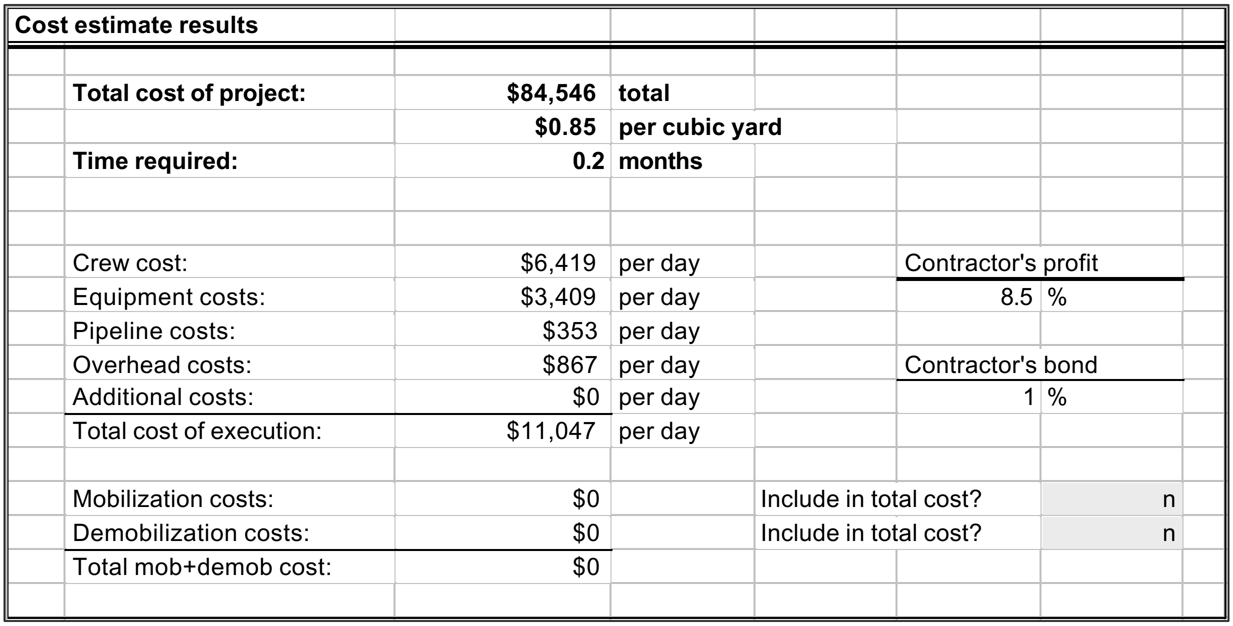
The dredge production can be entered manually if the production estimate is unsatisfactory. This input is provided in case the user has experience with the particular dredge in the given circumstances. If the value is set to zero, then the calculated production is used.

Sediment Type

The sediment type is a very significant factor in the determination of the production rate. A fine-grained silt material is easier to pump than larger grained sediments or clay. There are 10 sediment types listed and the user may input percentages of each type that are encountered in the channel to be dredged.

Cost Estimate

The cost estimate results are displayed below the main input section (Figure 5-3). The primary results of cost per cubic yard, total project cost, and time required are highlighted and displayed at the top of the section. Daily execution costs are displayed and broken down into the following categories: crew, equipment, pipeline, overhead, and additional costs. Also, the total costs of mobilization and demobilization are given.



Cost estimate results					
Total cost of project:	**$84,546**	**total**			
	$0.85	**per cubic yard**			
Time required:	**0.2**	**months**			
Crew cost:	$6,419	per day		Contractor's profit	
Equipment costs:	$3,409	per day		8.5	%
Pipeline costs:	$353	per day			
Overhead costs:	$867	per day		Contractor's bond	
Additional costs:	$0	per day		1	%
Total cost of execution:	$11,047	per day			
Mobilization costs:	$0		Include in total cost?		n
Demobilization costs:	$0		Include in total cost?		n
Total mob+demob cost:	$0				

Figure 5-3. CSDCEP Main Output Page.

On the same page as the main input is the program output. The costs of mobilization, demobilization, labor, equipment, and any additional costs are added together and the total is multiplied by the percentages for the contractor's profit and bond. The cost estimate results are displayed below the main input section. The cost per cubic yard, total project cost, and time required are highlighted and displayed at the top of the section. Daily execution costs are displayed and broken down into the categories of crew, equipment, pipeline, overhead, and additional costs. Also, the total costs of mobilization and demobilization are given.

DEFAULTS PAGE

The defaults page (Figure 5-4) lists values used in the program that are typical for current equipment and today's economy. These values will probably not need to be changed in the near future, but the capability exists in the program if differing conditions call for it. The defaults are grouped into four categories of general, mobilization and demobilization, execution, and production.

General

This section includes general calculation parameters, such as contractor's profit and bond, typical crew shift length, and typical hours per day of equipment operation.

Default Values			
Default value	Chosen value	Units	Description
General			
8	8	hrs/day	Crew shift
8	8	hrs/day	Equipment operating
8.5	8.5	%	Contractor's profit
1	1	%	Contractor's bond
1	2		Geographic labor rate factor
Mob/Demob			
$100	$100	/day	Supplies & small tools
$500	$500	/day	Support equipment with operators
$100	$100	/day	Fuel (plant idle)
$25	$25	/man/day	Subsistence
100	100	miles/day	Towing speed
$4,000	$4,000	/day	Towing vessel cost
1	1		Number of vessels
$100	$100	/man	Travel expenses
$200	$200	/day	Local hire
Execution			
$1.75	$1.75	/man/hr	Fringe benefits
14.3	14.3	%	Overtime
7	7	days/yr	Holidays
7	7	%	Vacation time
6.2	6.2	%	Social Security tax
45	45	%	Workers' compensation
3.5	3.5	%	State unemployment compensation
1	1	%	Federal unemployment compensation
300	300	days/year	Days per year dredge is in use
4	4	hrs/day	Dredge operating at 100%
14	14	hrs/day	Dredge operating at 75%
6	6	hrs/day	Dredge operating at 10%
Production			
1	1		Method of production estimation (1=CSDCEP, 2=USACE)
12	12		Digging depth (ft)
10	10		Discharge lift (ft)
40	40		Ladder length (ft)
1.025	1.025		Specific gravity of surrounding water
0.1	0.1		K for ball joints
1.6	1.6		K for head losses on the dredge
0.5	0.5		K for head losses at discharge
1.35	1.45		Maximum possible SG of slurry
1.2	1.2		Minimum allowable SG of slurry
5	5		Percent of total system head that must be greater than Hp-HL
1	1		Type of dredge (1=walking spud, 2=spud carriage)

Figure 5-4. CSDCEP Defaults Page.

Mobilization/Demobilization

This section includes typical values for calculations on the mobilization and demobilization page. Daily costs are listed here for supplies and small tools, support equipment (with operators), fuel, subsistence (per man), and tug boat cost. Other values listed here include towing speed, number of tugboats, and travel expenses (per person).

Execution

The execution section includes values used in the project execution calculations, including labor and equipment. Labor costs are the first values that may need to be changed, since taxes and benefits mandated by the government and unions change frequently. Some of the values used in the labor cost calculations include fringe benefits, overtime, holidays, vacation time, federal taxes, workers' compensation, and unemployment compensation. Equipment variables include hours per day the dredge works at 100 percent and days per year that the dredge is in use.

Production

Default values are given for use in the production estimation page. As with the other sections on this page, most of the values are self-explanatory, but some need further clarification. If a "1" is entered in the method of production estimation row, then the program uses its own production estimation algorithm, and if a "2" is entered, then the USACE method of production estimation is used. The minor loss coefficients (K) for certain parts of the dredge/pipeline system are entered. The maximum/minimum SG of slurry are entered to set the operating range of specific gravity for the dredging operation in question. The percent of total system head must be greater than the difference between the pump head and the pipeline loss head due to friction and minor losses. Finally, the type of dredge being used for the project is defined. If a walking spud dredge is to be used on the job, a "1" is entered here. For spud carriage dredges, a "2" should be entered. The vast majority of dredges currently in operation in the United States are walking spud dredges, so "1" is the default. The dredging efficiency value is 0.5 for a walking spud dredge and 0.9 for a spud carriage dredge.

MOBILIZATION/DEMOBILIZATION PAGE

Mobilization and demobilization costs are perhaps the most difficult to accurately estimate in a program of this type. The main problem lies in the fact that no two dredges have to travel the same distance to arrive at a job site. Also, different dredges are always in different stages of readiness to mobilize. For example, contractor A may be completing a project 10 mi away from the site being considered, while contractor B may have a dredge not in use 100 mi away. In this example, contractor A has less distance to travel to the job site but has more preparation to do before moving his operation. Also, contractor A's mobilization costs are basically included in the demobilization costs for the last project. Contractor B, however, has little preparation to do but must travel a greater distance. In this scenario, contractor A would likely have substantially less costs associated with mobilization, and would therefore give a lower bid price for the project. Many times the contractors are not compensated for demobilization costs and therefore do not include these costs in their bids. For this reason, an option is provided in the program to leave the demobilization costs out of the estimate.

The calculations shown on the mobilization/demobilization page (Figures 5-5 and 5-6) are based on the assumption that all dredges are not in use immediately prior to transfer to the job site. The main factors, therefore, in determining costs for this portion of the dredging project is the distance to and from the job site, the size of the dredge, and the length of pipeline used on the job. The page is broken down into five main sections: the mobilization and demobilization input parameters, the working rates for labor and equipment, standby rates for equipment, and the calculations.

Mobilization Input Parameters

The only manual inputs in this section are the distance to the job site, the number of crew needed for the tow to the site, and an input for any lump sums required by the site, such as cost of buoy placement, etc. The other parameters in this section are calculated based on size of dredge and length of pipeline. These calculations yield values for the length of time and number of crew required for the preparation and transfer of personnel, pipeline, and the dredge itself.

Demobilization Parameters

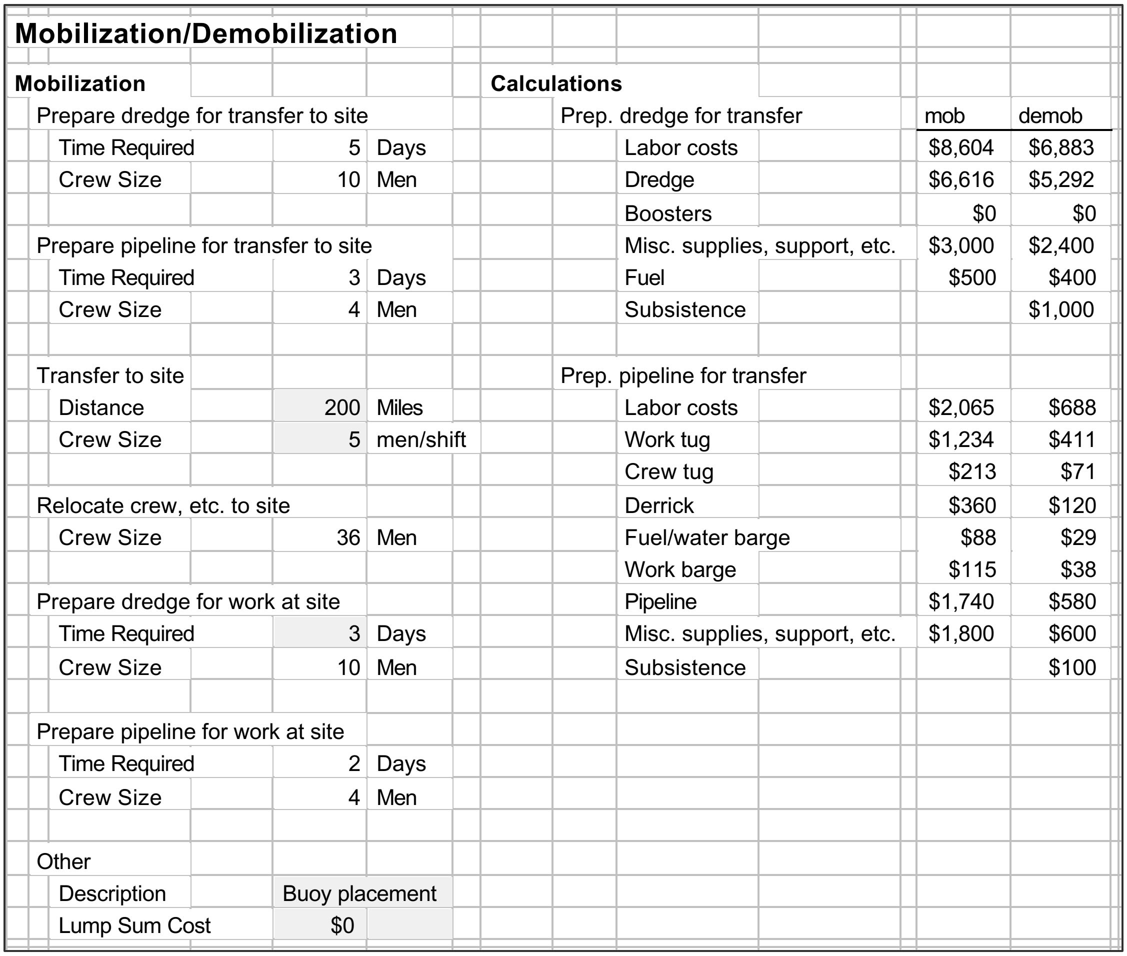
The distance of relocation and the lump sum value are the only manual entry values in this section. Other values are taken from the defaults page or calculated. These parameters describe only the length of time necessary for transfer and preparation for storage of the dredge and pipeline.

Working Rates

The cost per hour of the tugs and barges in operation as well as hourly labor rates are calculated here. The monthly working rates for the tugs and barges are taken from the database and divided by the hours operating time per month. The labor rates are calculated on the execution page.

Standby Rates

It also costs the contractor to have his equipment sitting idle while it could be earning money, so standby rates must also be taken into account. Once again, the values for the tugs and barges are taken from the database, this time with the addition of pipeline standby rates.



Mobilization/Demobilization

Mobilization		
Prepare dredge for transfer to site		
Time Required	5	Days
Crew Size	10	Men
Prepare pipeline for transfer to site		
Time Required	3	Days
Crew Size	4	Men
Transfer to site		
Distance	200	Miles
Crew Size	5	men/shift
Relocate crew, etc. to site		
Crew Size	36	Men
Prepare dredge for work at site		
Time Required	3	Days
Crew Size	10	Men
Prepare pipeline for work at site		
Time Required	2	Days
Crew Size	4	Men
Other		
Description	Buoy placement	
Lump Sum Cost	$0	

Calculations		
Prep. dredge for transfer	mob	demob
Labor costs	$8,604	$6,883
Dredge	$6,616	$5,292
Boosters	$0	$0
Misc. supplies, support, etc.	$3,000	$2,400
Fuel	$500	$400
Subsistence		$1,000
Prep. pipeline for transfer		
Labor costs	$2,065	$688
Work tug	$1,234	$411
Crew tug	$213	$71
Derrick	$360	$120
Fuel/water barge	$88	$29
Work barge	$115	$38
Pipeline	$1,740	$580
Misc. supplies, support, etc.	$1,800	$600
Subsistence		$100

Figure 5-5. Mobilization/Demobilization Page (Part 1).

Calculations

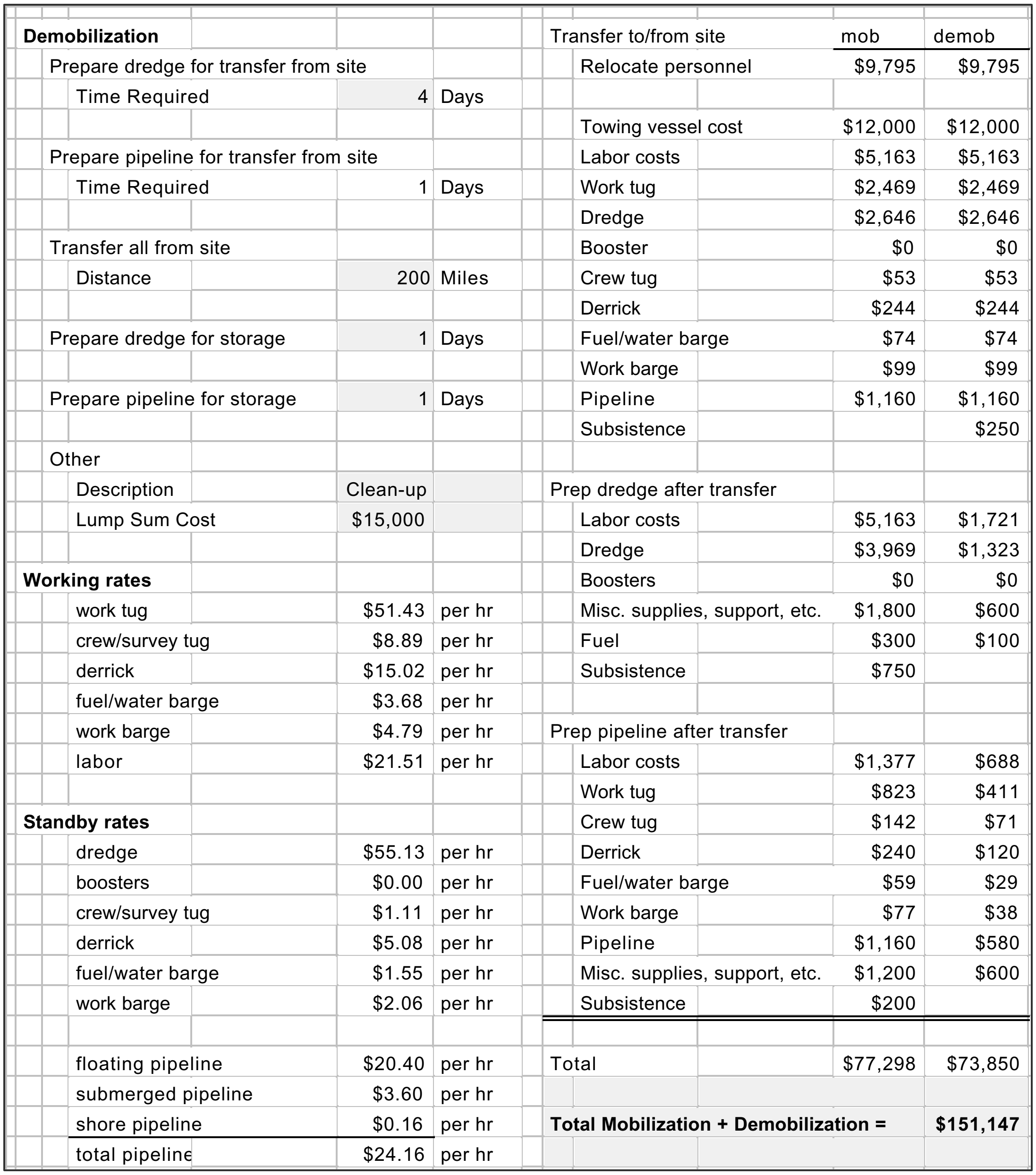
Costs are calculated for both mobilization and demobilization for each of the following sections.

Prepare Dredge for Transfer

Standby costs are calculated for the dredge and booster pumps. Also, labor costs, subsistence, fuel, and miscellaneous supplies are considered.

Prepare Pipeline for Transfer

Here the standby costs are calculated for the pipeline, as well as for the tugs and barges. The additional costs listed above are also calculated for this section.



Demobilization		
Prepare dredge for transfer from site		
Time Required	4	Days
Prepare pipeline for transfer from site		
Time Required	1	Days
Transfer all from site		
Distance	200	Miles
Prepare dredge for storage	1	Days
Prepare pipeline for storage	1	Days
Other		
Description	Clean-up	
Lump Sum Cost	$15,000	
Working rates		
work tug	$51.43	per hr
crew/survey tug	$8.89	per hr
derrick	$15.02	per hr
fuel/water barge	$3.68	per hr
work barge	$4.79	per hr
labor	$21.51	per hr
Standby rates		
dredge	$55.13	per hr
boosters	$0.00	per hr
crew/survey tug	$1.11	per hr
derrick	$5.08	per hr
fuel/water barge	$1.55	per hr
work barge	$2.06	per hr
floating pipeline	$20.40	per hr
submerged pipeline	$3.60	per hr
shore pipeline	$0.16	per hr
total pipeline	$24.16	per hr

Transfer to/from site	mob	demob
Relocate personnel	$9,795	$9,795
Towing vessel cost	$12,000	$12,000
Labor costs	$5,163	$5,163
Work tug	$2,469	$2,469
Dredge	$2,646	$2,646
Booster	$0	$0
Crew tug	$53	$53
Derrick	$244	$244
Fuel/water barge	$74	$74
Work barge	$99	$99
Pipeline	$1,160	$1,160
Subsistence		$250
Prep dredge after transfer		
Labor costs	$5,163	$1,721
Dredge	$3,969	$1,323
Boosters	$0	$0
Misc. supplies, support, etc.	$1,800	$600
Fuel	$300	$100
Subsistence	$750	
Prep pipeline after transfer		
Labor costs	$1,377	$688
Work tug	$823	$411
Crew tug	$142	$71
Derrick	$240	$120
Fuel/water barge	$59	$29
Work barge	$77	$38
Pipeline	$1,160	$580
Misc. supplies, support, etc.	$1,200	$600
Subsistence	$200	
Total	$77,298	$73,850
Total Mobilization + Demobilization =		**$151,147**

Figure 5-6. Mobilization/Demobilization Page(Part 2).

Transfer to and from Site

The towing vessel, relocation of personnel, subsistence, and labor costs are calculated. In this section, working rates are used for the work tug, but for all other equipment standby rates are used.

Prepare Dredge after Transfer

For mobilization purposes, this section computes costs for preparation for work. For demobilization, this section computes costs for preparation for storage. Miscellaneous supplies, fuel, subsistence, and labor costs are calculated, as well as standby costs for the dredge and boosters.

Preparation of Pipeline after Transfer

For mobilization, this section yields the cost of laying the pipeline at the job site and preparing it for work. For demobilization, this cost is simply preparation for storage. The tugs and barges are once again considered, as well as the miscellaneous costs listed above.

Project Execution Page

The bulk of the calculations in the cost estimation program are carried out in the project execution page. With the possible exception of very small jobs, the project execution costs will far outweigh the mobilization and demobilization costs, and therefore the most attention to detail is focused on this page. There are four main components to the project execution page: the production calculations, the labor and crew costs, the equipment costs, and the pipeline costs.

Production Calculations

Possibly the most vital number used on this page is the production rate. This value determines how long it will take to complete the job, and therefore how long the contractor will have to operate his equipment and pay his workers. The user will have the option to choose between two production estimation methods. The recommended method is to use the value calculated by the program in the production estimation page. If it is desired, however, to obtain a “second opinion” on the production estimate, the option is available to make use of the production estimation routine as prescribed by the USACE (1988).

Corps of Engineers Production Estimation Method

This method is based on previous dredging experience that the Corps of Engineers has compiled on typical dredge production rates based on dredge size and pipeline length. The program calls for three values of pipeline lengths and their corresponding production rates from the database based on dredge size. A production rate is interpolated using the pipeline length entered on the main page. If the resulting production rate is insufficient for an efficient operation, a message lets the user know that another booster must be added. After adding a booster, the line lengths corresponding to the production rates are multiplied by a “booster factor” that is roughly equal to one + the number of boosters. This works on the principle that pumps in series simply add to the head of the system. Or, simply stated, the length that pumps in series can pump is equal to the sum of the lengths that each can pump individually. Thus, the production rates in the table remain the same, but the line lengths are multiplied by the booster factor. This process repeats until a suitable number of boosters are reached and a sufficient production rate is obtained.

Material Factor

Both the built-in production estimation program and the Corps method yield production rates for slurry composed entirely of clean sand with a median grain diameter of 0.4 mm. Since the characteristics of sediments vary widely and have a great influence on the actual production rates, the Corps has introduced the concept of a "material factor" to account for the difference (USACE, 1988). This factor takes into account different viscosities, grain sizes, and in situ consolidation to provide a description of relative ease of pumping. For instance, silt is easily excavated and, due to its tendency to remain in suspension, easily transported. On the other hand, compacted clay is difficult to excavate and, once excavated, is difficult to pump through the line due to its tendency to consolidate and create "clay balls." Since the sediment at a particular job site is seldom composed of a single type, the user is allowed to enter percentages of the whole of 10 different sediment types to create a composite material factor. This factor is then applied to the calculated production rate. Therefore the silt mentioned above has a factor of greater than one while the clay has a factor of less than one (medium-sized sand has a factor of one).

Other Factors

In order to calculate the bank factor, the ratio of the cutter diameter to the bank height entered in the main page must be determined. This value is then used in conjunction with Figure 2-6 in Chapter 2 to obtain the bank factor. Two cells are left open for additional factors to be entered manually. Typical factors that may be necessary depending on the job site conditions are wind and wave factors. All of these factors are then applied to the production rate to yield the final production rate estimate.

Labor and Crew Costs

A dredging operation requires the services of many different personnel. A typical project requires a number of crewmen and laborers, both salaried and hourly. For a typical job, there is one each of the following salaried workers: a captain, officer, chief engineer, and an office worker. Depending on the size of the dredge being used, the number of the following hourly paid workers varies: levermen, dredge mates, booster engineers, tug crew, equipment operators, welders, deckhands, electrical engineers, dump foremen, cooks, and winchmen. Data for the number of crew and their respective pay rates are taken from the database. Adjustments are then made to the wages using the values from the defaults page for fringe benefits, overtime pay, holidays, vacation time, taxes, and workers' compensation. The resulting total hourly rate is multiplied by the hours per day each crewmember works to obtain the total daily cost of labor. These adjustments are not made to the salaried workers.

Equipment Costs

After the labor and crew costs, the equipment costs are the largest part of the total project cost. The capital costs of the dredge, boosters, tugs, and barges are obtained from the database along with the number of each needed for the project. Bray, Bates, and Land (1997) provide the method for computing each of the following:

Routine Maintenance and Repairs

For all of the equipment listed above, it is recommended to multiply the capital value by 0.00014 to obtain the daily costs for minor repairs that can be completed while the dredge is operating.

Major Repairs

For the average daily cost of repairs requiring the dredge or any other piece of equipment to be shut down, it is recommended to use a value of 0.0003 times the capital value.

Insurance

Insurance is calculated by multiplying the capital cost by 0.025 and dividing by the average number of working days per year.

Fuel Cost

In order to calculate the fuel consumption, one must determine the effective hours per day that the dredge operates at 100 percent power. The defaults page provides the user with the option of entering the hours per day of the dredge operating at 100 percent power, 75 percent power, and 10 percent power. From these values the effective hours at 100 percent are determined. The fuel cost per day is then taken as the item's horsepower times the hours per day at 100 percent times fuel cost per gallon times 0.048079. This is another value recommended by Bray, Bates, and Land (1997).

Cost of Lubricants

It is suggested to use 0.1 times the fuel cost to obtain this value.

Depreciation

To calculate this value, the useful life of the piece of equipment in question must be known. These values are contained in the database and accessed here by the program. The depreciation is calculated as the capital cost divided by the useful life and the number of days per year in operation.

Pipeline Costs

The total capital cost of the pipeline is determined by multiplying the total number of pipe sections by the cost per section obtained from the database. The same methods used above are used to calculate depreciation and repair costs, keeping in mind that the useful life of a section of pipe is much shorter than the equipment items due to the constant abrasive wear of the material being pumped through it. The average pumping distance entered on the main page is used to determine the costs of the main pipe lengths. The remaining length of pipe suffers less wear and therefore has a longer useful life as well as needing fewer repairs than the main pipe length.

After the equipment and pipeline costs are determined, the overhead costs are then taken to be 0.09 times the total daily costs of equipment and pipeline. Several cells at the bottom of the page are left open where additional specific costs can be entered and added to the daily cost of execution. The time required to complete the project is calculated based on the production rate and the dredge operating hours per month. This value is then multiplied by the daily costs to obtain the total cost of execution.

Database Page

The database contains information about equipment and labor involved with typical dredging projects. This information was obtained from the U.S. Department of Labor and the USACE. All of the data is listed as a function of the dredge size, and as such can be easily accessed from the main program.

Equipment Database

The first part of this section contains the dredge production versus line length data. Data for the tugs, barges, and boosters follows this and includes the capital costs and, where applicable, the horsepower of the unit and the quantity needed. Pipeline data is also contained in this section. Pipe section length, capital cost, and useful life are listed here.

Working Rates and Standby Rates

This section contains values for the monthly working rates of the tugs and barges and hourly standby rates for the tugs, barges, and pipeline.

Labor Database

For all the crewmembers listed on the execution page, this section gives the number needed as well as the hourly rates or monthly salary, depending on position.

Charts

The bank factor, dredge capital cost, and time required to prepare the pipeline for mobilization are determined from the charts found on this database page. The bank factor chart was taken from Turner (1996), and the capital cost chart was taken from Bray, Bates, and Land (1997). The pipeline preparation chart is an intuitive formula that is put into chart form for use with this program.

Production Estimation Page

The production estimation routine combines the friction head loss theory (Wilson, 1997) with dimensionless pump characteristics curves described by Herbich (1992) to provide the results needed by the program.

Determination of Critical Velocity

As a grain of sediment travels through a pipeline, there is a certain velocity that the fluid around it must maintain in order to prevent the grain from falling to the bottom of the pipe and becoming stationary. If this velocity is not maintained, much of the sediment will settle and clog the pipeline. This condition is very undesirable, because it means shutting down the operation while the line is being unclogged. This "critical velocity" is a function of the specific gravity of the sediment, the grain size, and the diameter of the pipe. Wilson et al. (1997) has presented a convenient method of determining the critical velocity using a nomograph (Figure 2-3 in Chapter 2) that has been entered into the spreadsheet and yields the critical velocity based on an assumed specific gravity of 2.65 (quartz) and median grain diameter of 0.4 mm. Even though optimum pump efficiency and production rates occur at higher velocities, contractors tend to operate near this critical velocity, because the lower velocities inflict less wear on the pipes.

Determination of Head Losses

It is important to calculate the head losses for the system because this is how the maximum pumping distance for a particular pump is determined. The major component of the head losses of a system is the frictional head loss. There are also minor losses due to pipe joints and bends, but when you are dealing with thousands of feet of pipe, the frictional losses far outweigh the rest. Head losses due to friction are determined in the program by the procedure outlined by Wilson et al. (1997). The head losses per unit length (feet of head per feet of pipe) are given by

$$i_m = \frac{fV^2}{2gD} + 0.22(S_s - 1)V_{50}^{1.7} C_v V^{-1.7} \tag{5-1}$$

$$V_{50} = w\sqrt{\frac{8}{f}}\cosh\left[\frac{60d}{D}\right] \tag{5-2}$$

$$w = 0.9V_t + 2.7\left[\frac{(\rho_s - \rho_f)g\mu}{\rho_f{}^2}\right]^{\frac{1}{3}} \tag{5-3}$$

where i_m is the head loss due to friction per unit length, d is particle diameter, D is pipe inside diameter, ρ_s and ρ_f are density of solid and fluid respectively, V is mean velocity of mixture, f is the friction factor for water, g is acceleration due to gravity, μ is dynamic viscosity of fluid, S_s is specific gravity of solids, C_v is the delivered concentration by volume, and V_t is particle terminal velocity.

Dimensionless Pump Characteristics Curves

In order to create a dredge production program that can be applied to any size dredge pump, Herbich's (1992) method of using dimensionless parameters in the pump characteristics curves is incorporated. A typical set of pump characteristics curves display the pump head, brake horsepower (or shaft horsepower), and pump efficiency as a function of discharge rate. In a dimensional format, these curves are only valid for a pump with the same specifications and operating at the same speed. However, when translated into a dimensionless format, the values of head (H), horsepower (P), and discharge (Q) may be calculated for any similar pump operating at any speed (Figure 2-4 in Chapter 2). Since efficiency (η) is a percentage, it is already dimensionless. The dimensionless values are determined by:

$$H_{\dim} = \frac{gH}{\omega^2 D^2} \qquad Q_{\dim} = \frac{Q}{\omega D^3} \qquad P_{\dim} = \frac{P}{\rho \omega^3 D^5} \tag{5-4}$$

where the subscript "dim" indicates a dimensionless quantity, g is the acceleration due to gravity, D is the impeller diameter, ω is the pump speed in radians per second, and ρ is the fluid density.

Transforming a number of dimensional curves from Georgia Iron Works and Mobile Pulley pump data and forming a composite set of dimensionless curves created the curves that are used in the program. With this set of dimensionless curves it is now possible to obtain the values of pump head, brake horsepower, discharge, and pump efficiency simply by entering any one of the values listed along with an impeller diameter and pump speed.

Determination of Production Rate

The production rate of a cutter suction dredge can be calculated using the following formula:

$$P(cy/hr) = Q(GPM) \times C_v \times 0.297 \times PF \times DE \tag{5-5}$$

where DE is dredge cycle efficiency (~.5 for a walking spud dredge), P is the production rate (cy/hr), C_v is maximum concentration by volume, PF the production factor that accounts for material differences, bank height and other factors, and 0.297 is a units conversion factor. In order to calculate the production using the above method, the specific gravity of the mixture, impeller diameter, pump speed, and discharge rate are needed.

Specific Gravity of the Mixture

This value is assumed to be 1.4 initially, but may become smaller if the friction head losses are too large at this value. It is desirable to pump at the highest possible specific gravity, because this means a greater concentration of solids by volume, which results in a higher production rate. This number will change incrementally down to a value of 1.2 in order to reduce head losses. It would be very inefficient to pump at a lower specific gravity than this, and a booster should be added at this point.

Impeller Diameter

The impeller diameter of the pump must be specified in order for the user to obtain the proper values, and contractors may change the impeller depending on the length of pipeline used on a job. It is common practice to use a smaller impeller for shorter line lengths, thus conserving horsepower, and larger impellers for longer pipe lengths, thereby maximizing pump head. In order to simplify the input for this program, a list of typical impeller diameters is incorporated into the program, with different diameters listed for each dredge size and pipe length. These values were obtained from pump specifications listed in various pump manufacturers' catalogues. The user need make no selection for this quantity because the program determines the appropriate impeller size.

Pump Speed

Each pump has its own most efficient operating speed, and this value does not vary nearly as much as the impeller size. The program accesses another table of typical values in order to obtain a suitable pump speed for its calculations.

Discharge Rate

The program varies the discharge rate in order to obtain the best possible operating conditions as the pump head decreases with increasing discharge rate. The first choice of discharge rate is about 20 percent higher than the discharge corresponding to the critical velocity. The pump head is then obtained from the dimensionless pump curves. If there is insufficient pump head to overcome the head losses, the chosen discharge velocity is incremented downward and the new pump head is determined. This process is repeated until either the pump head is found to be more than 5 percent greater than the head losses, or until the discharge corresponding to the critical velocity is reached. If the latter occurs, then the program prompts the user to add a booster to the system.

The addition of a booster increases the head of the total system by the amount of pump head achieved by the booster. The above process is then repeated for the new system configuration. Once an acceptable number of boosters has been selected, the pump efficiency is obtained from the curves and the production is calculated using Equation 5-5.

TESTING CSDCEP FOR ACCURACY

In order to determine the degree of accuracy that can be attained by using CSDCEP, a series of comparisons were made with other programs and actual data.

Comparison of Production Estimates

CSDCEP was tested against the USACE production estimation routine and Scott's (1997) "Cutpro" program. Production estimates were obtained for dredges with discharge lines in the range of 0.305 to 0.889 m (12 to 35 in) in diameter. The following parameters for the production estimates were held constant for each test:

- 100 percent sand of median grain diameter of 0.4 mm,
- bank height is 1.22 m (4 ft),
- sediment in situ specific gravity of 2.1, and
- walking spud dredge.

The estimates were made for each dredge with discharge line lengths of both 1,524 and 3,049 m (5,000 and 10,000 ft). The results of the comparison are displayed in Figures 5-7 and 5-8. It is apparent that the three methods of production estimation yield very similar results for the shorter pipeline, but for the longer pipeline there is more variation in the estimates. The large difference between the Cutpro estimates and the others can be attributed to the need for booster pumps at the longer length. Because Cutpro does not have an option to add a booster pump, it was difficult to correlate the results with the CSDCEP and USACE estimates. This limitation is no deficiency on the part of Cutpro, but simply a consequence of the fact that Cutpro is solely a production estimation program for a single pump system and requires detailed information about the pump in question. CSDCEP does not require specifics about a particular pump and is written with the knowledge that booster pumps are often necessary. The differences between the USACE and CSDCEP estimates can be explained by the introduction of boosters into the system. The large drop in production between the 16 in dredge and the 18 in dredge in the USACE estimates is caused by the fact that the booster pump was removed at this point. In order to consistently obtain accurate cost estimates, it is important to have an accurate production estimation program. Through comparison with other production estimation programs, it is evident that CSDCEP does indeed yield accurate production rates.

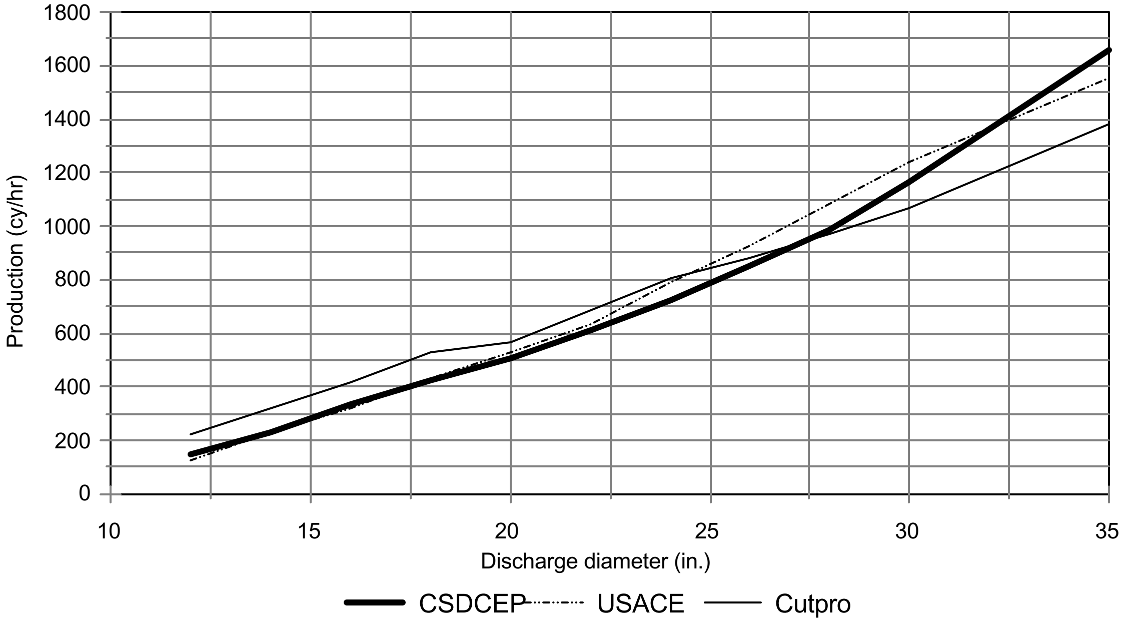


Figure 5-7. Comparison of Production Estimates, 5,000 ft Discharge Line.

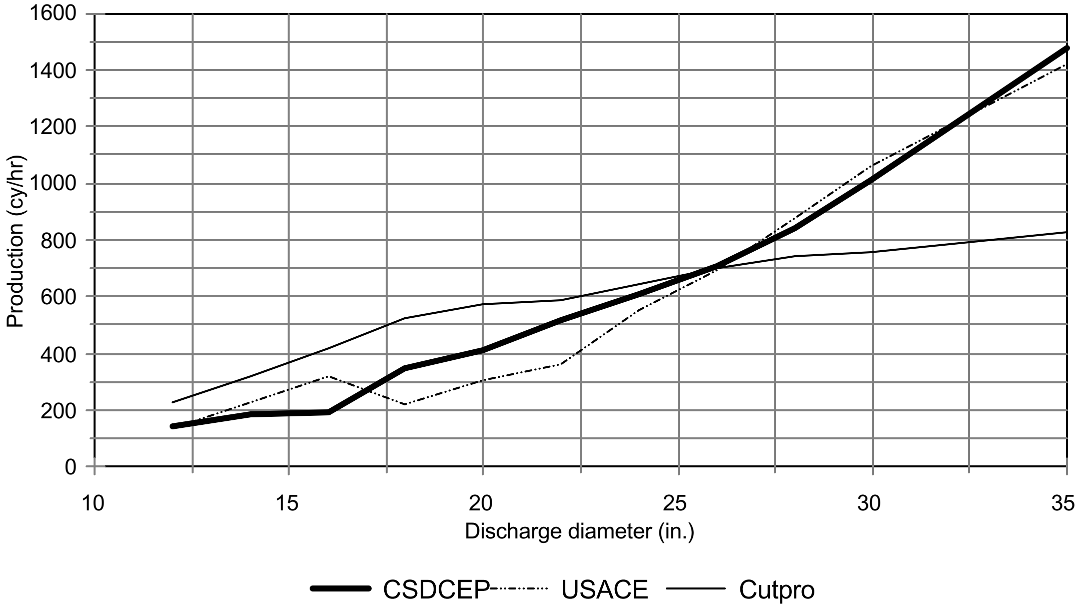


Figure 5-8. Comparison of Production Estimates, 10,000 ft Discharge Line.

COMPARISON OF COST ESTIMATES AND ACTUAL COSTS

In order to test the accuracy of the cost estimates yielded by CSDCEP, it was decided to test the results against cost data from previous dredging projects. Comparisons were made between CSDCEP and two sets of data: one from the Texas GIWW and one from the Great Lakes area.

Texas GIWW

Four dredging projects completed in the Texas GIWW, including data on bank height, sediment type, labor pay rates, discharge pipe length, and percent of floating, submerged, and shore pipeline used were provided by the Galveston District of the Corps of Engineers through the Texas Department of Transportation (TxDOT). Also provided was the government cost estimate, the winning bid, and the actual completion cost. The parameters of each project (Table 5-1) were used with CSDCEP, and the results are shown in Figure 5-9.

The average difference between the actual cost and the estimate given by CSDCEP is 47 percent. The error may seem large, but one must remember that CSDCEP is generalized and in most cases will not provide estimates that are as accurate as the contractors'. This trend is also seen in the large deviations between the actual costs and the government estimates, with the average difference even greater at 64 percent. CSDCEP yielded a more accurate cost estimate than the government's estimate in three of the four projects. The fourth project was unusual in that the dredging was conducted over a length of greater than 100 mi. The actual length of the dredging area is not considered in CSDCEP, and therefore the program predicts lower costs. One possible way to approach a scenario such as this would be to break the project down into several smaller projects, thus increasing the total costs of mobilization and demobilization. In situations such as this, it is left up to the estimator to adjust the cost given by CSDCEP to account for any job-specific factors that may change the actual cost.

Table 5-1. Texas GIWW Dredging Projects Used for Testing CSDCEP.

Project	Volume (cy)	Dredge Size (in)	Pipe Length (ft)	Bank Height (ft)	Sediment Properties
1	879,000	18	1,000	5.0	61% silt/mud 31.5% sand 5% clay 2.5% shell
2	150,000	24	4,500	2.5	35% silt/mud 60% sand 5% clay
3	3,100,000	20	2,600	6.5	80% silt/mud 10% sand 10% clay
4	826,637	20	2,400	2.5	85% silt/mud 11% sand 4% clay

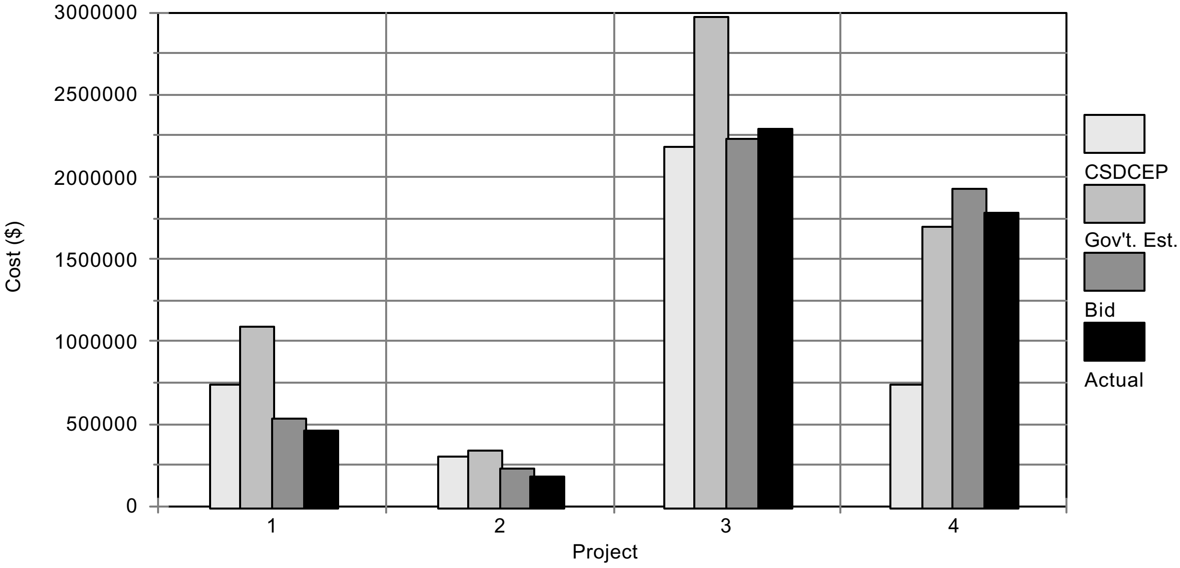


Figure 5-9. Comparison of CSDCEP Cost Estimating Results with Texas GIWW Dredging Projects.

Great Lakes

The USACE, Detroit District provided seventeen dredging projects completed in the Great Lakes area, including data on discharge pipe length. No data were available on the bank height, sediment types, or type of pipeline used, so estimates were made for these parameters. The data were entered into CSDCEP along with the educated guesses, and the results are compared with the actual costs in Figure 5-10. When considering the fact that many important items were left out of the data set, the results are surprisingly good. The average difference between the actual cost and the estimate is 19 percent.

In order to test the accuracy of the cost estimation software, data were obtained from the Corps of Engineers for some completed dredging projects in the Detroit District. These data were particularly useful for us because many project summaries included the distance to the disposal area. No data have been located for the GIWW that also includes these distances. From the current available database, 17 projects were selected for comparison based on similarity to projects on the GIWW. For this comparison, the Corps of Engineers' production estimation procedure was used, because the production routine is not completed yet. Figure 5-10 shows the results of the comparison. The results appear reasonable, with the smallest difference of around 2 percent, the largest at about 35 percent, and a standard deviation of about 10 percent. When considering the multitude of assumptions that must be made in determining a cost estimate, these numbers are reasonably accurate.

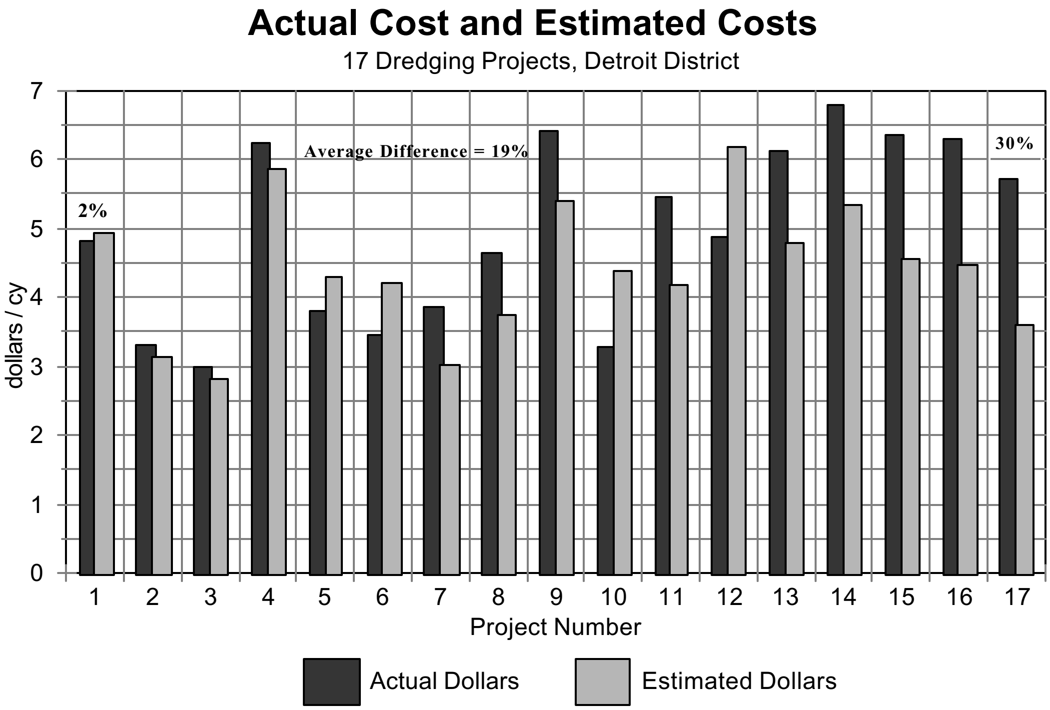


Figure 5-10. Comparison of CSDCEP Estimates with Actual Project Costs.

SENSITIVITY ANALYSIS

Example calculations were made and graphed using CSDCEP to show the effect of varying certain parameters while holding all others constant. In each example, four dredge sizes are displayed for the sake of comparison. The following parameters are held constant in each of the graphs except for the graph in which the particular value in question is varied:

- The volume of the material to be dredged is one million cubic yards.
- The discharge pipeline length is three thousand feet.
- The sediment is 100 percent medium grained (0.4 mm median grain diameter) loose sand.
- The bank height is 4 ft.

Figure 5-11 shows the effects of varying the bank height when all other parameters are held constant. As can be seen from the results, the bank height plays a significant role in the cost of the dredging project, due to the effect on the dredge production. These tests were run for a fairly large volume of sediment, and therefore the results indicate that the large dredges are more economical. However, with smaller volumes, the smaller dredges would become more economical than the large dredges as bank height decreased.

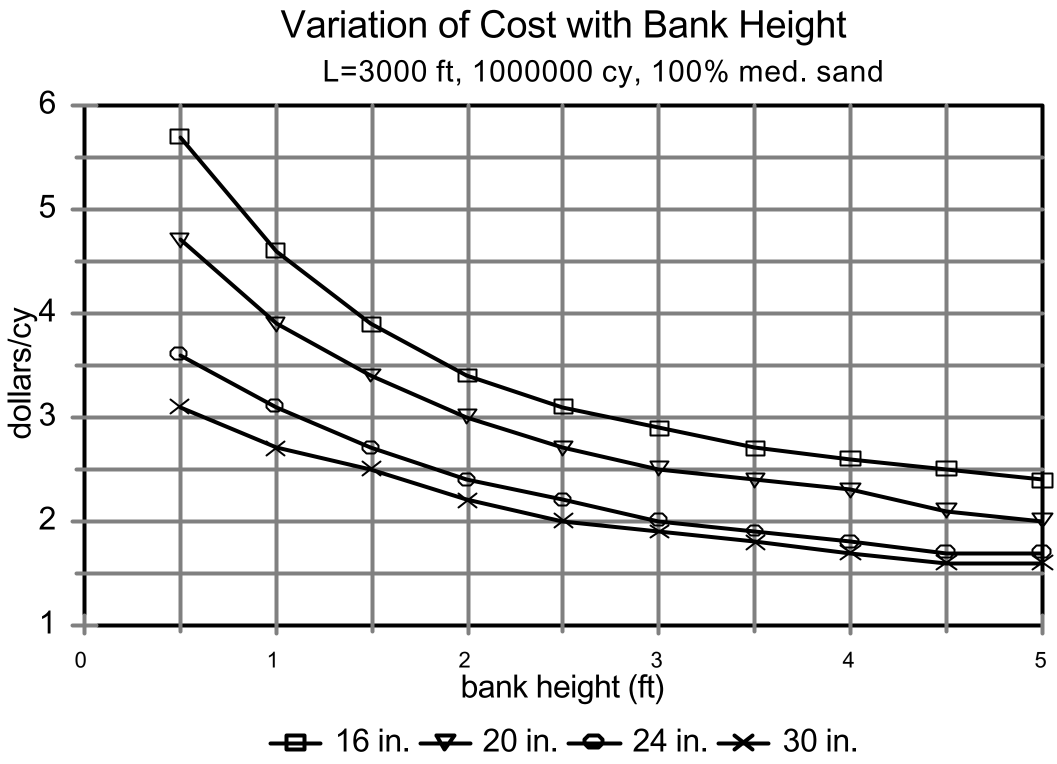


Figure 5-11. Variation of Cost with Bank Height.

Figure 5-12 shows the effects of varying the length of the discharge pipeline. As expected, the longer the pipeline is, the more the project will cost. From the graph it can be seen that for every mile of pipeline used, the price increases by about 1.8 dollars per cubic yard.

Figure 5-13 shows the effect on the cost of varying the volume to be dredged. The results displayed here are fairly intuitive, showing that it is cheaper to excavate large volumes of sediment using a larger dredge than a smaller one. One should note, however, that with smaller volumes, the smaller dredges become more economical. This trend can be seen developing in the graph.

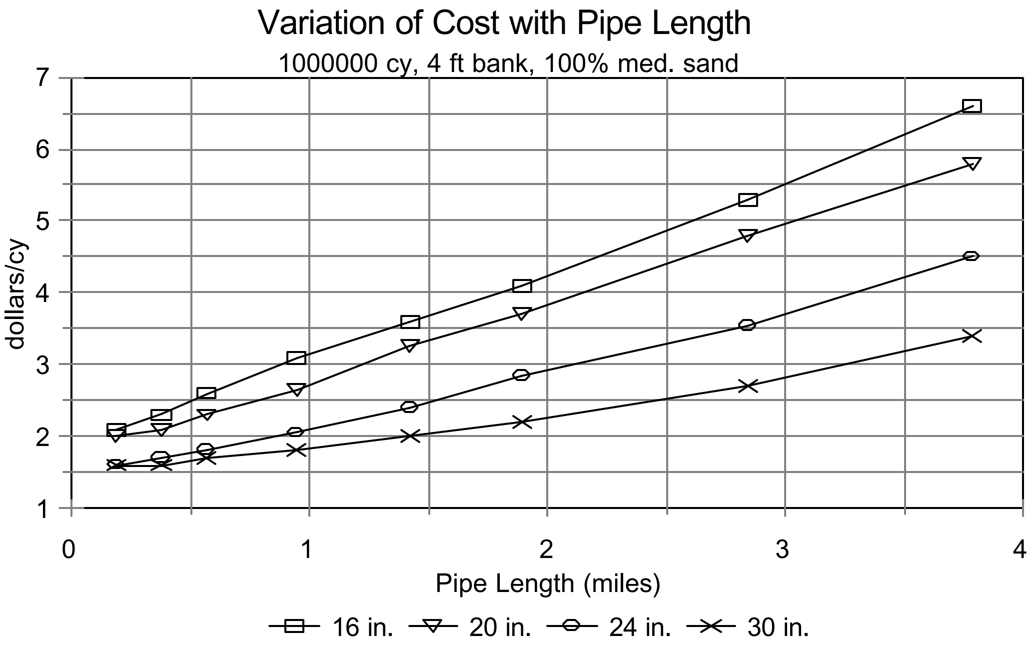


Figure 5-12. Variation of Cost with Discharge Line Length.

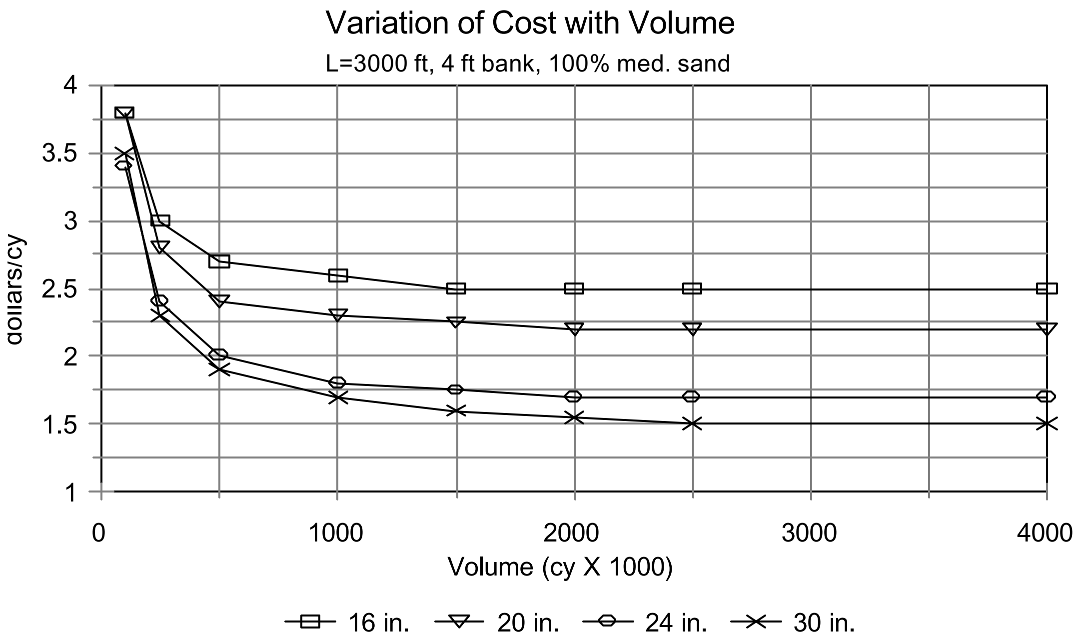


Figure 5-13. Variation of Cost with Volume of Dredged Material.

Figures 5-14 and 5-15 show the effect on the cost of pumping different types of sediment. Figure 5-14 shows the increasing cost of the operation as the amount of clay in the sediment increases. On the other hand, Figure 5-15 shows that the costs can be substantially lower if the material is mostly silt or mud. The smaller grain sizes of the silt and mud make it more easily suspended in water and easier to transport, thus reducing the costs. Clay, even though it has the smallest grain size of any sediment, is difficult to dredge because it is very cohesive and difficult to excavate, and once it is in the pipe, it has a tendency to ball up and roll along the bottom of the pipe.

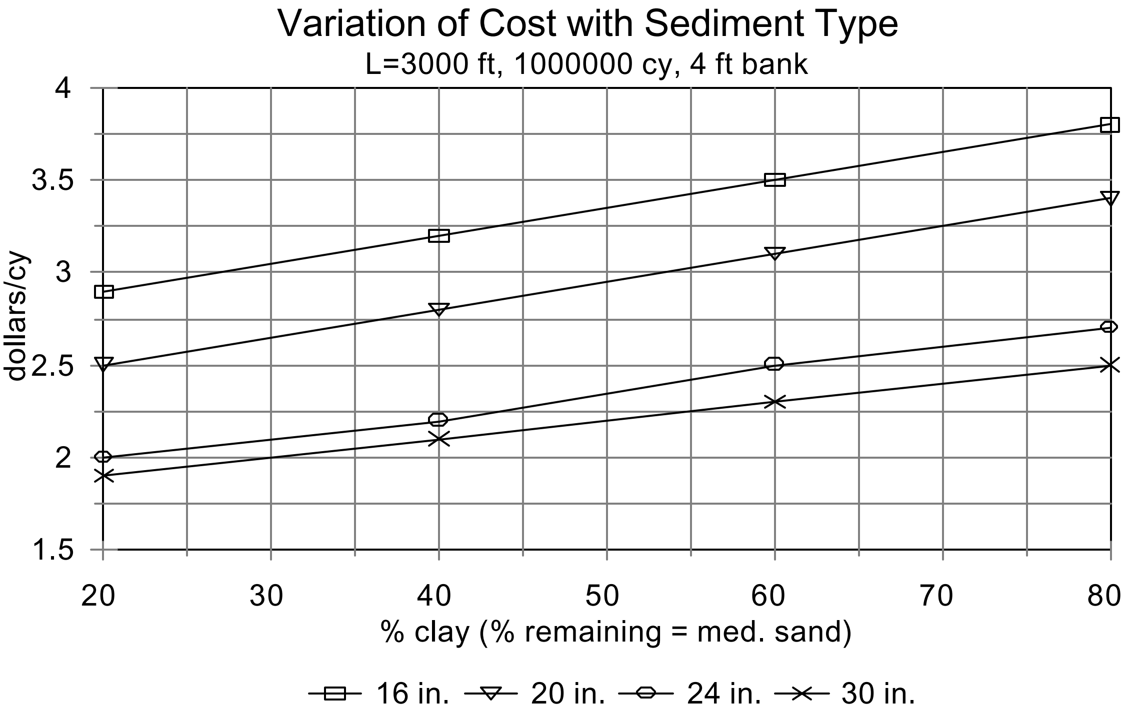


Figure 5-14. Variation of Cost with Percent Clay.

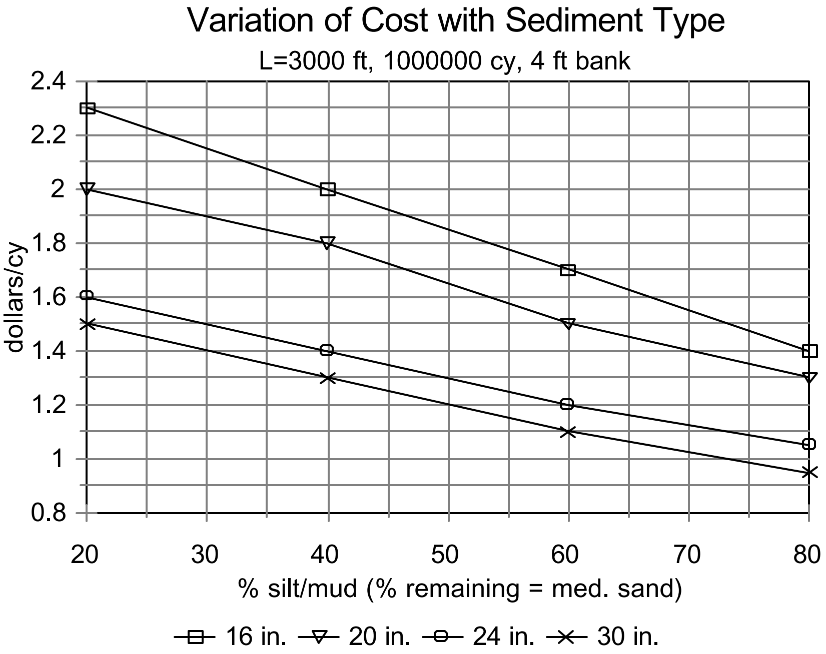


Figure 5-15. Variation of Cost with Percent Silt and Mud.

CONCLUSIONS AND RECOMMENDATIONS

The CSDCEP is a program that estimates the production rate of cutter head dredges and the cost of dredging projects using such dredges. The program is a non-proprietary cost estimation tool and is generalized so that estimates can be made for projects using any size dredge and any length of discharge pipeline. The theory used in the program is sound, and the practical components of the program are drawn from knowledgeable and experienced members of the dredging community. Based on the comparisons of production rates and project costs, it can be concluded that CSDCEP is an accurate and effective tool for estimating the production of a cutter suction dredge and the cost of dredging projects. The production estimation algorithm is the most important component of CSDCEP and therefore has the bulk of the theory and calculations associated with it. The Wilson et al. (1997) method of frictional head loss calculation is well respected in the dredging. This method is incorporated into CSDCEP and is used in conjunction with dimensionless pump characteristics curves as prescribed by Herbich (1992) to yield the production rate for any size dredge. The production rates are calculated for clean sand and then multiplied by the USACE (1988) material factor and Turner's (1996) bank factor. The production estimates given by CSDCEP were compared with other known production estimation routines. CSDCEP compared favorably with the other estimation methods and, though an option is provided in the program to use the USACE production estimate, it is recommended that the CSDCEP method be used.

The total amount of time required to complete the dredging project is calculated from the production rate, and this value is used to determine the costs of labor and equipment operation. Bray, Bates, and Land (1997) provide the bulk of the procedures used by CSDCEP to obtain these costs. The equipment capital costs and mobilization and demobilization costs are independent of the production rate and are calculated separately. These components also often contribute a significant amount to the final cost. The cost estimate results given by CSDCEP were compared with actual data and government cost estimates for several completed projects. The average difference between the estimate and the actual cost was 24 percent. This is a very reasonable figure considering the general nature of the CSDCEP program. In three of the four projects where a government estimate was provided, CSDCEP yielded a better estimate of the actual cost. The winning bidder was more accurate on all four, but this is to be expected due to the fact that more detailed information is known about the contractor’s particular equipment and methods.

The fact that CSDCEP is a generalized program means that it will not be quite as accurate as the estimates calculated by the individual dredging contractors. This is unavoidable due to the diverse nature of dredging contracts and equipment. Many of the inaccuracies can be minimized through careful attention by the user to all potential cost-impacting aspects of a particular project. When all the important factors are taken into account and the necessary adjustments are made to the cost estimate produced by CSDCEP, the end result should be an accurate approximation of the final cost.

CHAPTER 6 OPTIMUM SLURRY FLOW (TASK 5)

BACKGROUND

Sediment spread and turbidity that is related to open water placement of dredged material continues to be of concern for many dredging locations. It is desirable to increase mounding and decrease the suspended sediment concentration at the open water placement location. Parameters that affect mounding and turbidity include dredge size and efficiency, type of material, slurry density, discharge location (above water or below), and slurry exit velocity. The dredge size, relative depth of cut, swing speed, and digging depth affect the efficiency of the dredge. The objective is to determine the optimum dredge size to limit exit velocity and maximize slurry density while still operating as close to optimum dredge production as possible. The result is expected to help determine if there is an advantage in limiting dredge size and production to increase potential mounding and reduce turbidity at the disposal location.

INTRODUCTION

One of the most economical and convenient dredged material disposal methods is open water disposal. After the slurry is discharged into the ocean or bay waters, the dense sediment slurry falls to the seafloor in a diluted form. Hydraulic dredging entrains large volumes of ambient fluid and mixes it with the excavated sediment to form a slurry. The slurry is discharged from a pipeline as a jet and mixes with the surrounding water, and this mixing process is very effective for initial dilution of the sediment concentration.

For open water disposal using a pipeline discharge the dredged material enters the water body initially as a jet flow and then it becomes a plume as it falls to the bottom. A jet is the discharge of fluid from an orifice into a large water body of the same or similar fluid. A plume is a flow that looks like a jet, but is caused by a potential energy difference that provides the fluid with positive or negative buoyancy relative to its surroundings. For example, if the nozzle of a garden hose is held under water, then water from the hose is a jet. In the case of an open fire, the rising smoke is a plume. The prime difference is that the flow from the hose nozzle is driven by the momentum of the discharged water, whereas the smoke rising above the fire is driven by the air around the fire being warmed, and the smoke has a reduced density that causes it to rise.

For Texas Gulf Intracoastal Waterway (GIWW) dredging operations, the density of the discharged slurry flow is much larger than that of ambient ocean or bay water. Also, the slurry flow in the dredge pipe must be pumped at an average velocity that keeps the sediment suspended and does not allow the sediment to settle to the bottom of the dredge pipe. The velocity at which the sediment settles to the bottom of the dredge pipe is known as the critical velocity. Dredged material slurry discharges into the water environment are classed as a negatively buoyant jet that is driven by momentum and negative buoyancy. The initial flow is mostly driven by the momentum of the slurry exiting the pipe, but the effluent is denser than its surroundings and the resulting jet is forced downward by the negatively buoyant forces as illustrated in Figure 6-1.

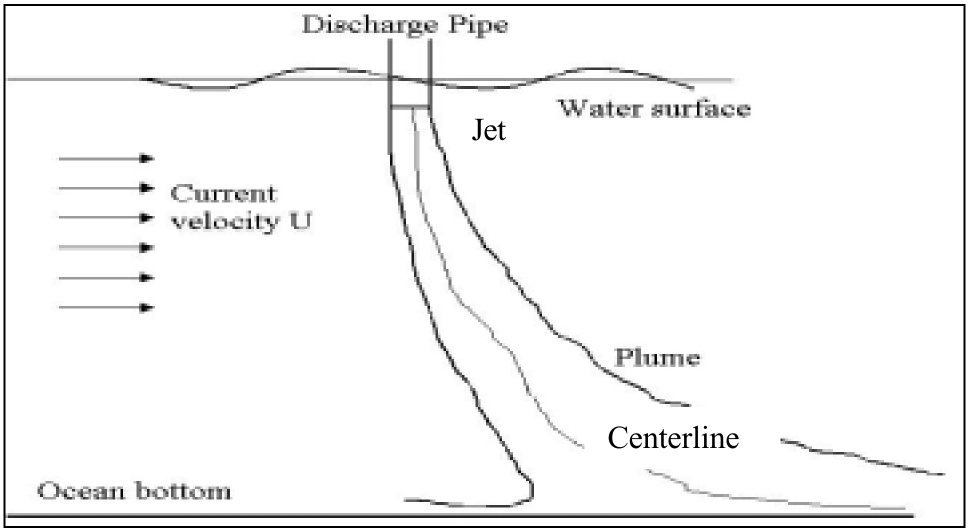


Figure 6-1. Schematic of a Negatively Buoyant Plume.

Near the source, the flow in a jet or plume is usually controlled entirely by the initial conditions that include the jet geometry, mean jet exit velocity, initial density difference between the discharge and ambient fluid, turbulence intensity, and velocity distribution in the supply pipe. Jet behavior depends on three classes of parameters:

(1) jet parameters,
(2) environmental parameters, and
(3) geometric factors.

The first class includes the initial jet velocity distribution and turbulence level, jet mass flow rate, jet momentum flux, and sediment flux. The environmental parameters include such ambient factors as turbulence levels, currents, and density stratification. These factors usually begin to influence jet behavior at some distance from the actual jet orifice. It is necessary to relate these parameters to the appropriate jet parameters in order to arrive at the actual distances at which the effects begin to be significant. The geometrical factors that enter into any jet analysis are the jet shape, orientation, solid boundary locations, and attitude of the jet with respect to boundaries or to the vertical. If the jet is submerged, then it is also necessary to know its relationship to any free surfaces.

The objective is to understand how each of the above factors modifies the dilution capability of a jet such as a slurry discharge from a dredge pipe. Since the environmental parameters such as water depth, ambient current, and density cannot be changed at a specific dredging location, then the effects on the dilution made by the jet parameters and geometric factors are the main factors considered.

One of the major environmental problems for open water disposal is the concern for adequate water quality in the disposal sites. Consequently, the dredging process must be conducted in such a way that the sediment dilution is as large as possible and the sediment can be deposited on the ocean or bay bottom as quickly as possible and over the smallest feasible area.

Dredging discharges are subject to federal and/or state regulations, and these regulations use the concept of a mixing zone. The mixing zone is a legally defined spatial area that allows for the initial mixing and dilution of a discharge. Legal criteria specify the mixing zone size and effluent concentrations that must be maintained outside and at the edge of the mixing zone.

The theory of buoyant jets and plumes presented is generally limited to simple geometry such as a single round discharge pipe and ambient conditions where currents are considered steady and uniform. In practice, the ocean or bay may be stratified in a nonlinear and dynamic manner, and the currents are usually neither steady nor uniform. No predictive capability yet exists that can accurately forecast the mixing of slurry discharges in the most general case. Fortunately, effective design can be made without such general tools. The Texas GIWW passes through several bays such as Galveston Bay, Matagorda Bay, Corpus Christi Bay, and the Laguna Madre. In the near field of the Texas GIWW, the water depth at the dredged material disposal sites is typically 3.05 m (10 ft) deep or less. The assumption of uniform density and steady and uniform current over the depth is reasonable because the ocean or bay water is quite shallow.

BASIC CONCEPT OF A JET AND PLUME

Simple Jet

It has been shown that an essentially Gaussian distribution of a tracer concentration (C), which is the sediment concentration in Texas GIWW dredging case, across the jet may be defined as

$$C = C_m \exp[-k(x/z)^2] \quad \textbf{(6-1)}$$

where the subscript "m" refers to the value of C on the jet axis, z is the vertical distance along the jet axis, x is the transverse (or radial) distance from the jet axis, and k is a first order decay coefficient. The mean velocity (V) distribution across a jet can be represented by a function of the form

$$V = V_m \exp[(-x/b_V)^2] \quad \textbf{(6-2)}$$

where the subscript "m" specifies the value of V on the jet centerline, x is the coordinate transverse to the jet axis, and b_V is the value of x at which V reduces to some specified fraction of V_m. Fischer et al. (1979) provides excellent description of mixing due to turbulent jets.

Simple Plume

The rate of decrease of the time-averaged maximum tracer concentration, C_m , in a buoyancy-driven discharge can be found in the same way as for a jet. If Y is the mass flux or equivalent mass flux of sediment, then C_m/Y has dimensions of time/length^3 and is specified by the buoyancy flux (B) and the distance (z) from the source. From this dimensional argument,

$$C_m / Y = b_4 / B^{1/3} z^{5/3} \qquad \textbf{(6-3)}$$

where b_4 is an empirical constant that is found to have a typical value of 9.1.

Buoyant Jet

The jet-like characteristics of a buoyant jet depend on its initial volume and momentum flux (M). Far enough from the source, the plume characteristics always dominate, which means a buoyant jet always turns into a plume if given enough free distance. For a round jet, the relationship between the buoyancy and momentum flux is

$$V_m \frac{M^{1/4}}{B^{1/2}} = f\left(\frac{zB^{1/2}}{M^{3/4}}\right) \qquad \textbf{(6-4)}$$

This equation can be simplified to the two cases that are written as

$$V_m \frac{M^{1/4}}{B^{1/2}} \approx c_1\left(\frac{M^{3/4}}{zB^{1/2}}\right) \quad \text{for} \quad z << \frac{M^{3/4}}{B^{1/2}} \qquad \textbf{(6-5)}$$

$$V_m \frac{M^{1/4}}{B^{1/2}} \approx c_2\left(\frac{M^{3/4}}{zB^{1/2}}\right)^{1/3} \quad \text{for} \quad z >> \frac{M^{3/4}}{B^{1/2}} \qquad \textbf{(6-6)}$$

where c_1 and c_2 are empirical constants.

CD-CORMIX EXPERT SYSTEM FOR CONTINUOUS DREDGE DISPOSAL MIXING ZONE ANALYSIS

The CD-CORMIX model (Continuous Dredge CORMIX) is a modification of CORMIX (Akar et al., 1991) that is the model used for predicting the mixing characteristics of wastewater discharge along with information on any applicable legal requirements. This modification mainly includes the physical characteristics of continuous dredge disposal. CD-CORMIX is a rule-based expert system that can predict the dilution and mixing zone of a typical continuous dredge discharge operation. This software is included in the ADDAMS software developed by the U.S. Army Engineer Waterways Experiment Station (WES) that can be downloaded from their web site (http://www.wes.army.mil/el/elmodels/index.html). The name of the software has been changed from CD-CORMIX to CDFATE.

Several new theoretical developments were incorporated into CORMIX to reflect the hydrodynamics of dredged material disposal. Physical dynamics were incorporated in the methodology for predicting water column effects of dredged material disposal. In particular, CD-CORMIX represents the loss of negative buoyancy due to particle settling within the plume and allows for typical continuous dredge source characteristics of multiple size classes of sediment.

Sediment Settling Characteristics

As the discharge plume travels away from the disposal point, particles within the plume settle to the ocean bottom. Settling of these sediment particles from the plume to the bottom forms a "fluid mud" over time (hours to days) and consolidates to become bottom sediment. The removal of particles from the plume decreases the negative buoyancy of the plume as it travels away from the discharge point. The boundary interaction, buoyant spreading, and passive diffusion modules of CORMIX have been modified to reflect particle settling. The methodology separates the dredge disposal slurry into five sediment particle fractions, with separate settling characteristics for each size fraction. The development of the governing equations for the particle settling in the density current regions and general description of the flow classification system is based on the knowledge of the dynamics of sediment transportation.

The dynamics of the fluid mudflow are not addressed with CD-CORMIX. The fluid mud exhibits viscous creep flow behavior that is beyond the range of turbulent plume methodology. Only water column concentrations of suspended sediment and a dissolved constituent are given by CD-CORMIX because it is a fully turbulent Newtonian fluid model. However, the accretion rate of fluid mud formed by a particle size fraction can be determined from model output. The percent of the original mass flux for each particle size is given as a function of the distance from the source. Most dredge discharge operations are intermittent, so the discharge site is usually relocated within a matter of hours or less. Therefore, an estimate of the depth of fluid mud can be calculated for each discharge location and time period before the source has been relocated.

Bottom Slope

CD-CORMIX models the effect of the bottom slope on the negatively buoyant plume behavior after bottom contact. This modeling is important for predicting density current behavior such as upstream intrusion and buoyant spreading in offshore coastal areas. Also, the interaction of the bottom slope and ambient density stratification on plume behavior is considered in CD-CORMIX.

Ambient Conditions

In CD-CORMIX, users model the layers of ambient arbitrary stable density profile with as many as three density layers for typical ambient coastal conditions. Hydrodynamic modules account for this as well as for the effect of density stratification on density current plume behavior after bottom interaction. Basic assumptions include:

(1) uniform channel section in downstream direction,

(2) uniform ambient current field: $U_a = \text{constant}$,

(3) positive ambient near shore slope (S1) with break to slope (S2) if there is a slope change,

(4) bounded laterally on one side only (allows for surface near-shore negative buoyancy discharge, far-shore is not important dynamically), and

(5) up to three layers of ambient density with arbitrary stable profile.

The assumptions related to the discharge conditions include:

(1) submerged pipe without deflector plate

$$\frac{D}{2}\sin\theta \le h_0 \le \frac{H}{2}$$

$$\text{for} \quad -90^0 \le \theta_0 \le 0^0$$

where D = diameter of a round discharge pipe
H = ambient water depth
h_0 = depth of discharge pipe below the water surface
θ = angle of discharge pipe with respect to the vertical

(2) submerged pipe with a deflector plate perpendicular to flow

(3) above surface pipeline disposal
- horizontal near-surface pipe without deflector plate,
- horizontal near-surface pipe with deflector plate, and
- upward sprayed discharge with or without deflector plate.

Discharge Properties

sediment characteristics are described using a cumulative distribution function (CDF), and the discharge is continuous. The clear water density (ρ_0) at dredging depth is specified, and the total solids concentration in dredge pipeline is expressed in grams per liter (g/L). The dissolved constituent (pollutant) concentration with decay is input. Additional properties input includes five particle sizes:

(1) large, non-suspended solids,
(2) sand fraction (> 0.062 mm),
(3) course silt fraction (0.031 mm – 0.062 mm),
(4) fine silt fraction (0.0039 mm – 0.031 mm), and
(5) clay fraction (< 0.0039 mm).

Program Output

The CD-CORMIX hydrodynamic simulation program creates a results file after CD-CORMIX is run. Three tables are printed in each output file.

> Table 1: Plume shape, trajectory, constituents, and constituent dilution in the water column are calculated for the near-field mixing region, the boundary layer/upstream spreading region, and the buoyant ambient spreading region along a flat bottom.
>
> Table 2: Plume suspended sediment distribution; the water column total solids concentration and particle size solids concentrations versus trajectory.
>
> Table 3: Sediment mass flux remaining and the percent of discharge mass flux remaining for each particle size fraction versus trajectory.

DREDGE DISPOSAL COMPUTATION EXAMPLE

Discharge Velocity Region

As shown in Chapter 2 (Figure 2-2), four regimes of solids-water mixtures exist for flow in a pipeline for a given mixture composition and pipe diameter. These flow regimes are homogeneous suspension, heterogeneous flow with all solids in suspension, flow with a moving bed and saltation (with or without suspension), and flow with a stationary bed. These regimes overlap and no distinct boundaries exist. In the heterogeneous flow, the particles are all in suspension, but the vertical distribution is not uniform with the concentration of particles greater near the bottom. This is the most economical regime for transport of solids in pipes. Homogeneous flow exhibits uniform distribution of sediment, but excessive power requirements are necessary. In flow with a moving bed, segregated distribution of sediment is present with the bed moving at a lower velocity than material above, and excessive power is required to transport the material. In these computation examples, it is assumed that all the dredging operations operate in such a way that sediment transport is in the heterogeneous regime, so that the dredging operation is in the most economical range.

The velocity ranges for heterogeneous flow depend on the different dredge sizes, sediment grain diameters, and the slurry densities. There are two velocities that are used as the transition velocities from the flow with a moving bed and saltation, to the heterogeneous flow. The first method uses the Wilson et al. (1997) nomographic chart (Figure 2-3 in Chapter 2) and the maximum velocity, V_{sm}, to determine the limit of stationary deposition. Another method is to use Equations 6-7 and 6-8 (Durand and Condolios, 1952) to determine the limit deposition velocity as the transition velocity between the heterogeneous flow to the flow with moving bed sediment.

$$F_L = 1.3C^{0.125}\left(1 - e^{-6.9\,d_{50}}\right) \tag{6-7}$$

$$V_c = F_L\left[2gD\left(SG_s - SG_f\right)\right]^{1/2} \tag{6-8}$$

where

F_L = coefficient based on the grain size and sediment concentration
V_c = transition velocity in ft/s
d_{50} = grain diameter in mm
C = sediment concentration by volume
D = pipe diameter in ft
SG_s = specific gravity of sediment particle
SG_f = specific gravity of the fluid
g = gravity acceleration (32.2 ft/s)

In this report, the two methods are used to calculate the transition velocities, but only the smaller value is used as the transitional velocity in this report, so that this computation can cover both cases.

The upper limit velocity for the heterogeneous flow regime is called the transition velocity that defines the boundary between the heterogeneous and pseudohomogeneous flow. The transition velocity is calculated using the relationship for the terminal velocity

$$V_t = \frac{134.14\left(d_{50} - 0.039\right)^{0.972}}{304.8} \tag{6-9}$$

and the transition velocity [V_{th}] is determined using

$$V_{th} = \left(1800\,g V_t D\right)^{1/3} \tag{6-10}$$

where
V_t = terminal velocity in ft/s
d_{50} = median grain size in mm
D = pipe diameter in ft
g = gravity acceleration (32.2 ft/s)
V_{th} = transition velocity in ft/s

Disposal Site Ambient Conditions

The selected characteristics of the ambient conditions for the disposal site used in the example computations are tabulated below:

- Typical water depth for a disposal site in the Texas GIWW is 3.05 m (10 ft).
- Specific gravity of the sea water is 1025 g/L and uniform throughout the water column.
- Ambient current velocity is 0.2 m/s (0.66 ft/s).
- Darcy-Weisbach friction factor is 0.05.
- The wind speed is 2 m/s (6.6 ft/s).
- The bottom is a single slope zone and the continuous slope is 1 (degree).

Discharge Types

The types of discharges used for the example computations are:

- 0.305 m (1 ft) submerged below water surface, offshore, discharged vertically downward,
- 0.305 m (1 ft) submerged below water surface, offshore, discharged horizontally in the same direction as the ambient current velocity,
- 0.305 m (1 ft) submerged below water surface, offshore, discharged horizontally in the opposite direction of the ambient current velocity,
- 0.305 m (1 ft) submerged below water surface, offshore, discharged 45 degrees downward in the same direction as the ambient current velocity,
- 0.305 m (1 ft) submerged below water surface, offshore, discharged 45 degrees downward in the opposite direction of the ambient current velocity,
- 0.305 m (1 ft) above water surface, offshore, discharged vertically downward,
- 0.305 m (1 ft) above water surface, offshore, discharged horizontally in the same direction as the ambient current velocity,
- 0.305 m (1 ft) above water surface, offshore, discharged horizontally in the opposite direction of the ambient current velocity,
- 1.5 m (5 ft) submerged below water surface, offshore, discharged vertically downward,
- 1.5 m (5 ft) submerged below water surface, offshore, discharged horizontally in the same direction as the ambient current velocity,
- 1.5 (5 ft) submerged below water surface, offshore, discharged horizontally in the opposite direction of the ambient current velocity,
- 0.305 m (1 ft) above the sea bottom, offshore, discharged horizontally in the same direction as the ambient current velocity, and

- 0.305 m (1 ft) above the sea bottom, offshore, discharged horizontally in the opposite direction of the ambient current velocity.

Slurry Sediment Data

The sediment data used in the example computations are summarized below:

- Median grain size d_{50} is 0.1 mm.
- Median grain size d_{50} is 0.4 mm.
- Median grain size d_{50} is 1.0 mm.
- Specific gravity SG_s of sediment is 2.65.
- Slurry sediment concentration C is 250 g/L by weight.
- Slurry sediment concentration C is 350 g/L by weight.
- The percentage of each component of the sediment in the slurry.

1)	Chunks 0%	Large, non-suspended solids (stones)
2)	Sand 15%	>0.062 mm
3)	Coarse silt 35%	0.016 mm – 0.062 mm
4)	Fine silt 45%	0.0033 mm– 0.016 mm
5)	Clay 5%	<0.0033 mm

Dredge Size and Discharge Velocity Range

Table 6-1 through Table 6-3 show the five different size dredges and the corresponding discharge velocity in the heterogeneous flow region. The velocities between the upper velocity limit (V_{th}) and lower velocity limit (V_c or V_{sm}) of the heterogeneous flow speed region are the values for which the mixing zone dilution analysis is conducted.

Computation Example Results

One computation case is demonstrated with the following:

Input Data

- Ambient velocity is 0.2 m/s (0.66 ft/s).
- Seawater density is 1025 g/L.
- Darcy-Weisbach friction factor is 0.05.
- The wind speed is 2 m/s (6.6 ft/s).

Table 6-1. Discharge Speed Range and Computation Values for d_{50}=0.1 mm.

Dredge size (in)	**DISCHARGE SPEED RANGE AND COMPUTATION POINT d_{50}=0.1 mm (ft/s)**							
	V_c or V_{sm} calculated	Arbitrary middle values						V_{th} calculated
8	4.50	5.00	5.50	6.00	7.00	8.00	9.00		10.40
12	4.92	5.50	6.00	7.00	8.00	9.00	10.00	11.00	11.90
16	5.15	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00
20	5.32	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.10
24	5.41	7.00	8.00	9.00	11.00	12.00	13.00	14.00	15.00

Table 6-2. Discharge Speed Range and Computation Values for d_{50}=0.4 mm.

Dredge size (in)	**DISCHARGE SPEED RANGE AND COMPUTATION POINT d_{50}=0.4 mm (ft/s)**							
	V_c or V_{sm} calculated	Arbitrary middle values							V_{th} calculated
8	9.50	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.50
12	11.80	13.00	14.00	15.00	16.00	18.00	19.00	20.00	21.10
16	13.80	15.00	16.00	18.00	19.00	20.00	21.00	22.00	23.30
20	15.10	16.00	17.00	18.00	20.00	22.00	23.00	24.00	25.10
24	16.40	17.00	18.00	19.00	20.00	22.00	24.00	25.00	26.60

Table 6-3. Discharge Speed Range and Computation Values for d_{50}=1 mm.

Dredge size (in)	**DISCHARGE SPEED RANGE AND COMPUTATION POINT d_{50}=1 mm (ft/s)**								
	V_c or V_{sm} calculated	Arbitrary middle values							V_{th} calculated
8	9.02	10.00	12.00	16.00	18.00	20.00	22.00	24.00		25.40
12	11.48	14.00	16.00	18.00	20.00	22.00	24.00	26.00	28.00	29.00
16	13.94	16.00	18.00	20.00	22.00	24.00	26.00	28.00	30.00	31.97
20	16.40	18.00	20.00	22.00	24.00	26.00	28.00	30.00	32.00	34.40
24	18.04	20.00	22.00	24.00	26.00	28.00	30.00	32.00	34.00	36.60

- The bottom is 1 degree single continuous slope.
- Water depth is 3.05 m (10 ft).
- 0.305 m (1 ft) submerged below water surface offshore vertically downward discharge.
- Slurry sediment median grain size d_{50} is 0.1 mm.
- Slurry sediment concentration C is 250 g/L by weight.
- Specific gravity SG_s of sediment is 2.65.
- The percentage of each component of the sediment in the slurry.
   1) Chunks 0% Large, non-suspended solids (stones)
   2) Sand 15% >0.062 mm
   3) Coarse silt 35% 0.016 mm – 0.062 mm
   4) Fine silt 45% 0.0033 mm – 0.016 mm
   5) Clay 5% <0.0033 mm
- Dredge discharge pipe diameter is 0.305 m (12 in).
- Discharge velocity is 5.5 m/s (18 ft/s).

Tabular Output of CD-CORMIX

In Table 6-4, the plume shape, trajectory, constituent concentrations, and constituent dilution in the water column are tabulated for the near-field mixing region, the boundary layer/upstream spreading region, and the buoyant ambient spreading region along a flat bottom.

Table 6-4. Jet/Plume Near-Field Mixing Region, Layer Boundary Impingement/Upstream Spreading and Bottom Density Current.

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X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the SURFACE and:
    1) directly above the port center for submerged discharges, OR
    2) at the point of entry into the water for above surface discharges:
       175.00 m from the LEFT bank/shore.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.

BEGIN CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION

Profile definitions:
   B = Gaussian 1/e (37%) half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

        X          Y         Z          S        C          B
       .00        .00      -.30       1.0   .212E+02     .15
       .04        .00     -1.59       1.0   .212E+02     .15
       .05        .00     -1.66       1.0   .212E+02     .16
       .05        .00     -1.71       1.0   .212E+02     .16
       .06        .00     -1.77       1.0   .212E+02     .17
       .06        .00     -1.83       1.0   .212E+02     .18
       .07        .00     -1.89       1.0   .204E+02     .18
       .07        .00     -1.95       1.1   .196E+02     .19
       .08        .00     -2.01       1.1   .189E+02     .20
       .08        .00     -2.07       1.2   .182E+02     .20
       .09        .00     -2.13       1.2   .176E+02     .21
       .09        .00     -2.19       1.2   .170E+02     .22
       .10        .00     -2.25       1.3   .165E+02     .22
       .10        .00     -2.31       1.3   .160E+02     .23
       .11        .00     -2.37       1.4   .155E+02     .24
       .11        .00     -2.43       1.4   .150E+02     .24
       .12        .00     -2.49       1.5   .145E+02     .25
       .13        .00     -2.54       1.5   .141E+02     .26
       .13        .00     -2.60       1.5   .137E+02     .26
       .14        .00     -2.66       1.6   .133E+02     .27
       .15        .00     -2.72       1.6   .130E+02     .28
       .15        .00     -2.78       1.7   .126E+02     .28

END OF CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
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Table 6-4. Jet/Plume Near-Field Mixing Region, Layer Boundary Impingement/Upstream Spreading and Bottom Density Current. Continued.

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BEGIN MOD132: LAYER BOUNDARY IMPINGEMENT/UPSTREAM SPREADING
Vertical angle of layer/boundary impingement    =     -83.56 deg
Horizontal angle of layer/boundary impingement  =        .00 deg

 UPSTREAM INTRUSION PROPERTIES:
        Upstream intrusion length               =      12.29 m
        X-position of upstream stagnation point =     -12.14 m
        Thickness in intrusion region           =        .18 m
        Half-width at downstream end            =      19.57 m
        Thickness at downstream end             =        .14 m

 Profile definitions:
   BV = top-hat thickness, measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

       X        Y       Z        S       C       BV        BH      ZU      ZL
    -12.14      .00   -3.05  9999.9  .000E+00    .00      .00   -3.05   -3.05
    -11.70      .00   -3.05     7.1  .300E+01    .04     2.77   -3.01   -3.05
     -9.54      .00   -3.05     2.9  .723E+01    .10     6.72   -2.95   -3.05
     -7.37      .00   -3.05     2.2  .956E+01    .13     9.10   -2.92   -3.05
     -5.21      .00   -3.05     1.9  .111E+02    .16    10.97   -2.90   -3.05
     -3.04      .00   -3.05     1.8  .121E+02    .17    12.56   -2.88   -3.05
      -.88      .00   -3.05     1.7  .126E+02    .18    13.98   -2.88   -3.05
      1.28      .00   -3.05     1.7  .122E+02    .18    15.26   -2.88   -3.05
      3.45      .00   -3.05     2.1  .101E+02    .17    16.45   -2.89   -3.05
      5.61      .00   -3.05     2.5  .844E+01    .15    17.55   -2.90   -3.05
      7.78      .00   -3.05     2.7  .772E+01    .15    18.59   -2.91   -3.05
      9.94      .00   -3.05     2.9  .743E+01    .14    19.57   -2.91   -3.05

END OF MOD132: LAYER BOUNDARY IMPINGEMENT/UPSTREAM SPREADING

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Table 6-4. Jet/Plume Near-Field Mixing Region, Layer Boundary Impingement/Upstream Spreading and Bottom Density Current. Continued.

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BEGIN MOD310: BOTTOM DENSITY CURRENT

Profile definitions:
   BV = top-hat thickness, measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

       X        Y       Z        S        C       BV       BH      ZU      ZL
     9.94      .00   -3.05      2.9  .743E+01    .14    19.57   -2.91   -3.05
    49.40    -1.81   -3.09     26.2  .808E+00    .73    33.94   -2.36   -3.09
    88.89    -2.15   -3.09     57.6  .368E+00   1.44    49.49   -1.65   -3.09
   128.40    -2.30   -3.09     96.3  .220E+00   1.62    64.84   -1.47   -3.09
   167.89    -2.37   -3.10    146.6  .145E+00   2.01    77.01   -1.08   -3.10
   207.39    -2.43   -3.10    206.2  .103E+00   2.44    87.91    -.65   -3.10
   246.88    -2.46   -3.10    274.2  .773E-01   2.89    98.02    -.21   -3.10
   286.39    -2.49   -3.10    349.9  .606E-01   3.34   107.56     .24   -3.10
   325.88    -2.51   -3.10    432.9  .490E-01   3.79   116.64     .69   -3.10
   365.39    -2.52   -3.10    522.9  .405E-01   4.25   125.35    1.15   -3.10
   404.88    -2.54   -3.10    619.5  .342E-01   4.70   133.75    1.61   -3.10
   444.39    -2.55   -3.10    722.6  .293E-01   5.16   141.87    2.06   -3.10
   483.88    -2.56   -3.10    831.8  .255E-01   5.62   149.76    2.52   -3.10
   523.39    -2.57   -3.10    947.2  .224E-01   6.08   157.43    2.98   -3.10
   562.88    -2.57   -3.10   1068.4  .198E-01   6.53   164.91    3.43   -3.10
   602.38    -2.58   -3.10   1195.4  .177E-01   6.99   172.22    3.89   -3.10
   641.87    -2.59   -3.10   1327.9  .160E-01   7.45   179.36    4.35   -3.10
   681.38    -2.59   -3.10   1466.0  .145E-01   7.91   186.37    4.81   -3.10
   720.87    -2.59   -3.10   1609.4  .132E-01   8.37   193.23    5.27   -3.10
   760.38    -2.60   -3.10   1758.1  .121E-01   8.83   199.98    5.73   -3.10
   799.87    -2.60   -3.10   1912.0  .111E-01   9.28   206.60    6.18   -3.10
 Cumulative travel time =        4114. sec

END OF MOD310: BOTTOM DENSITY CURRENT

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Table 6-5 presents the water column total solids concentration and particle size solids concentrations versus trajectory.

Table 6-5. Plume Suspended Sediment Distribution.

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PLUME SUSPENDED SEDIMENT DISTRIBUTION:

 CENTERLINE COORDINATES (m)      SEDIMENT CONCENTRATIONS   (g/l or kg/m^3)
       X        Y       Z         SAND    C.SILT    F.SILT     CLAY    TOTAL
       .00      .00    -.30      37.50     87.50    112.50     12.50    250.00
       .04      .00   -1.59      37.50     87.50    112.50     12.50    250.00
       .05      .00   -1.66      37.50     87.50    112.50     12.50    250.00
       .05      .00   -1.71      37.50     87.50    112.50     12.50    250.00
       .06      .00   -1.77      37.50     87.50    112.50     12.50    250.00
       .06      .00   -1.83      37.50     87.50    112.50     12.50    250.00
       .07      .00   -1.89      36.06     84.14    108.18     12.02    240.40
       .07      .00   -1.95      34.72     81.00    104.15     11.57    231.43
       .08      .00   -2.01      33.46     78.07    100.37     11.15    223.05
       .08      .00   -2.07      32.28     75.31     96.83     10.76    215.18
       .09      .00   -2.13      31.17     72.73     93.51     10.39    207.80
       .09      .00   -2.19      30.13     70.30     90.38     10.04    200.84
       .10      .00   -2.25      29.14     68.00     87.43      9.71    194.29
       .10      .00   -2.31      28.21     65.83     84.64      9.40    188.10
       .11      .00   -2.37      27.34     63.78     82.01      9.11    182.24
       .11      .00   -2.43      26.50     61.84     79.51      8.83    176.68
       .12      .00   -2.49      25.71     59.99     77.14      8.57    171.41
       .13      .00   -2.54      24.96     58.24     74.88      8.32    166.41
       .13      .00   -2.60      24.25     56.57     72.74      8.08    161.64
       .14      .00   -2.66      23.57     54.99     70.70      7.86    157.10
       .15      .00   -2.72      22.92     53.47     68.75      7.64    152.77
       .15      .00   -2.78      22.36     52.17     67.07      7.45    149.05
      1.28      .00   -3.05      19.04     51.47     66.35      7.37    144.24
      3.45      .00   -3.05        .00     29.93     50.87      5.76     86.56
      5.61      .00   -3.05        .00     23.01     47.62      5.46     76.09
      7.78      .00   -3.05        .00     17.41     45.12      5.25     67.77
      9.94      .00   -3.05        .00      9.57     41.26      4.96     55.78
     49.40    -1.81   -3.09        .00       .17      3.56       .47      4.21
     88.89    -2.15   -3.09        .00       .02      1.50       .22      1.73
    128.40    -2.30   -3.09        .00       .00       .84       .13       .98
    167.89    -2.37   -3.10        .00       .00       .53       .08       .61
    207.39    -2.43   -3.10        .00       .00       .36       .06       .42
    246.88    -2.46   -3.10        .00       .00       .26       .04       .31
    286.39    -2.49   -3.10        .00       .00       .20       .04       .24
    325.88    -2.51   -3.10        .00       .00       .16       .03       .19
    365.39    -2.52   -3.10        .00       .00       .13       .02       .15
    404.88    -2.54   -3.10        .00       .00       .11       .02       .13
    444.39    -2.55   -3.10        .00       .00       .09       .02       .11
    483.88    -2.56   -3.10        .00       .00       .08       .01       .09
    523.39    -2.57   -3.10        .00       .00       .07       .01       .08
    562.88    -2.57   -3.10        .00       .00       .06       .01       .07
    602.38    -2.58   -3.10        .00       .00       .05       .01       .06
    641.87    -2.59   -3.10        .00       .00       .05       .01       .06
    681.38    -2.59   -3.10        .00       .00       .04       .01       .05
    720.87    -2.59   -3.10        .00       .00       .04       .01       .04
    760.38    -2.60   -3.10        .00       .00       .03       .01       .04
    799.87    -2.60   -3.10        .00       .00       .03       .01       .04
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Table 6-6 presents the percent of discharge mass flux remaining for each particle size fraction versus trajectory.

Table 6-6. Sediment Mass Flux Remaining.

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  CENTERLINE COORDINATES (m)     SEDIMENT MASS FLUXES REMAINING      ( % )

         X         Y        Z        SAND    C.SILT    F.SILT      CLAY     TOTAL
       .00       .00     -.30      100.00    100.00    100.00    100.00    100.00
       .04       .00    -1.59      100.00    100.00    100.00    100.00    100.00
       .05       .00    -1.66      100.00    100.00    100.00    100.00    100.00
       .05       .00    -1.71      100.00    100.00    100.00    100.00    100.00
       .06       .00    -1.77      100.00    100.00    100.00    100.00    100.00
       .06       .00    -1.83      100.00    100.00    100.00    100.00    100.00
       .07       .00    -1.89      100.00    100.00    100.00    100.00    100.00
       .07       .00    -1.95      100.00    100.00    100.00    100.00    100.00
       .08       .00    -2.01      100.00    100.00    100.00    100.00    100.00
       .08       .00    -2.07      100.00    100.00    100.00    100.00    100.00
       .09       .00    -2.13      100.00    100.00    100.00    100.00    100.00
       .09       .00    -2.19      100.00    100.00    100.00    100.00    100.00
       .10       .00    -2.25      100.00    100.00    100.00    100.00    100.00
       .10       .00    -2.31      100.00    100.00    100.00    100.00    100.00
       .11       .00    -2.37      100.00    100.00    100.00    100.00    100.00
       .11       .00    -2.43      100.00    100.00    100.00    100.00    100.00
       .12       .00    -2.49      100.00    100.00    100.00    100.00    100.00
       .13       .00    -2.54      100.00    100.00    100.00    100.00    100.00
       .13       .00    -2.60      100.00    100.00    100.00    100.00    100.00
       .14       .00    -2.66      100.00    100.00    100.00    100.00    100.00
       .15       .00    -2.72      100.00    100.00    100.00    100.00    100.00
       .15       .00    -2.78      100.00    100.00    100.00    100.00    100.00
      1.28       .00    -3.05       86.09     99.71     99.98    100.00     97.80
      3.45       .00    -3.05         .00     74.24     98.15     99.94     75.15
      5.61       .00    -3.05         .00     60.16     96.86     99.89     69.64
      7.78       .00    -3.05         .00     47.33     95.42     99.84     64.49
      9.94       .00    -3.05         .00     27.51     92.22     99.73     56.12
     49.40     -1.81    -3.09         .00      5.17     83.04     99.37     44.15
     88.89     -2.15    -3.09         .00      1.44     76.63     99.10     39.94
    128.40     -2.30    -3.09         .00       .55     72.13     98.89     37.59
    167.89     -2.37    -3.10         .00       .26     68.83     98.74     36.00
    207.39     -2.43    -3.10         .00       .14     66.32     98.61     34.82
    246.88     -2.46    -3.10         .00       .09     64.31     98.51     33.90
    286.39     -2.49    -3.10         .00       .06     62.65     98.42     33.14
    325.88     -2.51    -3.10         .00       .04     61.25     98.35     32.49
    365.39     -2.52    -3.10         .00       .03     60.04     98.28     31.94
    404.88     -2.54    -3.10         .00       .02     58.97     98.22     31.46
    444.39     -2.55    -3.10         .00       .02     58.02     98.17     31.02
    483.88     -2.56    -3.10         .00       .01     57.17     98.12     30.64
    523.39     -2.57    -3.10         .00       .01     56.40     98.07     30.29
    562.88     -2.57    -3.10         .00       .01     55.69     98.03     29.96
    602.38     -2.58    -3.10         .00       .01     55.04     97.99     29.67
    641.87     -2.59    -3.10         .00       .01     54.44     97.95     29.40
    681.38     -2.59    -3.10         .00       .01     53.88     97.92     29.14
    720.87     -2.59    -3.10         .00       .00     53.36     97.89     28.91
    760.38     -2.60    -3.10         .00       .00     52.87     97.86     28.68
    799.87     -2.60    -3.10         .00       .00     52.41     97.83     28.48
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Computation Results Analysis

The computed data from Table 6-4 were used to create curves that show the discharged density slurry trajectory in the near-field region, the density current shapes in the boundary layer impingement, and the sea bottom density currents of the slurry. Figure 6-2 shows a comparison of three centerline sediment concentrations when a 30.5 cm (12 in) dredge is operated with the pipe outlet submerged 0.305 m (1 ft) below the water surface and the discharge is directed vertically downward at velocities of 1.83, 2.44, and 3.35 m/s (6, 8, and 11 ft/s), respectively. The concentration of sediment in the dredged slurry is 250 g/L for all three cases.

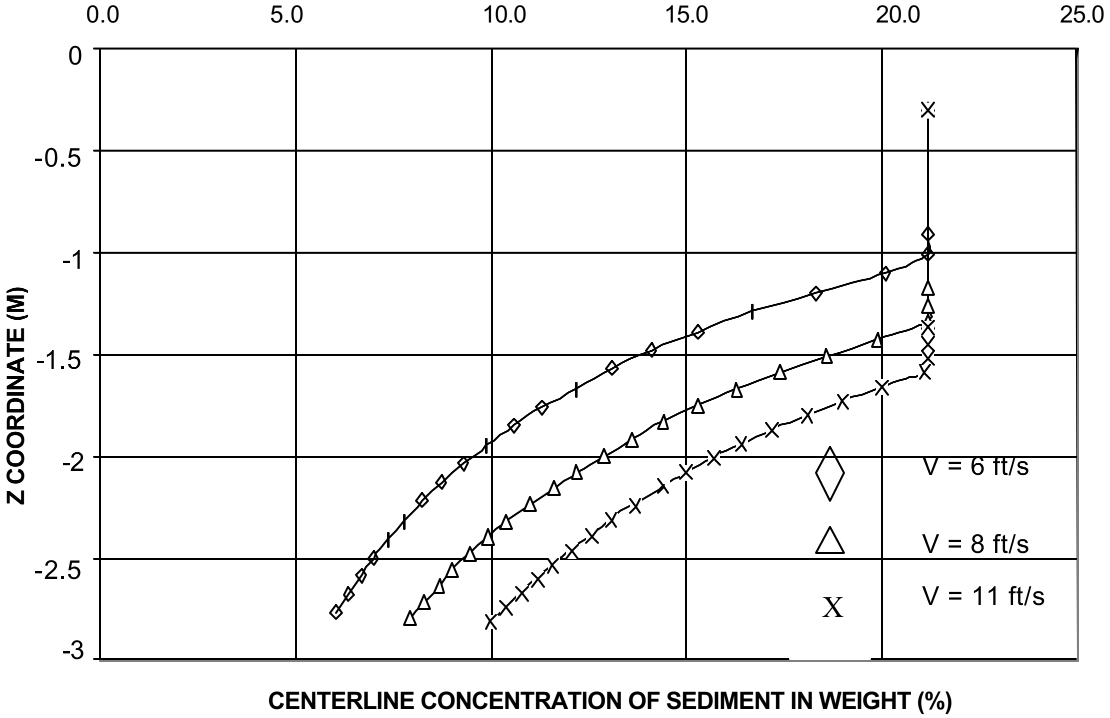

Figure 6-2. Jet/Plume Near-field Mixing Region for 1 ft Submerged Vertical Discharge (D = 12 in, C = 250 g/L, d50 = 0.1 mm).

In Figure 6-2, the centerline concentration of the plume can be used to show the vertical height of the plume sediment concentration corresponding to a desired or required concentration value. It shows that the lower discharge velocity results in the lowest bottom concentration. This result indicates that the discharge velocity closest to the critical velocity required to transport the sediment through the pipeline is the most desirable for minimizing turbidity in the water column.

Figure 6-3 and Figure 6-4 are used to estimate the area of the mixing zone. Figure 6-3 shows the plume extent upstream. For example, the lowest discharge velocity of 2.4 m/s (6 ft/s) extends 4 m (13.1 ft) upstream. If the maximum allowable concentration was 2 percent, then the upstream limit is 3.8, 5.4, and 6.4 m for the 1.8, 2.4, and 3.4 m/s (6, 8, and 11 ft/s) discharge velocities, respectively. The bottom density current data (Figure 6-4) shows the downstream distance of the plume concentration. If a 2 percent concentration was the required maximum then the downstream length is approximately 25, 30, and 40 m for the 6, 8, and 11 ft/s discharge velocities, respectively. After the permitted sediment concentration of a mixing zone is defined, then the distance from the discharge point to the boundary of the allowable sediment concentration can be found, and the area of the mixing zone can be determined for the specific dredge disposal operation.

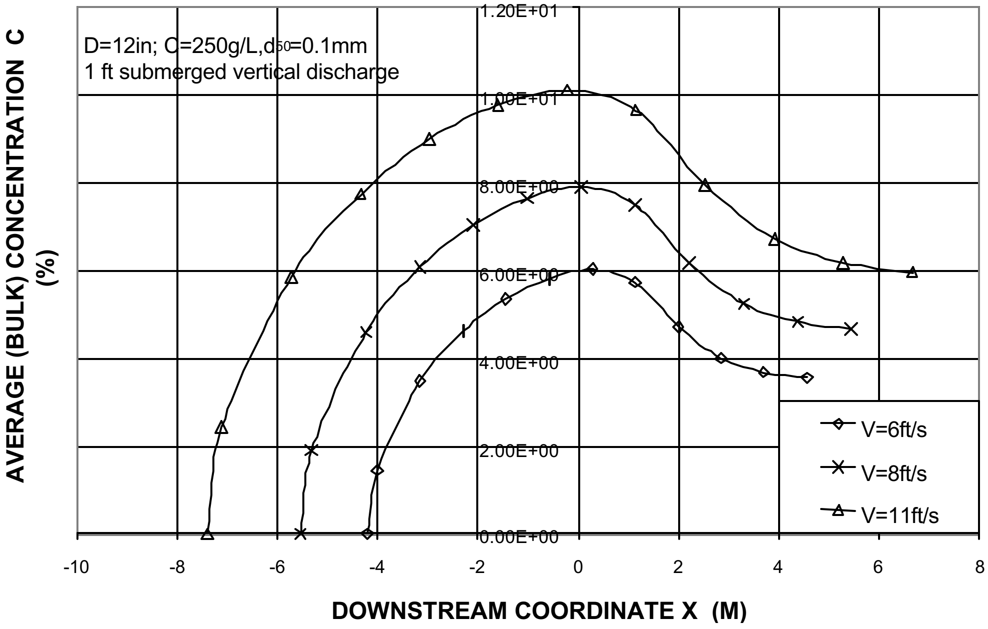

Figure 6-3. Layer Boundary Impingement/Upstream Spreading.

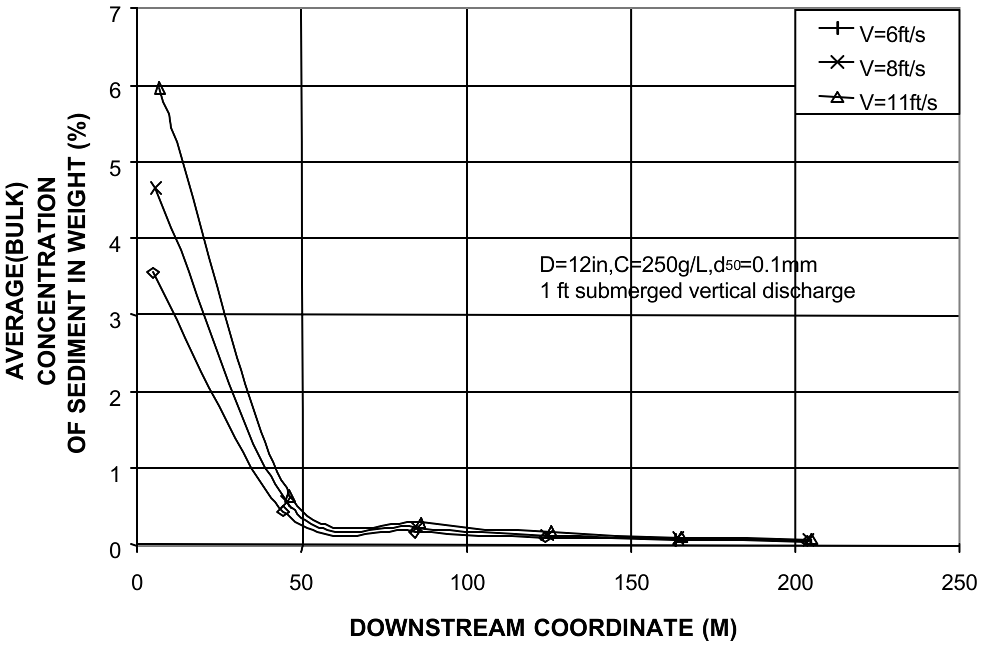

Figure 6-4. Bottom Density Current.

Figure 6-5 through Figure 6-7 are typical curves showing the change of the centerline sediment concentration after discharge for the same ambient conditions (d_{50}=0.1 mm, C=250 g/L), but different vertical locations (z = -1.0, -2.0, and –2.5 m) below the water surface. The values of the centerline sediment concentrations are shown for 20.3, 30.5, 40.6, and 50.8 cm (8, 12, 16, and 20 in) dredge sizes when the discharge velocity is changed from the upper velocity limit to the lower velocity limit of the heterogeneous flow velocity range as tabulated in Table 6-1. These results demonstrate that the lowest sediment concentration for a vertical discharge located 1 m (3.28 ft) below the water surface occurs for the 20.3 cm (8 in) dredge pipe at a velocity nearest the critical velocity. Recall that velocities below the critical velocity will not keep the dredged material suspended in the horizontal pipeline from the dredge to the discharge point. Also demonstrated is that the closer the discharge point is to the bottom, the smaller the sediment concentration.

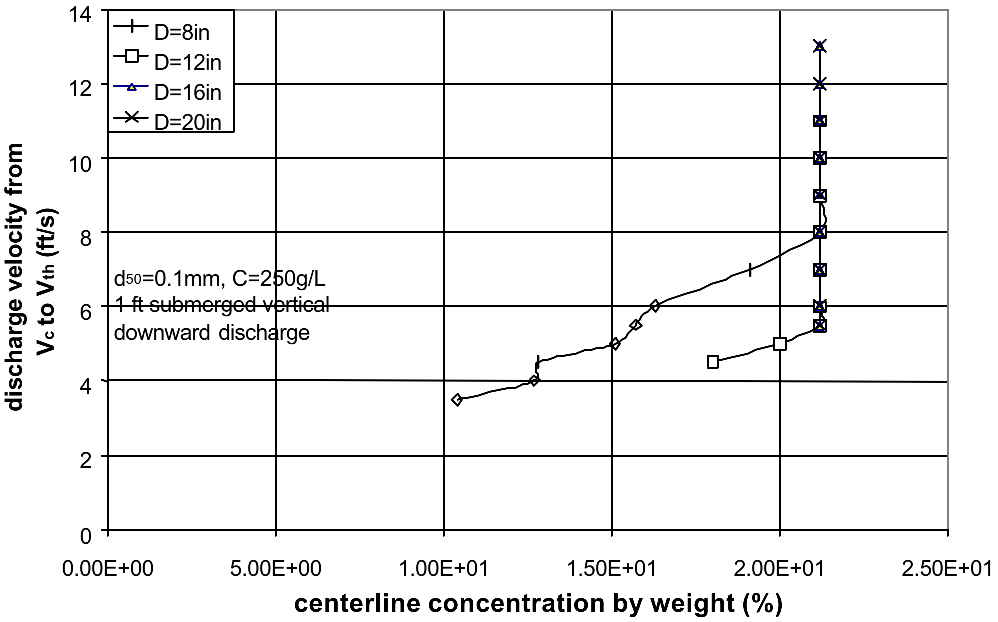

Figure 6-5. Centerline Concentration at Near-field Point of z = -1.0 m Versus Discharge Velocity.

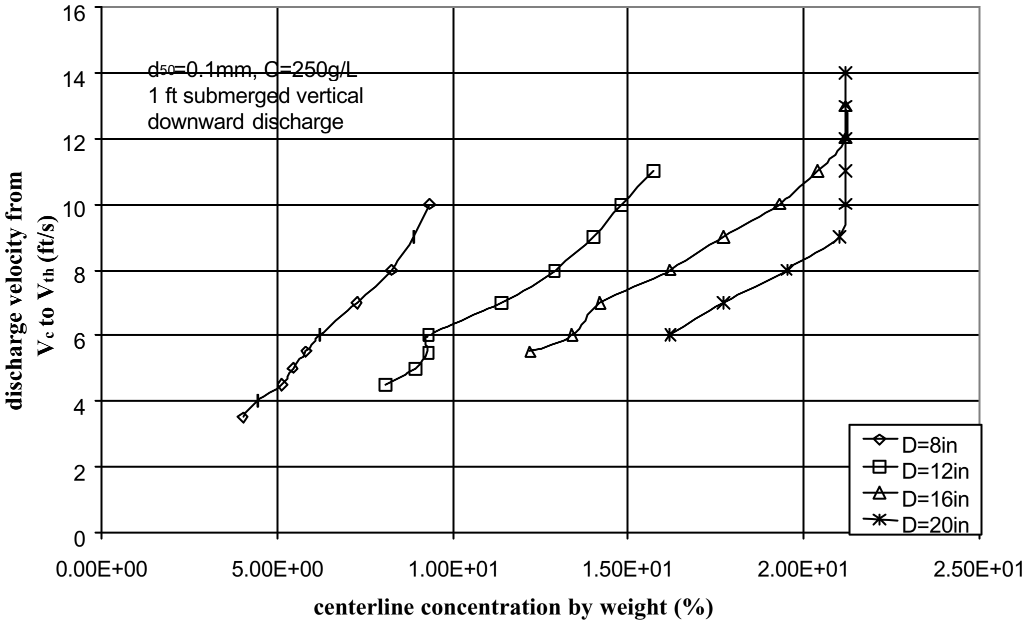

Figure 6-6. Centerline Concentration at Near-field Point of z = -2.0 m Versus Discharge Velocity.

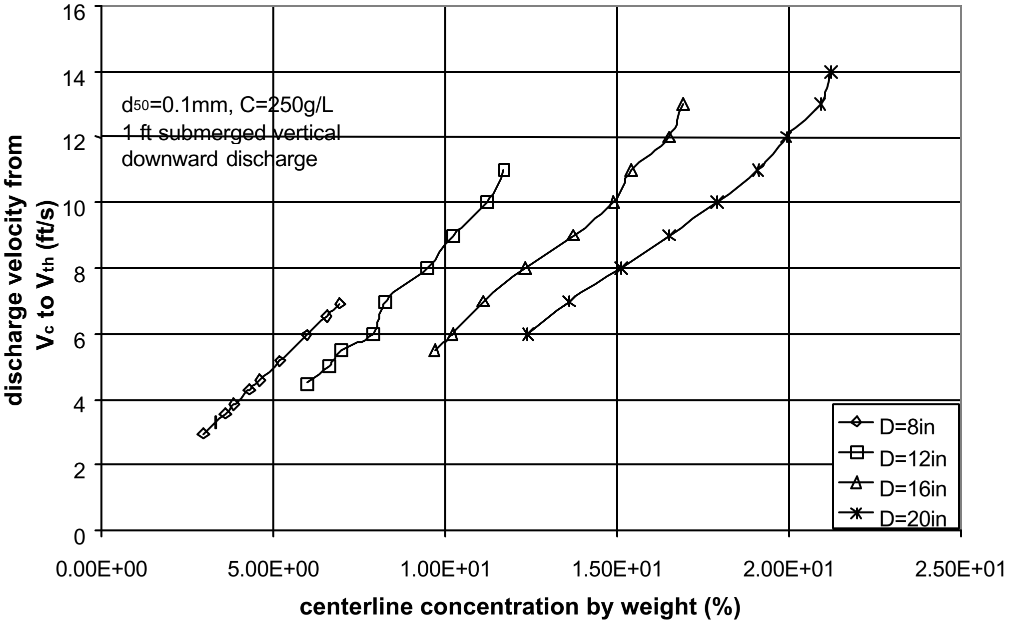

Figure 6-7. Centerline Concentration at Near-field Point of z = -2.5 m Versus Discharge Velocity.

Figure 6-8 through Figure 6-10 are typical curves showing the change of the centerline sediment concentration after discharge for a mean grain size (d_{50}) of 0.1 mm and a slurry concentration of 350 g/L, but at different vertical locations (z = -1.0, -2.0, and -2.5 m) below the water surface. The centerline sediment concentrations are shown for 20.3, 30.5, 40.6, and 50.8 cm (8, 12, 16, and 20 in) dredge sizes when the discharge velocity is changed from the upper velocity limit to the lower velocity limit of the heterogeneous flow speed. These results show the centerline concentration decreases with increasing depth and that the lowest concentrations occur for the 20.3 cm (8 in) dredge size at all discharge velocities within the range between the critical and threshold velocities. These trends are the same as those shown for the 250 g/L slurry concentration but the concentration values are slightly larger.

Figure 6-9, Figure 6-11, and Figure 6-12 show the effect of increasing the d_{50} grain size from 0.1 to 1 mm. The centerline concentration at a depth of -2.0 m for a slurry concentration of 250 g/L for a downward vertical discharge at 1 ft below the water surface indicates the lowest concentrations occur for the smaller mean grain size. The larger dredge sizes (20 and 24 in) show no dilution for the larger median grain sizes of 0.4 and 1 mm. The results show the centerline concentration is reduced by nearly one-half for the 20.3 cm (8 in) dredge size as compared to the larger 61 cm (24 in) dredge size. Thus, the dredge size has significant effect on the centerline concentration for vertically downward discharge and the least concentration occurs for the smaller 20.3 cm (8 in) dredge size.

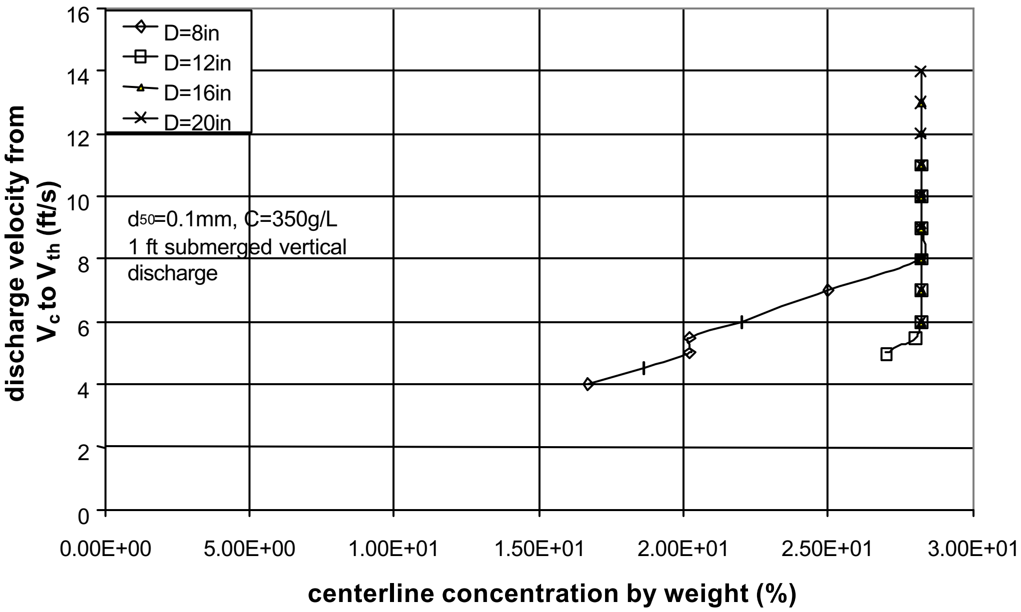

Figure 6-8. Centerline Concentration at Near-field Point of z = -1.0 m Versus Discharge Velocity.

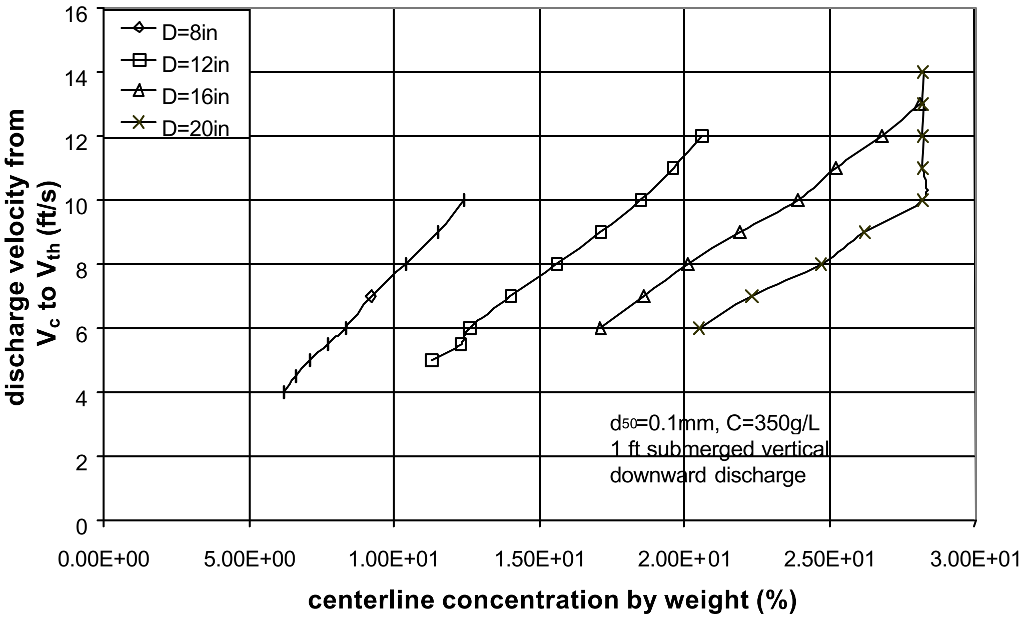

Figure 6-9. Centerline Concentration at Near-field Point of z = -2.0 m Versus Discharge Velocity.

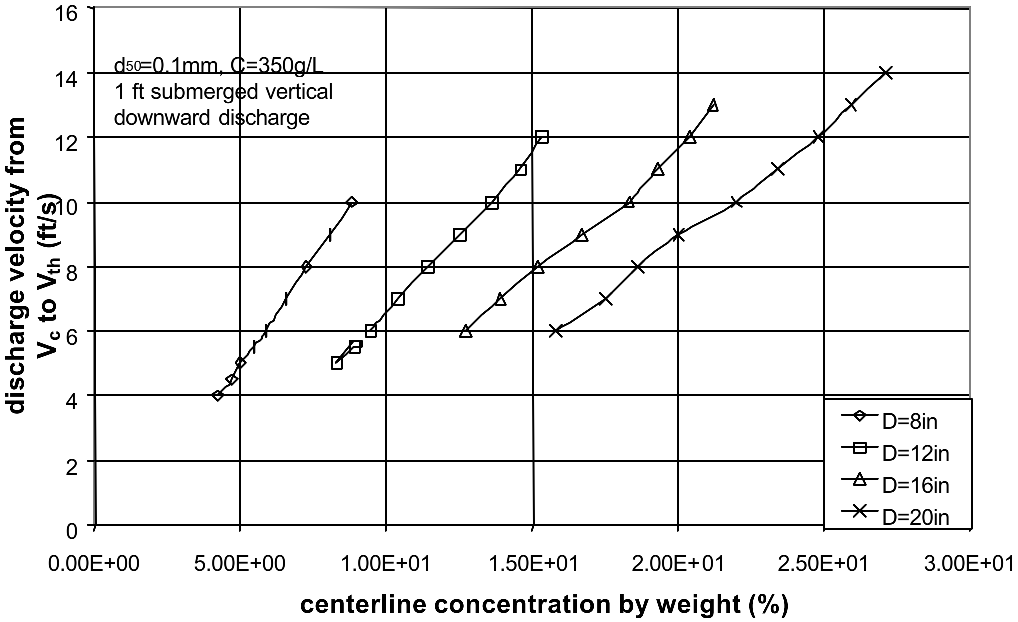

Figure 6-10. Centerline Concentration at Near-field Point of z = -2.5 m Versus Discharge Velocity.

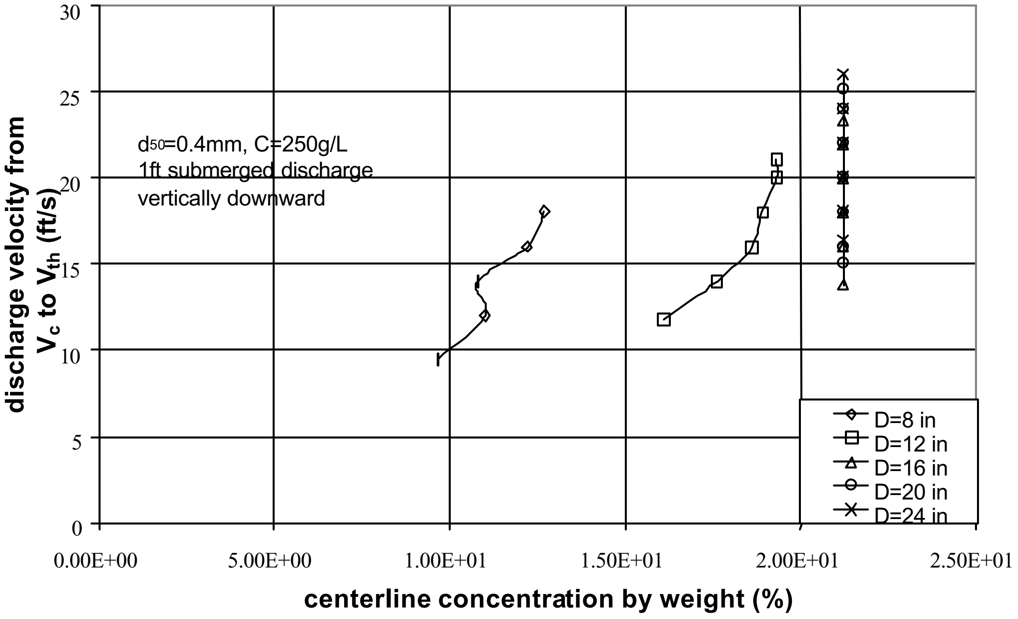

Figure 6-11. Centerline Concentration at Near-field Point of z = -2.0 m Versus Discharge Velocity.

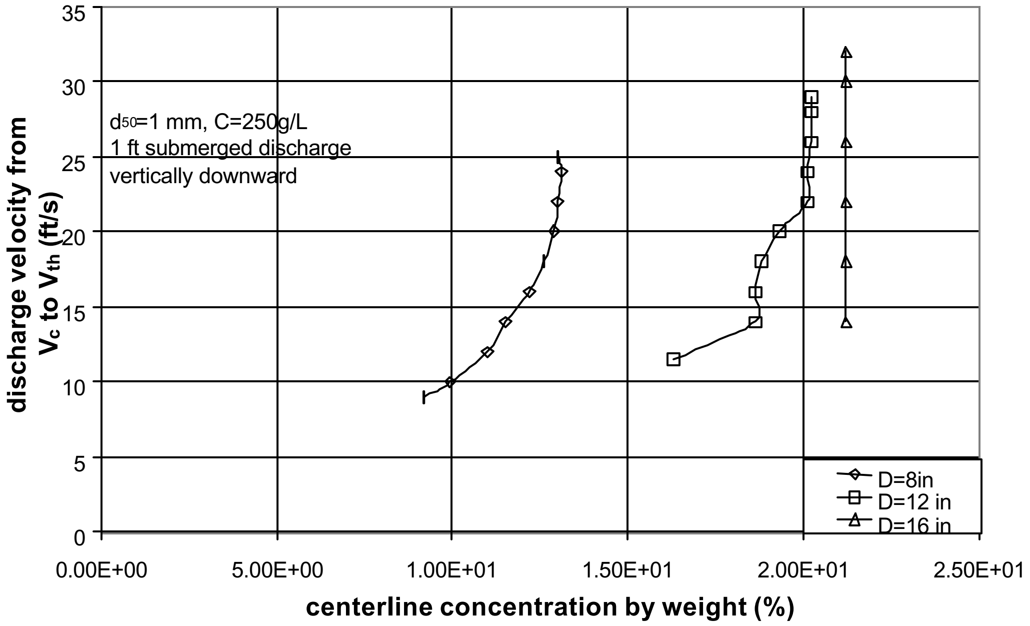

Figure 6-12. Centerline Concentration at Near-field Point of z = -2.0 m Versus Discharge Velocity.

Figure 6-5 to Figure 6-12 present results for the centerline concentration of plume and the discharge velocity at a specific water depth for different dredge sizes at the different combination of d_{50} and slurry concentration. From these figures for submerged vertical downward discharge, the centerline concentration will be increased with the increasing of discharge velocity and/or the increasing of dredge size. These results indicate that reduced turbidity can be obtained using smaller dredges and with lower slurry velocities that are above the critical velocity required to keep the sediment in suspension inside the slurry discharge pipe.

Consider a slurry that has a d_{50} of 0.1 mm and concentration of 250 g/L being discharged at a 45 degree downward angle and in the same direction as the current. In this case Figure 6-13 shows that centerline concentrations increase slightly with increasing discharge velocity for the smaller dredge sizes of 20.3 and 30.5 cm (8 and 12 in). However, the larger dredge sizes 40.6, 50.8, and 61 cm (16, 20, and 24 in) show the centerline concentration is nearly constant with increasing discharge. As the dredge size decreases the concentration at -2.5 m depth decreases from approximately 9 percent for the 61 cm (24 in) dredge to approximately 2.5 percent for the 20.3 cm (8 in) dredge. If the grain size is increased to 0.4 mm, then the concentration results at a depth of -1 m show the centerline concentration decreases as the discharge velocity increases as illustrated in Figure 6-14. However the effect of dredge size is unchanged.

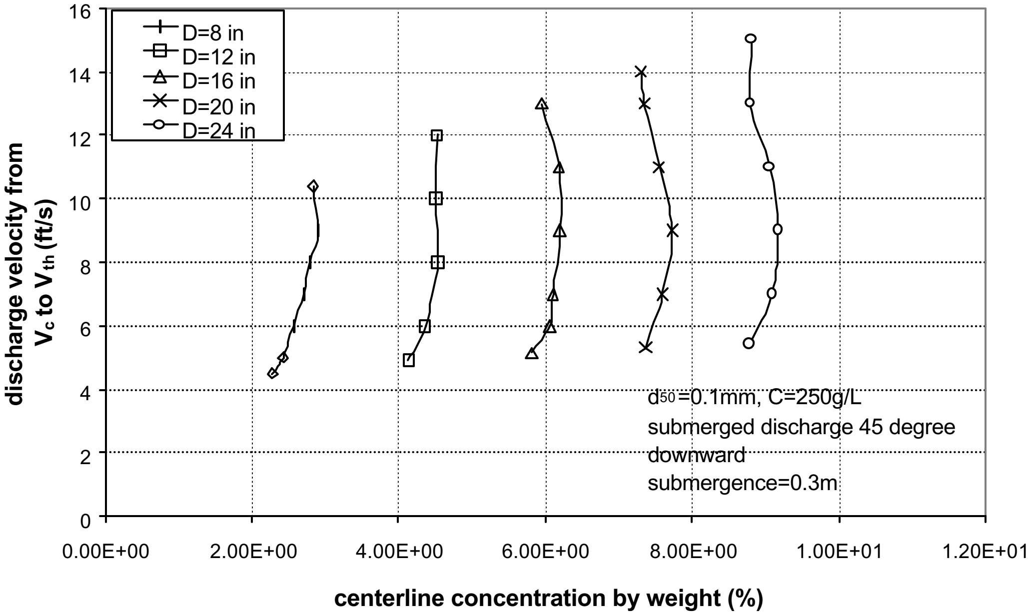

Figure 6-13. Centerline Concentration at Near-field Point of z = -2.5 m Versus Discharge Velocity.

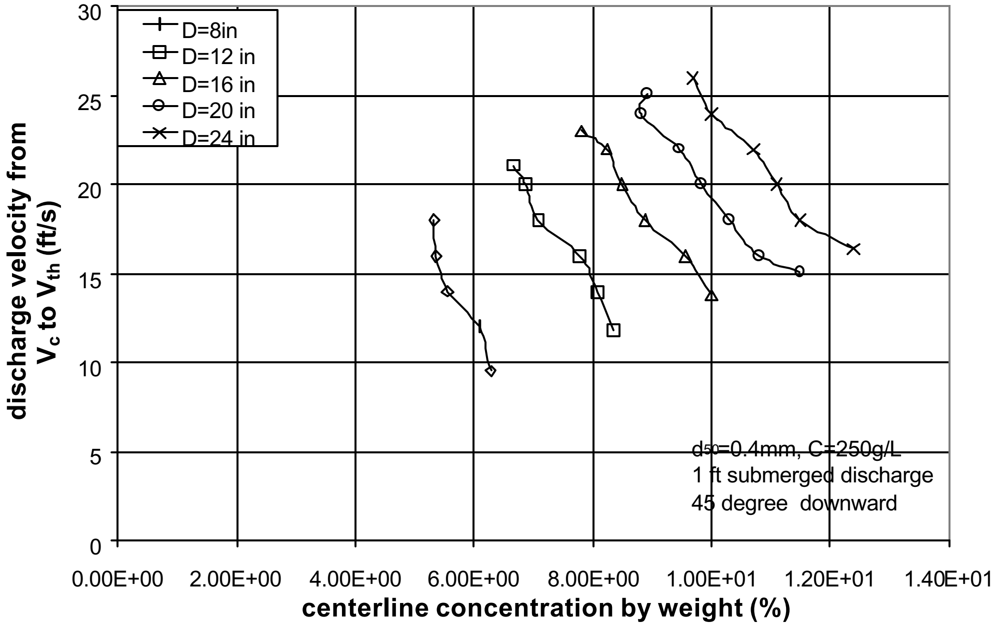

Figure 6-14. Centerline Concentration at Near-field Point of z = -1.0 m Versus Discharge Velocity.

In Figure 6-15 the mean grain size is reduced to 0.1 mm but the discharge is now horizontal at a depth of 1.5 m and in the same direction as the current. The centerline concentration at -2.0 m below the surface tends to decrease with the increasing of discharge velocity in all cases. This result is believed to be the result of the increased turbulence caused by the higher discharge velocity and the greater horizontal distance of the slurry jet for the higher jet velocity. In the case of the 61 cm (24 in) dredge size, the concentration decreases from 15 percent to 12 percent as the discharge velocity increases from approximately 5 to 15 ft/s. For the 20.3 cm (8 in) dredge the concentration decreases from 8.5 percent to 7 percent as the velocity increases from 4 to 10 ft/s. Thus, the submerged horizontal discharges show better dilution (less concentration) for the higher discharge velocities, but the concentration is still reduced by approximately one-half by reducing the dredge size from 61 cm (24 in) to 20.3 cm (8 in).

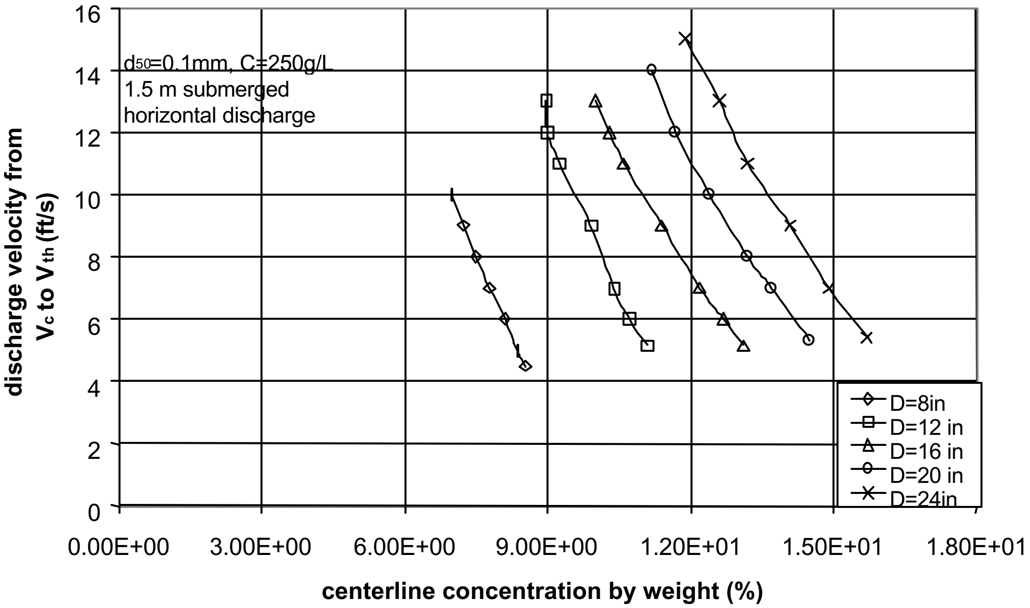

Figure 6-15. Centerline Concentration at Near-field Point of z = -2.0 m.

Consider the case where the slurry discharge is above the water surface. Figure 6-16 and Figure 6-17 show results for above water horizontal discharge on the centerline concentration at a depth of -2.5 m for a d_{50} of 0.1 and 0.4 mm, respectively. Large turbulence is produced when the discharge jet plunges into the water body. The small grain size sediment is influenced more than the large grain size sediment by the same turbulence intensity. So, when the discharge velocity is increased, the centerline concentration is changed more drastically in Figure 6-16 than that for the smaller d_{50} as shown in Figure 6-17 that has a large d_{50} value. The concentrations for the 0.4 mm mean grain size illustrate again that the smaller dredge size results in smaller centerline concentrations.

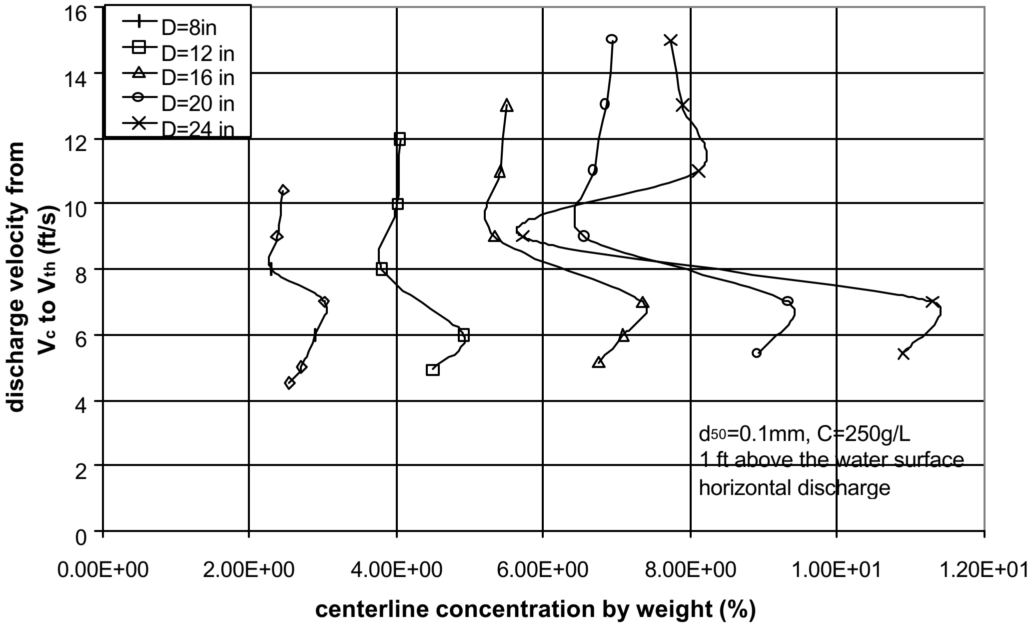

Figure 6-16. Centerline Concentration at Near-field Point of z = -2.5 m.

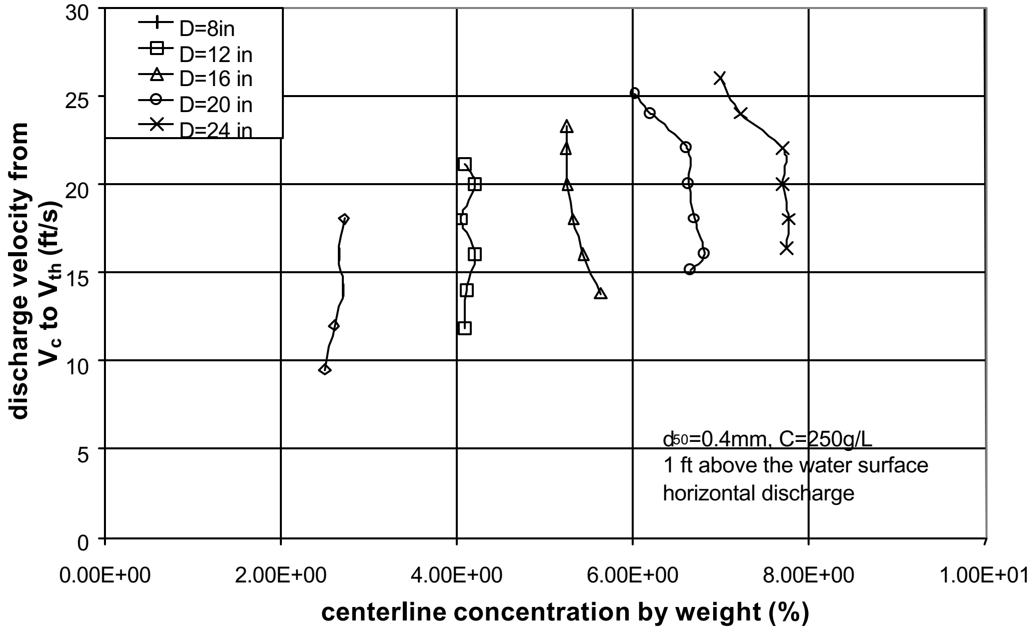

Figure 6-17. Centerline Concentration at Near-field Point of z = -2.5 m Versus Discharge Velocity.

Consider a slurry discharge with a concentration of 250 g/L and a mean grain size of 0.1 mm for a 40.6 cm (16 in) dredge with a discharge velocity of 1.8 m/s (6 ft/s). If the plume concentration is assumed to be normally (Gaussian) distributed, then the width of the plume is evaluated at a point where the concentration is 37 percent of the centerline concentration. The software calculates the half-width of the plume and the total width can be determined by multiplying by two because the distribution is assumed to be symmetric. Figure 6-18 reflects the plume half width for a discharge that is 0.305 m (1 ft) submerged at a 45 degree downward angle, 0.305 m (1 ft) submerged at a 90 degree angle (vertically downward), and 1 ft above the water surface. The results show the 0.305 m (1 ft) submerged vertical downward discharge has the smallest plume half-width.

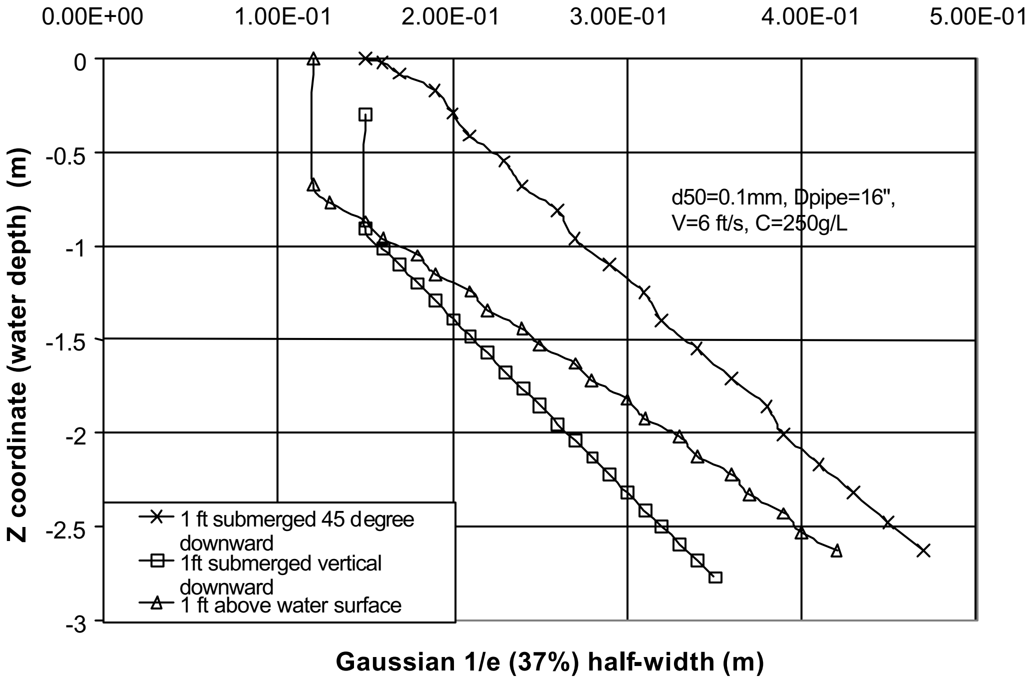

Figure 6-18. Water Depth and Plume Half Width.

CONCLUSIONS AND RECOMMENDATIONS

The CD-CORMIX software (now called CDFATE) is a very useful tool in evaluating the sediment concentration and mixing zone boundaries for dredged material disposal in open water and can be applied to the dredged material disposal in shallow water such as encountered in dredging in the Texas GIWW.

In the case of a submerged steady discharge that is directed vertically downward, the centerline concentration of the plume for the small dredge size is always smaller than that of a large dredge size under the same discharge conditions. This means the turbidity created is smaller for a small dredge (0.203 m, 8 in) than for a large dredge (0.61 m, 24 in). The discharge velocity closest to the critical velocity required to transport the sediment through the pipeline is the most desirable for minimizing turbidity in the water column. Recall that velocities below the critical velocity will not keep the dredged material suspended in the horizontal pipeline from the dredge to the discharge point. Also, the closer the discharge point is to the bottom, the smaller the sediment concentration.

In the case of above water discharge from 0.203 m (8 in) and 0.305 m (12 in) small dredges, the results are the same as that for the case of a submerged vertical downward discharge. For the above water surface discharge, the intensity of turbulence is stronger than that of submerged vertical downward discharge after the jet plunges into the water body, especially when the jet speed is high. So, in this case, the larger the dredge size, the more turbulence in the plume, then the sediment diffuses to a wide range and the centerline concentration is smaller.

In the case of the 45 degree or horizontally submerged discharge that is in the same direction as the ambient current, the sediment can be suspended over a wider range. The diffusion region becomes wider, and the centerline concentration becomes smaller when the discharge velocity is increased. The centerline concentration or turbidity is also smaller for the smaller dredge size. Therefore, this study shows that using smaller dredges can reduce turbidity during the dredging process.

The submerged horizontal discharges show better dilution (less concentration) for the higher discharge velocities, but the concentration is still reduced by approximately one-half by reducing the dredge size from 61 cm (24 in) to 20.3 cm (8 in).

For slurry discharge above the water surface, the centerline concentration is reduced by increasing the discharge velocity. This is a result of the increased turbulence caused by the slurry jet as it plunges into the water. However, the smaller dredge size still results in a smaller centerline concentration or less turbidity than for a large dredge size.

Recommendations for the optimum discharge operation that reduces turbidity, mixing zone size, and deposits more of the discharged sediment on the bottom are:

(1) The ambient current velocity has an important influence on the dilution process. The smaller the ambient current, the faster the sediment is deposited. So, the disposal site should be chosen in a small ambient current field.

(2) The angle between the ambient current direction and the slurry discharge direction must not be bigger than 90 degrees. If the angle is larger than 90 degrees, then the jet produces a large turbulence with ambient water body. The sediment is suspended for a long time in the turbulence, and the diffusion region is much wider.

(3) In the same ambient conditions and the same discharge operations, the larger dredge always produces higher turbidity (concentration) and a larger mixing zone region than the small-size dredge for the same discharge velocity, mean grain size, and slurry concentration.

(4) The plume of the above water surface discharge is always larger than that of the submerged discharge as a result of the influence of turbulence.

(5) For the same ambient conditions and the same discharge operations, the plume sizes of slower discharge velocity are always smaller than that of a higher discharge velocity for a specific dredge. Discharging at a velocity just above the critical velocity for heterogeneous flow is the recommended operational procedure for the purpose of reducing mixing region size.

(6) The lowest centerline concentration of suspended sediment occurs at the lowest discharge velocity, so a small dredge is more desirable in the same dredging condition for small plume size and lowest concentration.

(7) The plume size of a more submerged vertical downward discharge is always smaller than that of above water discharge, 45 degree downward submerged discharge, and submerged horizontal discharge.

CHAPTER 7 ALTERNATIVES FOR ANALYZING DREDGE MATERIAL DISPOSAL

INTRODUCTION

Disposal of dredged material from the Texas GIWW is a cost to taxpayers, and one of the least costly dredged material disposal options is to place the material in open water. Because of the physical and environmental concerns after the open water disposal, software is needed to predict stability of the disposal mound that is created by the release of dredged material. LTFATE is a modeling program that was developed by Corps of Engineers. The Automated Dredging and Disposal Alternatives Management System (ADDAMS) is a collection of software developed by the U.S. Army Corps of Engineers for analyzing and managing dredged material disposal. The software is available from the U.S. Army Engineer Waterways Experiment Station website (www.wes.army.mil/el/elmodels/index.html). The models that are discussed in this chapter are LTFATE and SETTLE. The LTFATE user's manual (Scheffner et al., 1995) and the SETTLE documentation (USACE, 1987) can be obtained from the National Technical Information Service or downloaded from the web site.

COMPUTER MODEL (LTFATE) FOR PREDICTING SEDIMENT MOUND MOVEMENT

Overview of LTFATE

LTFATE means long-term fate and is a site evaluation tool that estimates the dispersion characteristics of a dredged material placement site over a long period, ranging from days for storm events to a year or more for ambient conditions. Simulations are based on the use of local wave and current conditions. Input of local site-specific hydrodynamic information is developed from numerical model-generated databases; however user-supplied data files can be substituted for the database-generated files.

LTFATE has the capability of simulating both noncohesive and cohesive sediment transport. In addition, avalanching of noncohesive sediments and consolidation of cohesive sediments are considered to accurately predict physical processes that occur at the disposal site. It is a site-analysis program that utilizes coupled hydrodynamic, sediment transport, and bathymetry change models to compute site stability over time as a function of local waves, current, bathymetry, and sediment size. If the site is demonstrated to be dispersive, the model output can provide an estimate of the temporal and spatial fate of the eroded sediment or dredged material. This determination is often difficult to quantify because the movement of sediment is a function of not only the local bathymetry and sediment characteristics, but also the time varying wave and current conditions. These difficulties are overcome by using an information database to provide design wave and current time series and boundary conditions that realistically represent conditions at the disposal site.

The wave simulation methodology and the elevation and current databases were developed during the Dredging Research Program (DRP) at the U.S. Army Engineer Waterways Experiment Station (WES). The procedures for generating stochastic wave height, period, and direction time series are reported in Borgman and Scheffner (1991). The database of tidal elevations and currents for the East Coast, Gulf of Mexico, and Caribbean Sea are described in Westerink, Luettich, and Scheffner (1993) and the database of tropical storm surge and current hydrographs are reported in Scheffner (1994). These data are used to generate wave and current boundary condition data for input to LTFATE for evaluating mound stability. If the database is not available for the geographic area of interest, then the replacement input files must be supplied by the user and copied into the appropriately designated files.

Noncohesive Mound Movement

The LTFATE model uses four coupled subroutines to predict dredged material movement of various types of noncohesive material during different stages of mound evolution. These subroutines simulate hydrodynamics, sediment transport, mound cascading, and bathymetry change. LTFATE uses the equations reported by Ackers and White (1973) as the basis for the noncohesive sediment transport model. The equations are applicable to uniformly graded noncohesive sediment with a grain size in the range of 0.04 to 4.0 mm (White, 1972). Because many disposal sites are located in relatively shallow water, a modification of the Ackers-White equations are incorporated to reflect an increase in the transport rate when ambient currents are accompanied by surface waves. The modification is based on an application of the concepts developed by Bijker (1971) and referenced by Swart (1976). An early model was verified with prototype data by Scheffner (1991) and was shown to be a valuable approach to providing quantitative prediction of disposal site stability.

Kraus and Larson (1988) found that in some large wave tank cases the local slope of a mound of noncohesive material exceeded the angle of repose due to constant wave and water levels. Therefore, the concept of slope failure was incorporated in the LTFATE to ensure stability of the dredged material mound by employing an algorithm developed by Larson and Kraus (1989). This algorithm is based on the laboratory studies by Allen (1970) who investigated the steepness of slopes containing granular solids. Allen (1970) recognized two limiting slopes, the angle of initial yield and the residual angle after shearing. If the slope exceeds the angle of initial yield, material is redistributed along the slope through avalanching, and a new stable slope is attained, known as the residual angle after shearing.

Cohesive Mound Movement

LTFATE incorporates an algorithm developed by Teeter and Pankow (1989) to account for transport of fine-grained material, e.g., silts (0.072-0.004 mm) and clays (0.004-0.00045 mm). Fine-grained sediments are hydraulically transported almost entirely in suspension rather than as bedload, and therefore the Ackers-White equations are not applicable for these conditions. Teeter and Pankow reasoned that because of the differences in cohesion and settling characteristics, fine-grained sediments are sometimes characterized as the sum of algebraic expressions for settling velocity, deposition, and resuspension. Suspended sediment concentrations are assumed to be in the enhanced settling range (100-10,000 mg/L), and the functional form developed by Ariathuria, MacArthur, and Krone (1977) was used to determine the settling velocity. The description of deposition or flux of sediment material to the bed was determined by Mehta et al. (1989) as the sum over a number of fractions of settling flux times deposition probability. Resuspension is related to the shear stress exceeding a critical value when particles are individually dislodged from the sediment bed as inter-aggregate bonds are broken (Ariathuria, MacArthur, and Krone 1977).

Consolidation of the cohesive materials is evaluated using the procedure developed by Poindexter-Rollings (1990) for predicting the behavior of a subaqueous sediment mound. Consolidation calculations used by Poindexter-Rollings and implemented in LTFATE are based on the finite strain theory first proposed by Gibson, England, and Hussey (1967). Numerical solutions of this are well-suited for the prediction of consolidation in cases of thick deposition of fine-grained material because it provides for the effect of self-weight, permeability varying with void ratio, a nonlinear void-effective stress relationship, and large strains. Poindexter-Rollings (1990) verified the predictive capability of this relationship through several field studies.

Components of LTFATE

The LTFATE software consists of following three main programs: PC_WAVEFIELD, PC_TIDAL, and PC_LTFATE. LTFATE may be used as a complete site evaluation package, or individual programs may be accessed independently for other applications.

PC_WAVEFIELD creates a time series of wave height, period, and direction based on the computed intercorrelation matrix describing the statistical properties of wave height, period, and direction and their respective interrelationships. The matrix is computed from a time series of data corresponding to the location of interest. PC_WAVEFIELD includes the following four options: (a) wave field simulation, (b) statistical analysis on the simulated wave field, (c) wave field histogram plotting, and (d) wave field time series plotting.

PC_TIDAL is a database containing the harmonic constituents for tidal elevation and currents for a site-specific location that are used to generate an arbitrary long sequence of tidal data. PC_TIDAL includes the following two options: (a) simulation of the long-term tide sequence, and (b) generation of time history plots for the tide elevation, velocity components, and direction.

The program PC_LTFATE automatically accesses data generated by the programs PC_WAVEFIELD and PC_TIDAL to simulate long-term dredged material mound movement. These two programs require input files describing the statistical distribution of waves and currents of the site. If these data are not available, the user is required to supply appropriately named files to substitute for the files ordinarily generated by PC_WAVEFIELD and PC_TIDAL.

PC_LTFATE has the capability of determining the fate of noncohesive and cohesive sediments. The PC_LTFATE program should be employed only after executing programs

PC_WAVEFIELD and PC_TIDAL. PC_LTFATE includes the following options (a) seabed geometry configuration, (b) simulation of dredged material mound movement, consolidation, and avalanching, (c) generation of dredged material mound evolution contour plots, and (d) generation of dredged material mound evolution cross-sectional plots.

Required Input Files

In addition to the LTFATE executable files, three external user-supplied input files are required to specify wave, tidal, and storm surge boundary conditions for a specific location of interest. Example files have been included with the LTFATE model, but site-specific files must be obtained or generated by the user in order to define wave and current boundary condition input files corresponding to the location of interest.

TIDAL.DAT is the first of these external files, and it is used to define a time series of tidal elevations and current boundary conditions at the subject disposal mound. The TIDAL.DAT file contains amplitude and harmonic tidal constituents for both elevation and current corresponding to the location of the mound.

Because the LTFATE model requires both tidal elevation and current (u and v components) time series input, harmonic constituents for all three variables must be contained in the data files. This input file can be generated through execution of the program TIDES.EXE. However, the TIDES.EXE program requires an input database of harmonic constituents at discrete locations, and through interpolation, the program generates elevation and current constituents for any desired location in the appropriate format for the file TIDAL.DAT. The tidal constituent database has been generated for the East Coast, Gulf of Mexico, and Caribbean Sea (Westerink, Luettich, and Scheffner, 1993) and described in DRP Technical Notes DRP-1-13 (Scheffner, 1994). Constituent output for a specific location can be obtained by contacting the Coastal Engineering Research Center or the Coastal and Hydraulics Laboratory at WES in Vicksburg, Mississippi.

If the tidal constituent coverage of the area of user interest is not available, then the tidal constituent data can be obtained from alternative sources such as WES technical reports, the National Oceanic and Atmospheric Administration, university sources, open literature, or through harmonic analyses of available or collected elevation and current time series data. If the user supplies the necessary data, it must be formatted as shown in the example of the required input data file, TIDAL.DAT (Table 7-1), and should be named TIDAL.DAT.

The second file (Table 7-2) required for long-term simulation of dredged material mound movement is a file containing a time series of wave height, period, and direction named HPDSIM.OUT. This file can either be user supplied or generated internally by LTFATE and is in the format shown in the required input file, HPDSIM.OUT.

If LTFATE generates the file, then the additional file HPDPRE.OUT is required. The HPDPRE.OUT file represents the pre-computed cross-correlation matrix corresponding to a WIS station location nearest the mound. The HPDPRE.OUT (Table 7-3) is shown in the example of the required input data file, HPDPRE.OUT. Borgman and Scheffner (1991) and

Scheffner and Borgman (1992) describe the combined LTFATE/HPDPRE.OUT wave simulation capability. This approach is used to generate an arbitrarily long time sequence of simulated wave data that preserves the primary statistical properties of the full 20-year WIS hindcast, including wave sequencing and seasonality. Once the matrix has been computed, multiple wave field simulations can be performed with each time series stored on the files HPDSIM.OUT.

Table 7-1. Example TIDAL.OUT File.

The required input data file: TIDAL.OUT

```
GALVESTON, TEXAS
TIDAL HEIGHT HARMONIC CONSTITUENTS (CM/SEC)
     6          0.0        -5.8        -10.4
  CONST    SPEED – D/H    AMP-M    EPOCH-D    AMP-C/9   EPOCH-D    AMP-C/8   EPOCH-D
                               HEIGHT                VEL-V                 VEL-V
   M2      28.984104      .01      321.00       4.3        46.        6.7        41.
   S2      30.000000      .01      309.60       1.2        47.        1.8         5.
   N2      28.439730      .00      339.10       0.6       317.        1.2       255.
   K1      15.041069      .13      325.70       0.5       229.       14.3       231.
   O1      13.943036      .12      313.30       6.7       242.       10.4       235.
   M1      14.492754      .00      332.80       0.6       330.        0.6       346.
   J1      15.584415      .01      281.30       0.3         7.        1.2        92.
   Q1      13.398661      .03      293.30       1.2       157.        1.5       159.
   P1      14.958931      .04      326.20       0.0         0.        0.0         0.
************************************************************************
```

Table 7-2. Example HPSIM.OUT File.

The required input data file: HPSIM.OUT

```
START MO = 3            START YR = 1987     END MO = 6          END YR = 1987
NYR,NNY,NMO=            20                  20                  12
IYEARS=   1   1   1   1   1   1   1   1   1   1   1   1  1   1   1   1   1   1   1   1
MONTHS=   1   1   1   1   1   1   1   1   1   1   1   1
CUTOFF=        0.083333     0.083333     0.083333     0.083333     0.083333
CUTOFF=        0.083333     0.083333     0.083333     0.083333     0.083333
CUTOFF=        0.083333     0.083333
IJY=   1   2   3   4   5   6   7   8   9   10   11   12   13   14   15   16   17   18   19   20
IJY=   1   2   3   4   5   6   7   8   9   10   11   12
198703    100        1.00000      5.00002      343.83057
198703    103        1.10000      5.00000       35.42109
198703    106        1.20000      5.00001       52.58537
198703    109        1.20000      5.00000       58.00993
198703    112        1.20000      5.00000       53.44814
198703    115        1.10000      5.00000       36.73721
198703    118        1.00000      5.00000      340.76096
198703    121        0.90000      5.00000      293.34930
198703    200        0.80000      5.00000      283.34152
198703    203        0.76876      5.00000      279.52328
198703    206        0.70000      5.00000      277.62357
198703    209        0.60000      5.00001      276.96350
198703    212        0.60000      5.00000      276.80725
198703    215        0.70000      5.00001      277.28809
198703    218        0.80000      6.00001      279.52725
198703    221        0.90000      6.00000      292.18671
198703    300        1.00000      6.00000       67.54181
198703    303        1.10000      6.00001       76.68757
```

The primary advantage of using this statistically based wave simulation approach is that the user is not limited to a finite length of data. Instead, seasonal or yearly repetitions of time series data can be used for evaluations of site stability. Each simulation is statistically similar to the hindcast data, but it contains variability consistent with observations. If HPDPRE.OUT matrix is not available for the location of interest, one can be computed by the user through use of a U.S. Army Corps of Engineers Wave Information Study (WIS) 20-year hindcast input file and execution of the program HPDPRE. If the location of interest is not covered by the WIS hindcast database, the user must supply existing time series of wave height, period, and direction. Therefore, the user must do one of the following: (a) compute the HPDPRE.OUT matrix using HPDPRE (described in Borgman and Scheffner (1991)) and use the model LTFATE to obtain the HPDSIM.OUT output data file, or (b) convert the existing user-supplied time series data into the appropriate format shown in the required input data file: HPDSIM.OUT, and rename the file HPDSIM.OUT.

Table 7-3. Example HPDRE.OUT File.

The required input data file: HPDRE.OUT

```
GALVESTON         WIS          PRE           SIM
NYR,NNY,NMO=          20              20             12
IYEARS=    1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
MONTHS=    1   1   1   1   1   1   1   1   1   1   1   1
CUTOFF=          0.083333       0.083333       0.083333       0.083333       0.083333
CUTOFF=          0.083333       0.083333       0.083333       0.083333       0.083333
CUTOFF=          0.083333       0.083333
IJY=    1   2   3   4   5   6   7   8   9   10   11   12   13   14   15   16   17   18   19   20
IJY=    1   2   3   4   5   6   7   8   9   10   11   12
PREPROCESS OUTPUT FOR MO.              1
SCALE FACTORS:             1.00000              1.00000
N,M,NTM,NTOP,NSIM=     240                20             4800                120               480
DT=                 3.0000
BW,FCO,FRACT=           0.16667E-01        0.83333E-01          0.99990
RANKED ORIGINAL        (H(J);J=M,NTM,M)
     0.40000         0.50000         0.50000          0.50000         0.50000
     0.60000         0.60000         0.60000          0.60000         0.70000
     0.70000         0.70000         0.70000          0.70000         0.70000
     0.70000         0.80000         0.80000          0.80000         0.80000
     0.80000         0.80000         0.80000          0.80000         0.80000
     0.90000         0.90000         0.90000          0.90000         0.90000
     0.90000         0.90000         0.90000          0.90000         0.90000
     0.90000         0.90000         0.90000          0.90000         0.90000
     0.90000         0.90000         1.0000           1.0000          1.0000
     1.0000          1.0000          1.0000           1.0000          1.0000
     1.0000          1.0000          1.0000           1.0000          1.0000
     1.0000          1.0000          1.0000           1.0000          1.0000
     1.0000          1.0000          1.0000           1.0000          1.0000
     1.0000          1.0000          1.0000           1.0000          1.0000
```

The long-term simulations (i.e., simulations of months to years) compute disposal mound stability as a function of residual currents specified by the user in LTFATE. The normal seasonal wave climate is specified in the HPDSIM.OUT file, and the tidal elevation and currents are computed from the specified tidal constituent in the TIDAL.DAT file. Storm event erosion calculations are based on surge elevation and currents and the wave field associated with a specific event. These data are contained in the final input file from existing databases or generated by the user. However, the file is required only if the user desires to simulate the passage of an event over the disposal site.

The STORM.DAT file (Table 7-4) contains either a tropical or extra tropical storm surge elevation and current time series hydrograph with a corresponding storm wave height and period corresponding to the selected event. A database of tropical storm hydrographs for 134 historically based tropical storms has been completed for the 486 WIS and offshore discrete locations along the East Coast and Gulf of Mexico coast and for selected stations offshore of Puerto Rico. This database is described by Scheffner et al. (1994).

The STORM.DAT file can be created by the user of LTFATE to describe a particular storm event of assumed shape and duration. An example of a hypothetical event used in a disposal analysis is described in Scheffner and Tallent (1994). The Mud Dump example described in Scheffner and Tallent (1994) is based on hindcast and prototype data. Whether a historically based or assumed shape storm event is used in the stability analysis, the input data field containing the surge hydrograph must be consistent with the format shown in the required input data file, STORM.DAT, and must be named STORM.DAT.

Table 7-4. Example STORM.DAT File.

The required input data file: STORM.DAT

```
221.00      1.250      6.000     -4.567      6.168     -0.494
224.00      1.250      6.000     -7.112     10.226      0.555
227.00      1.250      6.000      7.288     -6.485      0.562
230.00      1.250      6.000      9.844     -8.801     -0.517
233.00      1.250      6.000     -4.865      9.580     -0.646
236.00      1.250      6.000     -9.739     16.096      0.396
239.00      1.250      6.000      4.076      0.147      0.641
242.00      1.250      6.000     10.692     -7.381     -0.377
245.00      1.250      6.000     -2.330      9.199     -0.725
248.00      1.250      6.000     -9.578     18.565      0.281
251.00      1.250      6.000      3.803      2.967      0.742
254.00      1.250      6.000     13.418     -7.612     -0.175
257.00      1.250      6.000      3.463      6.052     -0.691
260.00      3.230      6.000     -4.254     18.632      0.237
263.00      6.633      7.654     10.083      6.538      0.977
```

An Example of Using LTFATE

After the necessary input data have been collected and installed, long-term or storm-induced mound migration may be simulated. In this example, the long-term movement of a dredged material mound is simulated for a dispersive disposal mound. The assumed dredged material mound is located offshore of the entrance to Galveston Bay, Texas. For this example case, a 3-month simulation period extending from March 1987 through August 1987 was selected. Environmental data (wave, current, and tide) were not readily available for Galveston Bay, so the data available in LTFATE were used to demonstrate this example.

Wave Field Simulation Program

The user selects PC_WaveField from the LTFATE Main Menu. In this case, enter 3 for the Beginning Month, 1987 for the Beginning Year, 6 for the Ending Month, and 1987 for the Ending Year, and enter 123456789 as a random number seed. Once all data have been generated and stored in the data file HPDSIM.OUT, the statistical program and plotting programs can be used and will access the user-supplied file HPDSIM.OUT. If the user supplies wave field, then the user should not select the simulation program.

Wave Field Statistical Program

In this example, the user is asked to specify a period of the simulated data (stored in the file HPDSIM.OUT) over which to perform the statistical calculations. In this example, 3 months of data were simulated, so the entire 3-month period or a portion of the data is chosen for the statistical calculation. Data generated by the statistical program are stored in one of the following five files: GHG_HST.DAT; HGT_TIM.DAT; PER_HST.DAT; DIR_HST.DAT; and DIR_TIM.DAT. HGT, PER, and DIR represent wave height, period, and direction respectively, and HST and TIM represent the histogram and time series plot data respectively.

Wave Field Histogram Plotting Program

This plotting package gives the user an opportunity to examine the wave field data used to simulate dredged mound movement. Two options exist for viewing the simulated wave field characteristics: (a) histogram plots (Figures 7-1 and 7-2), and (b) time series plots (Figures 7-3 through 7-5). The wave histogram shows the wave height versus the frequency of occurrence and Figure 7-1 shows that a wave height of 3 ft has the highest frequency of occurrence of 16. The highest wave height was approximately 12.6 ft with a frequency of occurrence of one. The wave direction histogram (Figure 7-2) is a plot of wave direction versus frequency of occurrence. The results show most frequent wave direction was between about 75 and 90 degrees (North-northeast). Figure 7-3 is a time series plot of the wave periods and it shows maximum wave period is about 9 s for a 3-hr sampling rate and the long-term average wave period was just over 5 s. A time series of wave height is illustrated in Figure 7-4 that shows the long-term average wave height is approximately 3 ft (dashed line). The time series of wave period is shown in Figure 7-5 with the solid line representing the 3-hr sampling direction and the dashed line representing the long-term mean.

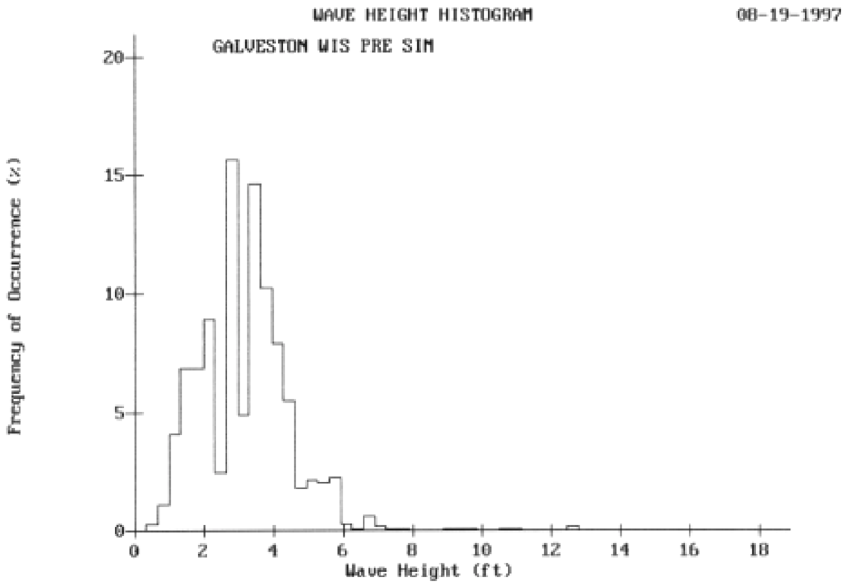

Figure 7-1. Wave Height Histogram.

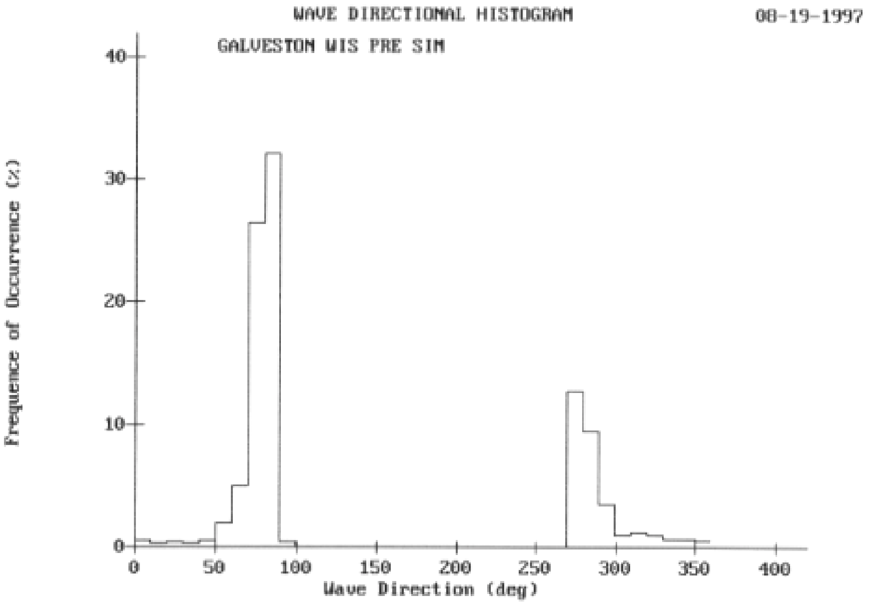

Figure 7-2. Wave Direction Histogram.

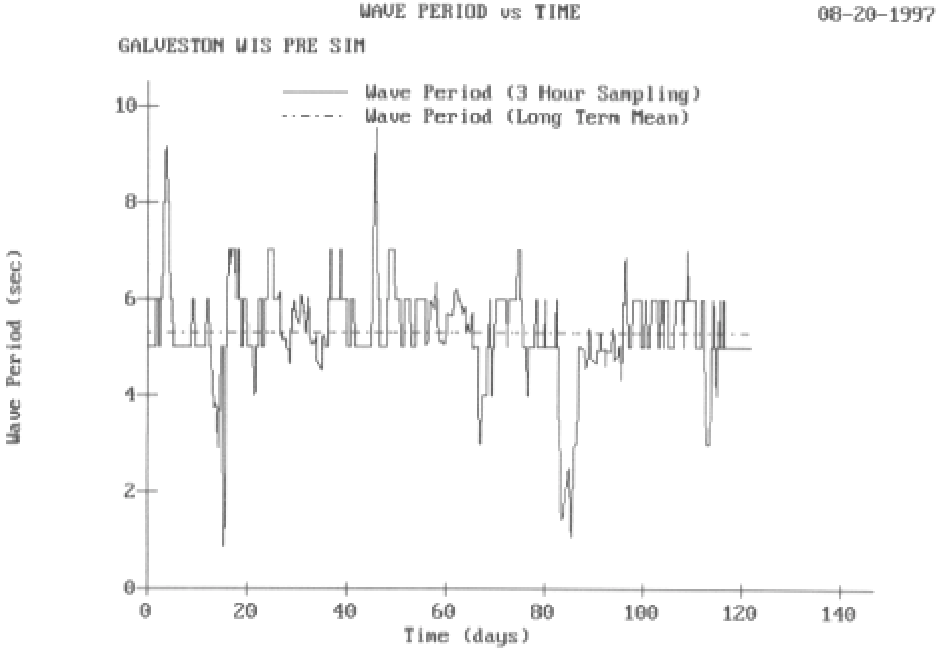

Figure 7-3. Wave Period Time Series Plot.

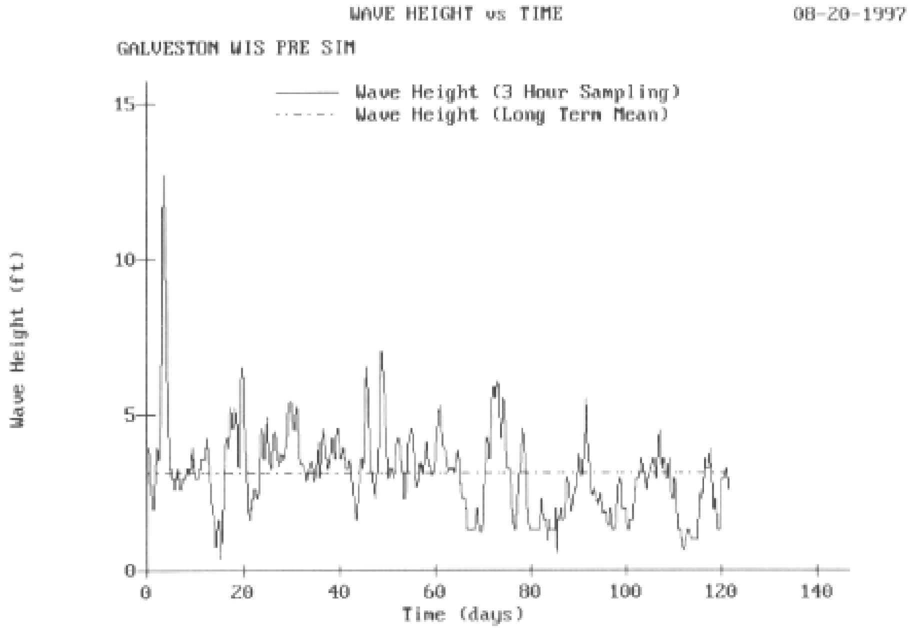

Figure 7-4. Wave Height Time Series Plot.

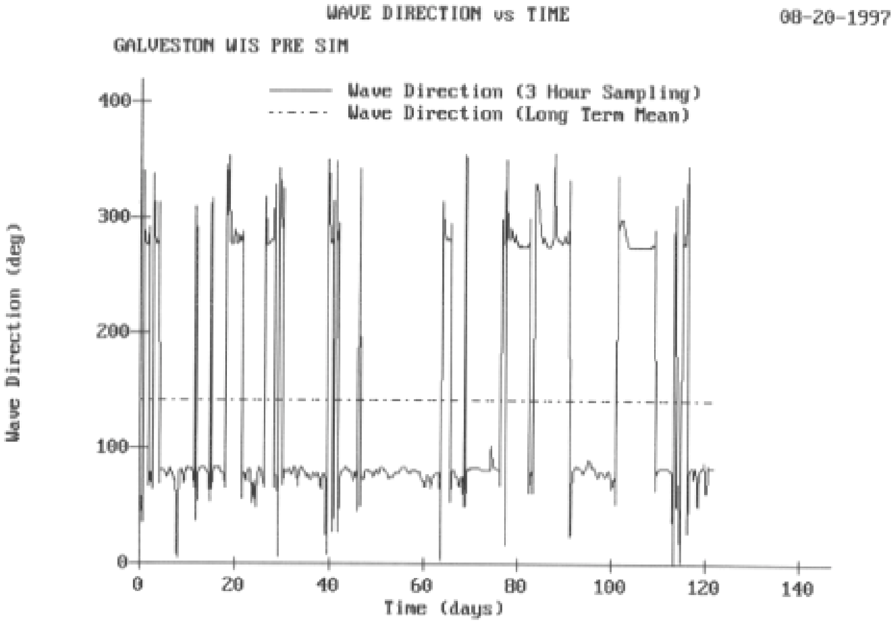

Figure 7-5. Wave Direction Time Series Plot.

Tidal Simulation Program

The tide simulation program serves two purposes. The first purpose is to provide input data to the dredged material mound movement simulation program. The second is to provide input data to the tidal graphics program. Figures 7-6 and 7-7 are examples of the output for the u-component and v-component of tidal velocity, and the tidal current direction is illustrated in Figure 7-8. The u-component fluctuates between approximately 12.2 to 18.3 cm/s (0.4 to - 0.6 ft/s) for the 3-hr sampling and the mean is -0.61 cm/s (-0.2 ft/s). The v-component shows a mean of approximately -12.2 cm/s (-0.4 ft/s) and the range is 15.2 to 30.5 cm/s (0.5 to - 1.0 ft/s) over the selected time period of approximately 3,000 hr.

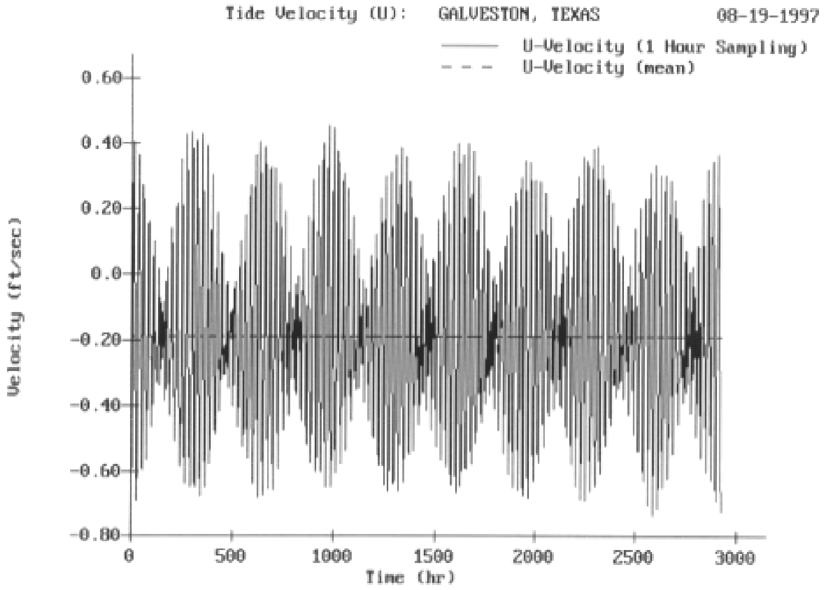

Figure 7-6. Tide Velocity (U) Time Series Plot.

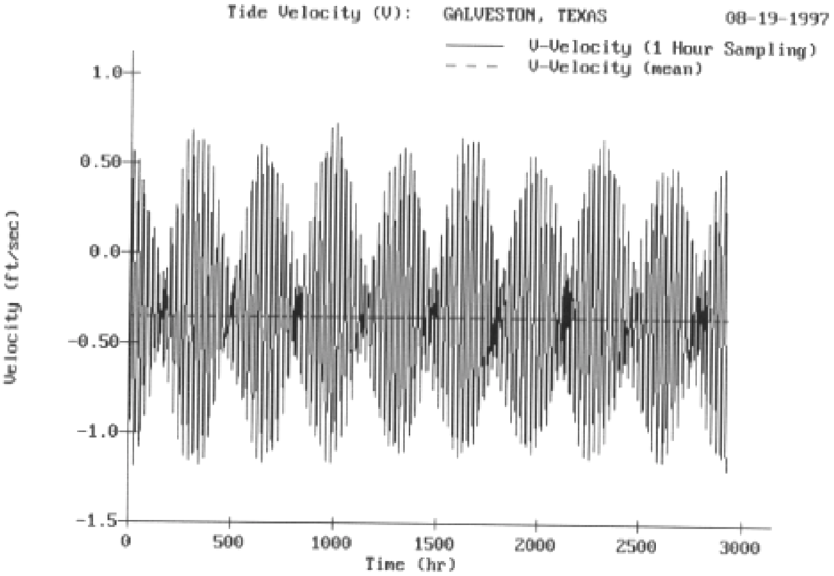

Figure 7-7. Tide Velocity (V) Time Series Plot.

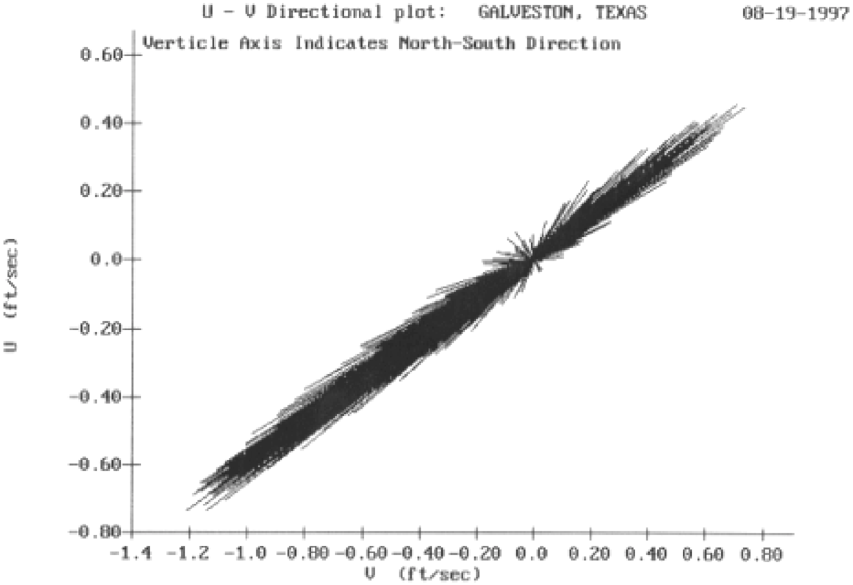

Figure 7-8. Tidal Current Direction Plot.

Long-Term Mound Movement Simulation

The LTFATE software simulates and graphically displays the long-term movement of the dredged material mound. To execute the simulation program PC_LTFATE, the database created or supplied by the user in PC_WAVEFIELD and PC_TIDAL is used. In this example, a simple mound geometry file was created where d_{50} is 0.1 mm, mound diameter is 488 m (1,600 ft), water depth is 3.05 m (10 ft), and the mound height is 0.91 m (3 ft). Using this input data, the mound simulation program PC_LTFATE yields the mound movement as shown in Figures 7-9 through 7-12. Part of the results of simulation is shown in Table 7-5. The simulated sand island mound cross-section plot at the centerline is shown in Figure 7-13. The initial mound configuration is shown in Figure 7-9 with the mound center at 3,811 m (12,500 ft) on the horizontal and vertical axes. Mound movement is illustrated in Figure 7-10 towards the origin of the graph with the simulated contours after 49 days. Further movement of the mound is shown in Figures 7-11 and 7-12, and it shows the mound center has moved approximately 2,500 ft in both the horizontal and vertical directions that corresponds to the predominant wave direction and resulting u- and v-component velocities previously shown. Figure 7-13 illustrates a cross section through the original centerline of the mound. The results show the original 0.91 m (3 ft) elevation is eroded to approximately 0.76 m (2.5 ft) after 505 hr. By the end of the simulation (2,925 hr), the simulation indicates the environmental forces have created a small scour hole at the original mound center location. The software provides the capability of providing additional cross-section plots for different locations in the defined disposal area.

These results illustrate the use of LTFATE in predicting mound movement as a result of environmental forces due to waves, currents, and tides. It is concluded that LTFATE is a useful tool for predicting the movement of dredged material deposited in open water such as in Galveston Bay or other shallow water bodies used for open water disposal of dredged material from the Texas GIWW. Use of this model is usually enhanced with expert advice on the creation of the wave, current, and tide input files and characteristics of mound behavior that can be obtained from the U.S. Army Engineer WES and the Texas A&M Center for Dredging Studies. Experience with this model indicates that obtaining the environmental data for the Texas bays and estuaries is the most significant challenge in applying the LTFATE model.

Table 7-5. Time Series Mound Simulation Output.

DREDGE MOUND TRANSPORT, CONSOLIDATION,
AND AVALANCHING PROGRAM INITIATED

N	T hrs	SETT ft	UVEL ft/sec	VVEL ft/sec	TIDE H ft	DEEP H ft	PERD sec	X-CENT ft	Y-CENT ft
1	3	0.000	-0.537	-1.006	0.044	2.768	5.000	-7.7	-14.5
2	6	0.000	-0.732	-1.206	-0.545	3.045	5.000	-51.2	-87.6
3	9	0.000	-0.453	-0.647	-0.768	3.322	5.000	-53.7	-91.2
4	12	0.000	0.152	0.260	-0.626	3.322	5.000	-53.7	-91.3
5	15	0.000	0.402	0.565	-0.209	3.322	5.000	-52.9	-90.2
6	18	0.000	0.124	0.163	0.376	3.045	5.000	-52.9	-90.2
7	21	0.000	-0.181	-0.270	0.824	2.768	5.000	-52.9	-90.2
8	24	0.000	-0.274	-0.515	0.767	2.491	5.000	-53.0	-90.3
9	27	0.000	-0.442	-0.883	0.217	2.215	5.000	-54.8	-94.0
10	30	0.000	-0.689	-1.183	-0.403	2.128	5.000	-74.3	-128.1
11	33	0.000	-0.555	-0.813	-0.722	1.938	5.000	-77.3	-132.6
12	36	0.000	0.006	0.059	-0.681	1.661	5.000	-77.3	-132.6

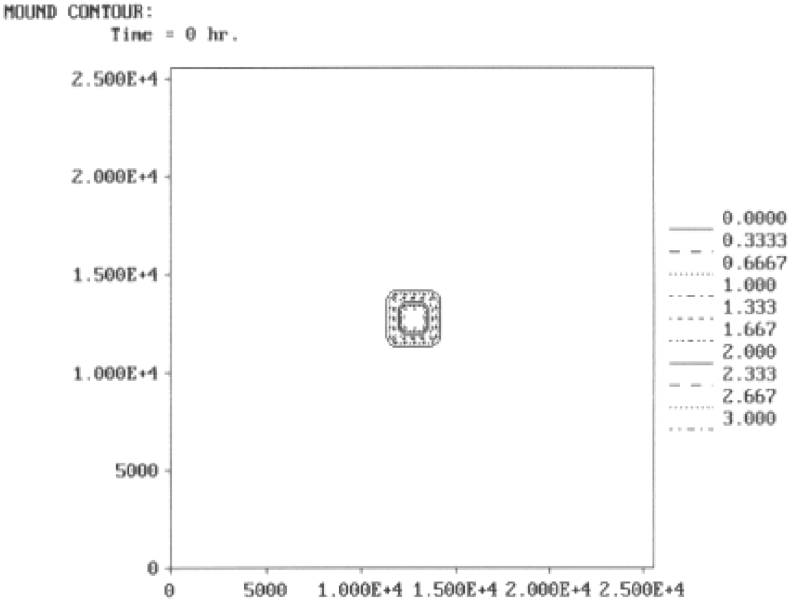

Figure 7-9. Initial Mound Contour (0 day).

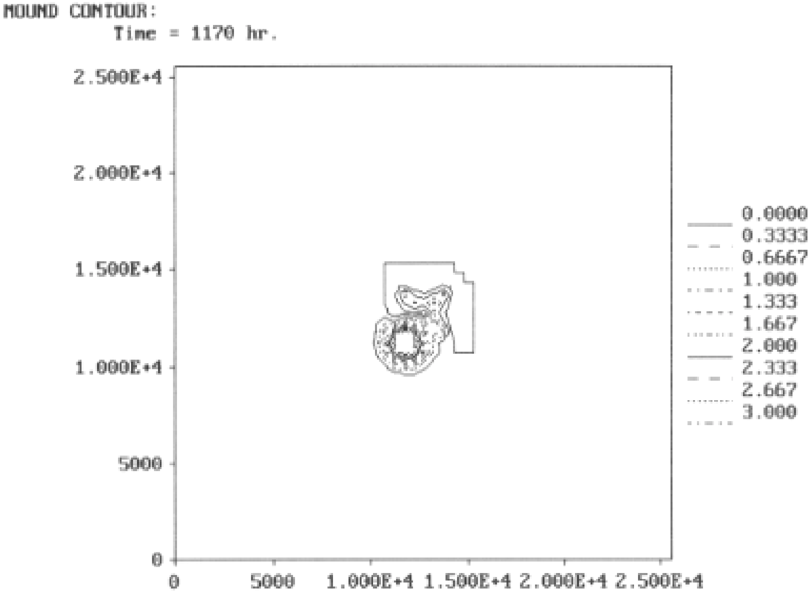

Figure 7-10. Simulated Mound Contour after 1170 hr (49 days).

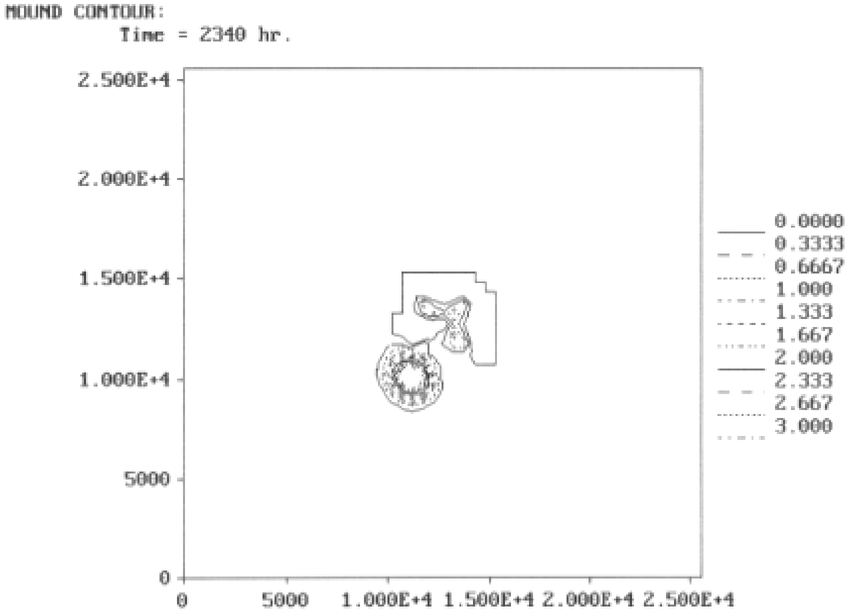

Figure 7-11. Simulated Mound Contour after 2340 hr (98 days).

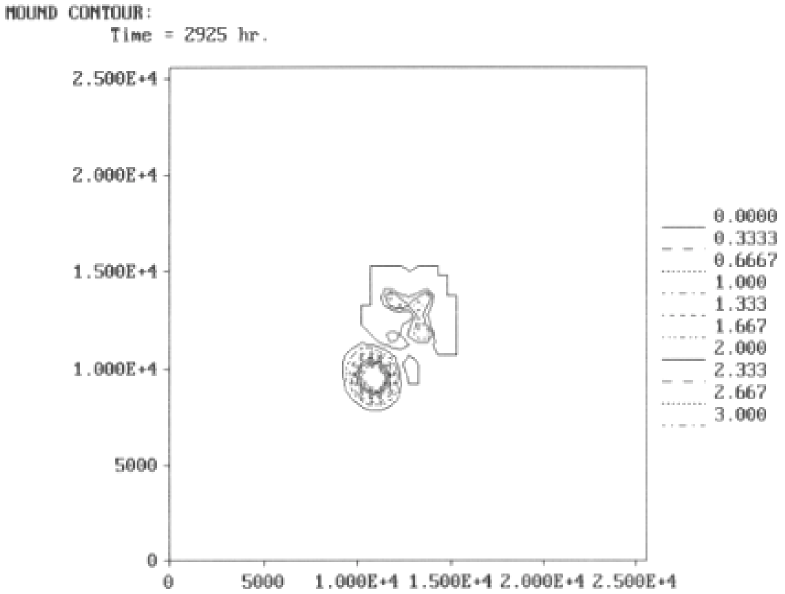

Figure 7-12. Simulated Mound Contour after 2925 hr (122 days).

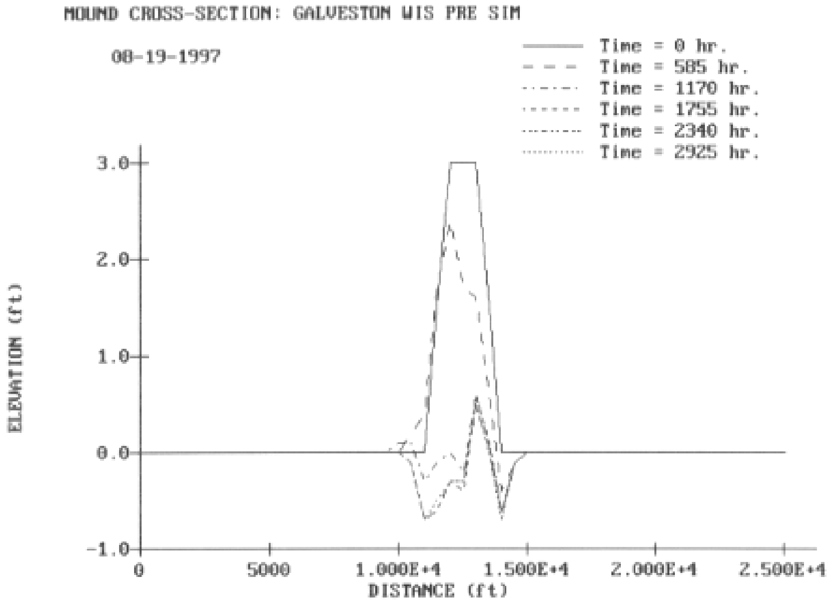

Figure 7-13. Simulated Mound Cross-Sectional Plot at Centerline of Grid.

Conclusions

LTFATE is a numerical model for estimating the long-term response of a dredged material disposal site to local environmental forces such as waves, currents, and tides. The software was developed to determine whether an existing or proposed disposal site is dispersive or nondispersive over a period of time on the order of months to years. For a specific disposal site, the database of environmental forces is required to provide a means of defining realistic boundary conditions at a proposed or existing disposal site without requiring the collection of prototype data.

The model has the capability to predict the long-term stability of dredged material mounds as well as short-term storm surges. The results in this chapter only demonstrate an example of a long-term fate application in Galveston Bay, but the environmental data were not available for Galveston Bay so the existing data in the model were used for demonstration purposes only. Further work is needed to get the database of environmental forces (tides, waves, and currents) of the specific disposal site of interest, as well as to scale the interested area into the coordinate system of the model. It is recommended that assistance from the Corps of Engineers or the authors of this report be obtained for a first time user. This software can be downloaded from the U.S. Army Engineer WES website.

COMPUTER MODEL (SETTLE) FOR OPTIMIZING THE DESIGN OF CONFINED DISPOSAL FACILITY (CDF) SITES

Background

The U.S. Army Engineer WES in Vicksburg, MS, developed the computer program SETTLE, and it is a part of ADDAMS (Schroeder and Palermo, 1990). USACE (1987) describes the design and operation of CDFs. This section briefly describes the use of SETTLE for evaluating alternatives to retain solids, provide initial storage, and meet effluent discharge limitations for suspended solids during a dredged material disposal operation.

CDFs must be designed to retain and store sediment dredged from navigation channels, estuaries, lakes, and other waterways. For the Texas GIWW, the dredging alternatives usually are hydraulic dredging operations. These conventional dredging processes add large volumes of water and result in a slurry of solids being discharged into the CDF. Hydraulic dredging operations add this water to facilitate pipeline transport. Hydraulically pumped dredged material slurries typically contain sediment concentrations between 50 and 200 mg/L depending upon the sediment and dredge characteristics. Mechanical dredging operations entrap water during dredging and tend to have higher solids concentrations than hydraulic dredges. Either dredge type requires that the CDF provide sufficient hydraulic retention time for removal or settling of the suspended solids to meet local, state, and federal effluent water quality standards as well as prevent the dredged material from reentering the GIWW in the effluent flow.

Water quality certification must be obtained from the state. The certification may specify water quality standards that the effluent from the CDF must meet. State water quality certification usually includes specific concentration limits for water quality constituents of concern and should specify geographic limits for a mixing zone outside of which these concentration limits can not be exceeded. Additional treatment beyond primary clarification within the CDF may be required to meet the effluent standards for some constituents.

The numbered CDFs along the Texas GIWW are for long-life and for multiple disposal purposes. The discussion that follows describes the use of SETTLE for optimizing the use of CDFs including determining the inflow rate, inflow solids concentration, ponded water depth, dike height, minimum initial storage volume, and maximum allowable effluent solids concentration for a particular dredging location. A series of SETTLE runs should be used to evaluate an array of design alternatives before selecting the most appropriate design that balances the requirements for storage and effluent quality.

Computational Procedures

Design for Initial Storage

A CDF design for a single dredging project must be capable of storing the dredged material for a particular disposal activity at its largest volume. This occurs just as disposal ends and is commonly referred to as the initial storage volume. The initial storage volume for the dredged material depends on many aspects of the dredging project, including sediment characteristics (primarily the fraction of fines versus the fraction of sands), settling characteristics of the material, volume of sediment to be dredged, and disposal rate. The required CDF volume, however, is significantly larger than just the initial volume of sediment to be dredged, particularly for hydraulic dredging transport or disposal projects.

SETTLE determines the average concentration of settled solids within the CDF at the end of disposal, referred to as the design concentration, using the compression settling test data. The design concentration is used to calculate the initial storage requirements for the fine-grained (smaller than No. 200 sieve) fraction of the dredged material. Coarse-grained (larger than No. 200 sieve) material behaves independently and much differently. Thus, the storage volume required for the coarse-grained material is determined based upon the input data and then added to the volume of fine-grained material to yield the minimum initial storage required. This volume is not an estimate of the long-term needs for multiple-disposal activities; it is the volume for the single disposal project under consideration.

Because of the siting, concentration, and permitting complications, CDFs are frequently sized to receive multiple disposals. The number and frequency of disposals depend upon the location and dredging project being served. Under these circumstances, initial storage volume will likely become a constraint only as the CDF nears the end of its service life. Estimates for the long-term storage capacity can be made using the consolidation and desiccation (PCDDF) module of ADDAMS.

Initial storage volume can be the controlling design factor regardless of the settling behavior exhibited by the material. In the unusual case that the material exhibits compression settling at a concentration at or below the expected inflow concentration, the design for the initial storage might well be the only design consideration required.

Design for the Clarification

Sediment containing saline pore water (>3 ppt salt concentration) frequently settles as a tightly formed soil matrix restricted by the upward flow of water through the matrix. The result is clarified supernatant above a well-defined soil-water interface that continuously settles downward at a slow rate. This is commonly referred to as zone settling. Besides occurring in salt-water sediments, zone settling may occur in the fresh water sediments if the solids concentrations are high enough or if the particle surface characteristics are flocculent enough.

If the dredged material exhibits zone settling behavior at the expected inflow concentration, the zone settling test results are used to calculate the required ponded surface area in the CDF for effective zone settling (clarification). This surface area is the minimum area required to remove suspended solids from the surface layers at a rate sufficient to form and maintain a clarified supernatant that can be discharged.

Flocculent settling occurs in the supernatant water above the interface and controls the quality of the supernatant. Suspended solids concentration in the clarified supernatant varies widely between sediments but is generally on the order of 50 to 500 mg/L. Additional calculation using flocculent settling data for the solids remaining in the ponded supernatant water are required to design the CDF for a specific effluent quality standard, and for suspended solids these calculations are identical to those described below.

Design for Effluent Quality

The concentration of effluent suspended solids depends on the flocculent settling characteristics of the sediment, on the depth from which fluid is withdrawn at the weir, and the hydraulic retention time within the CDF. Because of the low viscosity of the supernatant water and the high flow rates commonly found for a CDF, the withdrawal depth is essentially equivalent to the ponded water depth. SETTLE uses the average ponded depth to estimate the time and an average of 0.61 m (2 ft) is usually recommended. Greater depths of ponding reduce the surface area required for adequate solids removal. For most cases, constant ponded depth can be maintained by raising the weir crest.

Confined disposal facilities that are constructed in a rectangular shape with sides that are near the same length minimize the dike length required for a given surface area or storage volume. This typical shape combined with point source inflow results in an actual hydraulic retention time that is considerably less than the theoretical retention time. Thus, calculating the effluent suspended solids concentration requires correcting the theoretical retention time for hydraulic inefficiencies. Actual mean hydraulic retention time and hydraulic efficiency for a given flow rate, design area, and ponding condition and the theoretical residence time can be estimated using the DYECON module in ADDAMS.

Calculating Weir Length

The fact that withdrawal depth is essentially the ponding water depth at the weir does not minimize the importance of determining the necessary weir length. The weir must be long enough that the overflow rate does not attempt to draw water from depths greater than the depth of the free water surface pond. The settled solids layer is loosely compacted and scouring begins at very low velocities. High overflow rate may cause enough scouring of settled solids to violate effluent water quality standards. SETTLE calculates the weir length necessary to avoid this entrainment of solids for slurries that result in either zone or flocculent settling.

SETTLE Application of ADDAMS

Introduction

A properly designed CDF removes solids from the dredged material slurry sufficiently to meet state water quality certification, provides temporary or permanent storage for retained solids, and prevents the dredged material from reentering into the GIWW in the effluent. The quality of water discharged from a CDF is a significant environmental concern associated with dredging, especially in areas where the dredged material may contain a contaminant of concern. Thus, it is important to size and operate the CDF in such a manner that the best practicable solid and contaminant removal occurs. This is accomplished by designing the CDF for solids removal during the most critical stage of the disposal operation and the most critical stage usually occurs during the final days of disposal when the ponded volume is the smallest.

Confined disposal facility design, however, is not simply the determination of the surface area required for solids removal and initial volume required to store the freshly deposited dredged material. Surface area, free water ponded depth, hydraulic efficiency, weir length, inflow rate, and inflow concentration all affect solids removal efficiency in a CDF. Large surface area and storage volume requirements combined with land acquisition difficulties usually make over-construction economically prohibitive. Thus, the design of a CDF requires careful evaluation of these design variables in conjunction with design constraints. For example, land constraints can substantially restrict the area available for construction of the CDF. The CDF design must focus on the controllable design aspects that affect effluent quality such as ponded water depth, inflow rate, and weir length. If the allowable range of modification for these parameters cannot meet state water quality certification requirements, then additional treatment may be required before discharging the CDF effluent into the receiving water body.

Capability

SETTLE implements CDF design procedures based on data from laboratory settling tests, information on the dredging project, anticipated dredged volumes, dredged material characteristics, expected hydraulic dredged CDF, and desired effluent quality. SETTLE can consider constraints on the CDF design such as dike height and surface area limitations in the design calculations and provides the capability to consider all CDF design alternatives.

The SETTLE module of ADDAMS has the following specific capabilities:

- analyze and reduce laboratory settling test data required for CDF design,
- size a CDF for solids retention and initial storage of dredged material, and
- compute the weir length required to prevent resuspension and excessive discharge of suspended solids.

CDF Design Using SETTLE

Designing a CDF consists of sizing for initial storage of the slurried dredged material and adequate clarification to meet effluent quality standards through solids removal. While sizing for initial storage is relatively straightforward, solids removal depends on a combination of surface area, ponded water depth, hydraulic efficiency, average inflow rate, and weir length. The final CDF design must satisfy both storage and effluent quality criteria within the physical constraints placed upon the site. Design calculations in SETTLE are based upon laboratory settling test data and dredging project data that reflect the anticipated use of the CDF. Several SETTLE runs should be used to evaluate an array of design alternatives and select the most appropriate design that balances the requirements for storage and effluent quality should be selected.

Data Requirements

Various settling processes begin immediately once dredged material is discharged into the CDF. A properly designed CDF facilitates these settling processes to enhance solids removal, compaction, and fractional retention of solids. Dredge material slurries exhibit either flocculent or zone settling, depending on the slurry concentration, particle type, and salinity of carrier water. Slurries with salinity greater than 3 ppt usually exhibit zone settling because the dissolved ions act as a coagulant. Freshwater slurries typically exhibit flocculent settling but may exhibit zone settling if solids concentration is high enough or if the particle surface characteristics exhibit low stability forces.

Regardless of whether the upper layer of the settling material in the CDF exhibits flocculent or zone settling, the bottom layer of settled material will exhibit compression settling or thickening. As settled solids accumulate, the concentration of settled solids in the bottom layers increases. Settled solids begin to rest on and be supported by the bottom of the disposal area. Successive layers of settled solids then rest on each other. The point at which the bottom begins to provide some physical support is defined as the beginning of compression settling. The change from flocculent or zone settling to compression settling occurs at a concentration of approximately 200 to 300 g/L for most dredged material slurries.

Sedimentation characteristics can vary widely between sediments. Thus, laboratory test data that reflect the settling properties of the dredged material planned for disposal must be available to appropriately design the CDF. Data requirements for a complete design analysis include the laboratory results from a flocculent settling test, a 15-day compression settling test, a zone settling test (when zone settling occurs), disposal area information, dredge information, and physical and engineering properties of the dredged material. Specific requirements for each data type are described below. SETTLE runs can be made using data from a partial set of settling tests; however, this provides only design information based on the results of those tests. This report mainly focuses on the compression settling data and flocculent data used in SETTLE module.

Compression Settling Data

Data entry for the compression settling option consists of two data input screens plus one results screen and an optional graphical display of the test results. Table 7-6 lists the necessary input parameters from the compression settling tests and their corresponding units. From the interface height and initial solids concentration data, SETTLE computes the settled solids concentration each time the interface height was measured. The settled solids concentration versus time data are fitted (using the least-squares technique) to a power curve of the form:

$$C = aT^{b} \qquad \textbf{(7-1)}$$

where C is the settle solids concentration, g/L, T is the time since disposal, days, and a and b are regression coefficients.

The results screen shows the computed power function and its coefficient of determination. The user can choose to view a graph of the data and the fitted curve to examine for goodness-of-fit, outlier, and typographical errors in data entry. The graph can also be sent to the printer or plotter specified in the hardware configuration file.

Table 7-6. Compression Settling Data Requirement and Associated Units.

Parameter	Units
Average influent solids concentration	g/L
Initial height of slurry in column	ft
Times when solids interface height was measured	days
Solids interface height at times when interface was measured	ft

Flocculent Settling Data

Flocculent settling data consist of three data input screens, three data reduction results screens, and one graph of the flocculent settling data. Table 7-7 lists the input parameters with their corresponding units. From the raw flocculent settling data that is entered in the first three screens, SETTLE computes the percent of the initial suspended solids concentration remaining in suspension for each sample. It displays the results on screen in a matrix of sampling times (rows) and port heights (columns). Power curves of the suspended solids concentration as a function of depth from the surface are fitted (using the least-squares technique) for each sampling time. The curves are of the form:

$$C_T = a' D^{b'} - C'_T \qquad \textbf{(7-2)}$$

where C_T is the suspended solids concentration, D is the depth from water surface (ft), $C_T^{'}$ is the suspended solids concentration at the surface (mg/L), T is the time since disposal (hr), and $a^{'}, b^{'}$ are regression coefficients.

Table 7-7. Flocculent Settling Data Requirement and Associated Units.

Parameter	Units
Heights of the sampling ports	ft
Sampling times	hr
Height of the water surface at the sampling times	ft
Suspended solids concentration of the supernatant sample	g/L

SETTLE displays the regression equations and their coefficients for each time. Regression coefficients are not displayed since each curve results from only a small number of data points (usually 2 to 4) and the values would have little significance. A number of constraints are placed upon the regression results to ensure reasonable curves when using only a small number of data points.

SETTLE uses the regression equations to compute the suspended solids removal percentages as a function of the sampling times for user-specified withdrawal depths. Solids removal increases with time and decreases with increasing depths of withdrawal. The computed values are displayed for the user to evaluate.

Enter/Edit Project Data

Data from the SETTLE *Activity Selection Menu* initiate the entry and editing process for data describing the dredging project. Table 7-8 lists the required project data and appropriate units. Close inspection of the list in Table 7-8 indicates some apparent over specification. For example, it appears that the inflow rate, pipe velocity, and pipe diameter are required input data; actually, the user only needs to input any two of these parameters and SETTLE computes the third. Similarly, the input for several project data parameters can be expressed in alternative ways; in-situ sediment solids concentration can be expressed in terms of water content or void ratio and specific gravity. SETTLE allows the user to enter the data either way and then calculates the value for the other. Some of the input parameters may also be the focus of design calculations. Although they are not required, entering them does not affect the design calculations. For example, if you wish to determine the minimum area and volume required for storage given the dike height, depth of ponding, and freeboard, then the interior area for storage need not be specified because it will be the result of the analysis as opposed to a variable used in the analysis.

The project data are entered through four data input screens. The first two screens request information about the sediment to be dredged that include the dredging volume, percent fines, specific gravity, and settled sands concentration. The third screen asks for dredge production data such as pipe diameter, inflow concentration, inflow rate, and pipe velocity. Disposal area configuration constraints are entered in the final screen. These constraints include maximum dike height, minimum depth of ponded water, maximum total and surface area considering effects of sloped dikes, minimum dike freeboard, minimum hydraulic efficiency, and maximum effluent solids concentration.

Table 7-8. Project Data Requirements and Associated Units.

Parameter	Units
In-situ sediment volume to be dredged	cu yd
Quantity of coarse-grained material in sediment in percent weight	percent
Average specific gravity of sediment	none
Average in-situ void ratio of sediment	none
Average in-situ water content of sediment	percent
Influent suspended solids concentration	g/L
Production rate of dredge (in-situ sediment)	cu yd/hr
Influent flow rate	cfs
Influent dredge pipe diameter	feet
Influent pipeline flow velocity	ft/sec
Dredging or disposal during	days
Disposal time per day	hour
Percent of disposal time spent as down time	percent
Dike crest height	ft
Freeboard depth	ft
Depth of ponded water	ft
Total interior surface area of CDF for storage	acre
Percent of storage area ponded	percent
Hydraulic efficiency	percent
Effluent suspended solids limit	mg/L

Program Execution Using Laboratory Settling Data

Once the settling test and dredging project data have been entered, SETTLE is ready to determine the desired parameters by performing design calculations for the CDF. Design calculations using laboratory settling data are initiated by selecting option 3, execute using laboratory settling data, from the SETTLE *Activity Selection Menu.* Selecting this option provides the user with a screen containing available design options (Table 7-9) for initial storage, clarification, and effluent quality. The user must select the design parameter (i.e., surface area, ponded depth, and dike height) to be calculated for each criteria. The design parameters for each criteria are fully independent, and the user may select the same or different design parameters for each criteria.

One of four design parameters can be calculated based on the compression settling data, two based on the zone settling data, and three based on the flocculent settling data. Compression settling data may be used to compute either the initial storage volume required if given the disposal duration, the minimum dike height required to provide adequate storage volume given the surface area of the disposal facility, and the disposal duration. The maximum influent flow rate permits compression settling to reduce the storage requirements to the available volume of the disposal facility, or the minimum storage area required to provide adequate storage volume given the dike height and disposal duration.

Table 7-9. Design Options Available for Settle Runs.

Compression Settling for Initial Storage	Zone Settling for Clarification	Flocculent Settling for Effluent Quality
None	None	None
Minimum area and storage volume	Minimum ponded area and interior area for clarification	Minimum area, ponded area and volume, and mean residence time
Minimum average dike height, storage volume, and depth	Maximum influent flow rate for clarification	Minimum ponded depth and volume, and mean residence time
Maximum flow rate, maximum production rate, and minimum disposal period		Maximum flow rate and minimum residence time
Maximum volume of in-situ material		Effluent suspended solids concentration

Flocculent settling data may be used to compute either the effluent suspended solids concentration given the ponded water depth, ponded area, and influent flow rate. It can be used to determine the minimum surface area required to achieve the desired effluent suspended solids concentration given the depth of ponding and influent flow rate. The maximum influent flow rate permitted to achieve the desired effluent suspended solids concentration can also be determined when the ponded depth and ponded area averages are known. The minimum depth of ponding that achieves the desired effluent suspended solids concentration in the ponded area and maximum influent flow rate can be determined. The actual minimum ponded depth must be great enough to prevent scouring and resuspension.

Texas GIWW Dredging Project Example

SETTLE calculates design parameters based on laboratory settling test data and dredging project data. It provides CDF sizing calculations that are based on the two types of settling, compression, and flocculent settling, that are likely to occur in a CDF along the Texas GIWW. The SETTLE user must understand the differences in these settling characteristics and be capable of determining which controls the design.

For a fiscal year 1997 dredging project from Rollover Pass to Bolivar Peninsula in the Texas GIWW, the material dredged was 600,000 cy. The proposed dredged material placement areas were CDF No. 35, No. 36, No. 42, and emergent CDF No. 43 as well as beach nourishment. The analyses herein only reflect the concept of the relations among those parameters. The reason is that a set of assumed compression settling data, flocculent settling data, average in-situ sediment data, and average settled sediment data is used for this discussion. Here, some effort has been made to find the relations among the inflow rate, the dike height, ponded water depth, initial storage volume, and the sediment volume to be dredged.

Compression Settling Data

Figure 7-14 reflects the change of required minimum initial interior area with that of inflow rate, dike height, and inflow solids concentration, while the other parameters are kept constant. These results show the minimum interior area decreases as the dike height increases from 10 to 12 ft and the inflow of solids concentration decreases from 40 to 30 percent. As the slurry inflow rate from the dredge increases, the minimum interior area must increase.

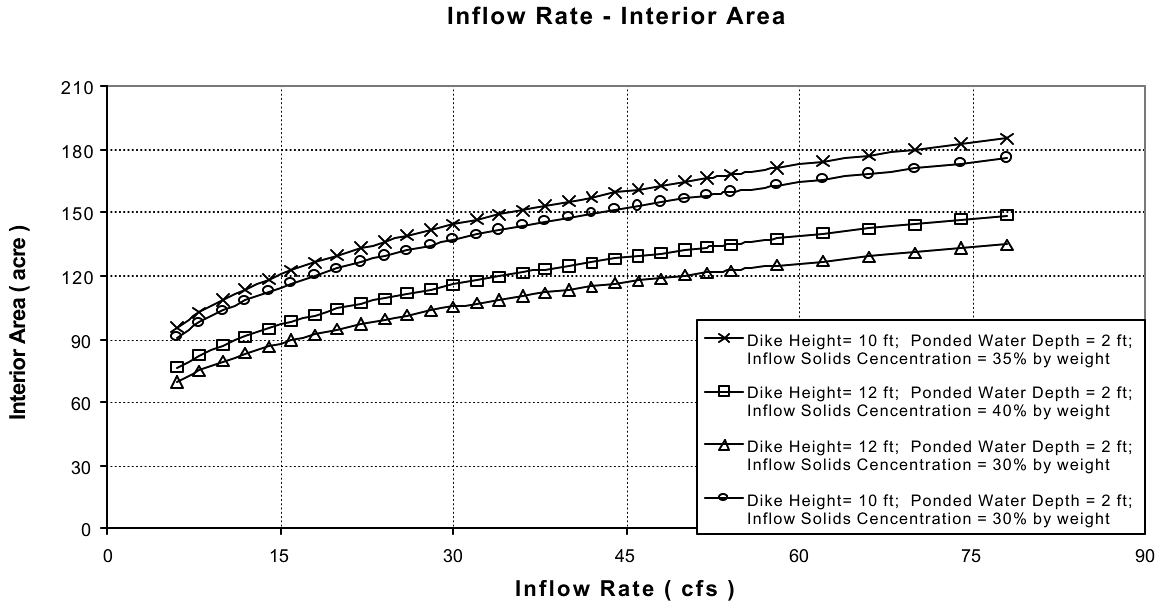

Figure 7-14. Minimum Initial Interior Area Versus the Inflow Rate from the Dredge.

The change of required minimum initial storage volume with that of the inflow rate, dike height, ponded water depth, and inflow solids concentration, while the other parameters are kept constant is illustrated in Figure 7-15. Similar to the previous figure, the minimum initial storage volume increases as the slurry flow rate increases. Increasing the dike height always increases the minimum initial storage volume. If the solids concentration is decreased from 40 to 30 percent by weight for the same dike height, the minimum initial storage volume is decreased. For example, at an inflow rate of 45 cfs, the minimum initial storage volume reduces from approximately 1,125 to 1,100 acre-ft as the concentration is reduced from 40 to 30 percent respectively.

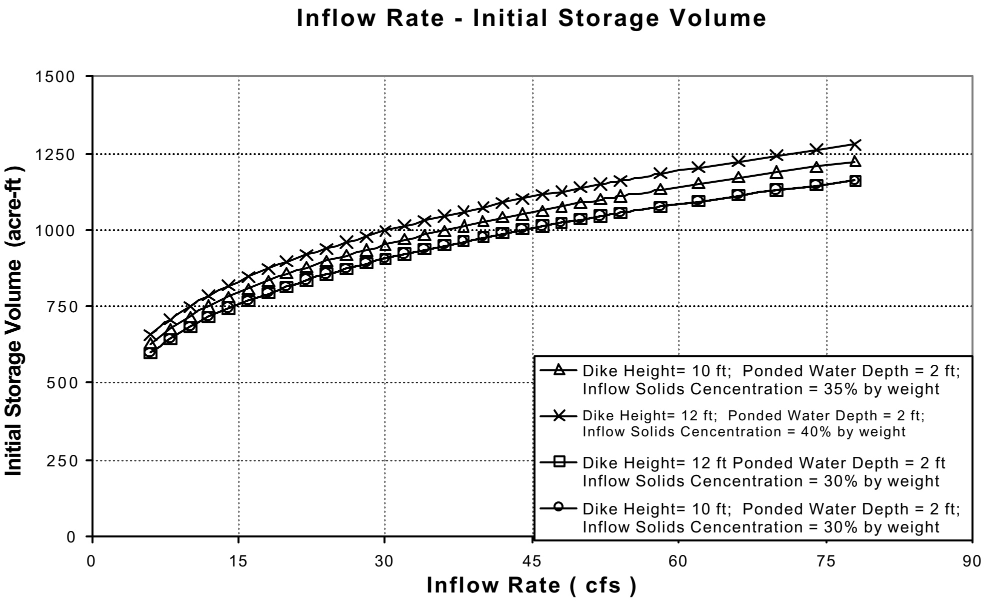

Figure 7-15. Minimum Initial Storage Volume Versus the Inflow Rate from the Dredge.

Flocculent Settling Data

Figure 7-16 shows the change of required minimum interior area with that of the inflow rate and maximum allowable effluent solids concentration ranges from 120 to 200 mg/L, while the other parameters are kept constant. At low inflow rates the effluent solids concentration has only a small effect on the area, but at the higher rates the larger concentrations reduce the minimum interior area.

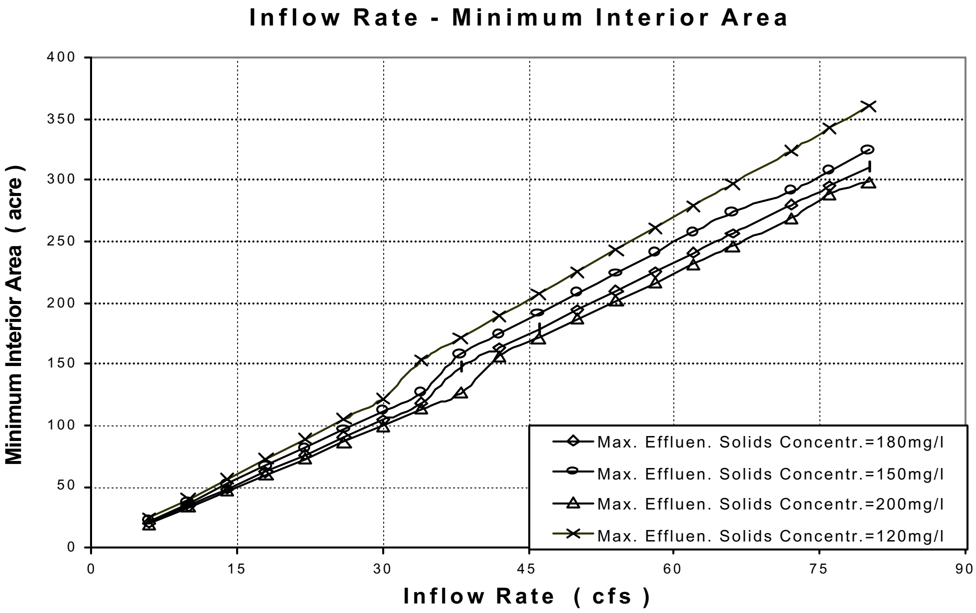

Figure 7-16. Minimum Interior Area Versus the Inflow Rate from the Dredge.

Figure 7-17 reflects the change of required minimum ponded area with that of the inflow rate and maximum allowable effluent solids concentration, while the other parameters are kept constant. Similar trends are illustrated for the minimum ponded areas as found for the minimum interior area.

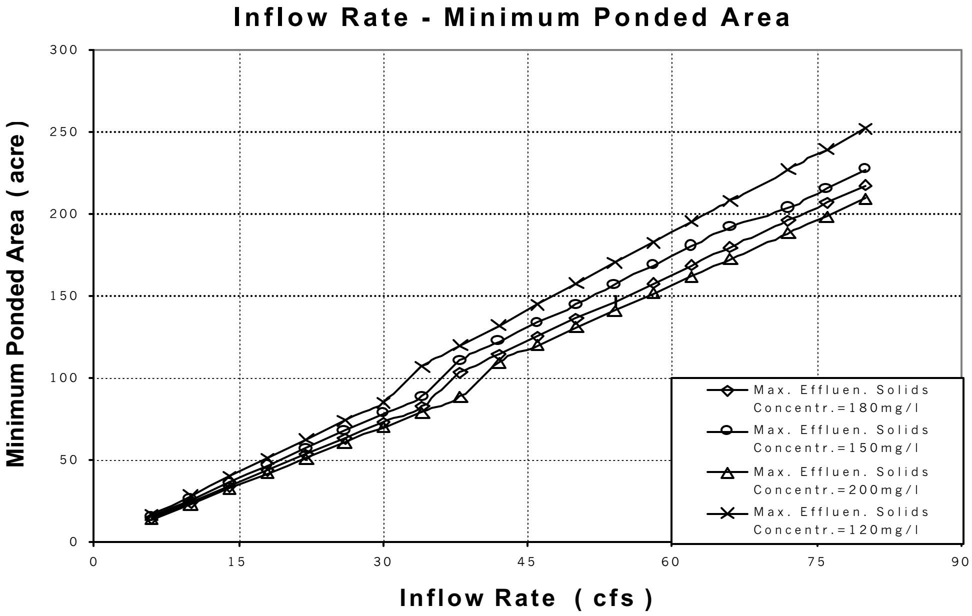

Figure 7-17. Minimum Ponded Area Versus the Inflow Rate from the Dredge.

Figure 7-18 reflects the change of required minimum ponded volume with that of inflow rate, maximum allowable effluent solids concentration, while the other parameters are kept constant.

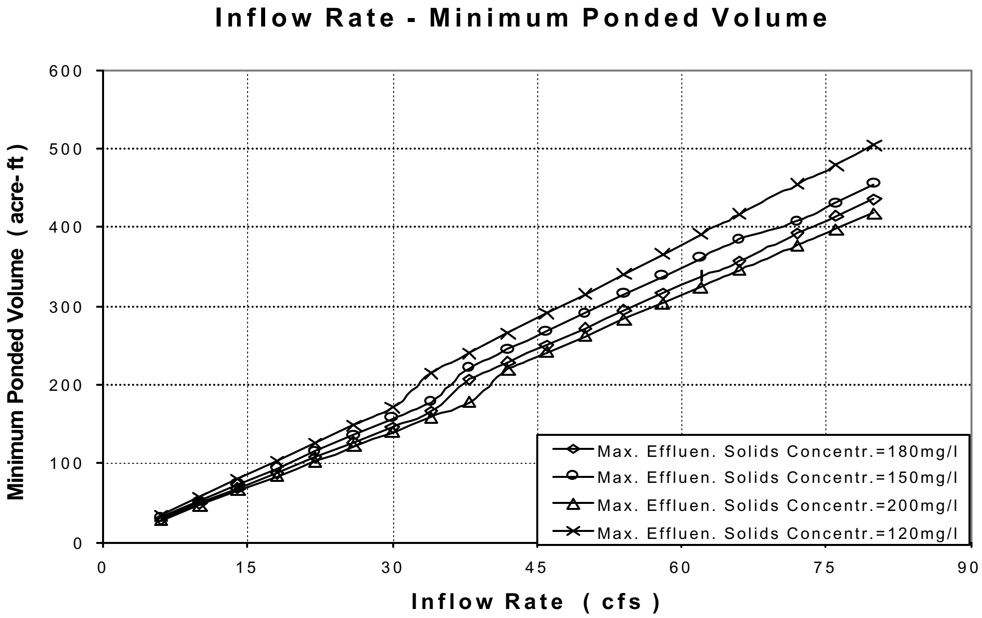

Figure 7-18. Inflow Rate - Minimum Ponded Volume.

Conclusions

SETTLE is another ADDAMS tool that facilitates properly dredged material management by providing an effective and efficient means of performing CDF design calculations. SETTLE is easy to use and encourages the evaluation of an array of design alternatives. Laboratory tests are required until reliable relationships between sediment characteristics and settling properties can be established.

CHAPTER 8 EXECUTIVE SUMMARY

INTRODUCTION

A two-year study has been completed that investigated alternative dredging techniques and dredged material disposal methods that are applicable to the Gulf Intracoastal Waterway and consistent with the Texas Coastal Zone Management policy. The report discusses the results for the project tasks that include: costs and engineering of long distance pumping (Task 1), beneficial use of the dredged material to benefit the Texas coastal zone (Task 2), methods for separating different types of dredged material (Task 3), development of computer software for estimating the cost of long distance pumping of dredged material (Task 4), optimum slurry flows (Task 5), and alternatives available for analyzing dredged material disposal (Task 6).

The results from the study are expected to benefit the state of Texas, general public, and users of the GIWW. The identification of beneficial uses of dredged material from the GIWW for Texas specific applications may develop a market for dredged material that is currently placed in disposal sites. Reuse of the material placed in upland disposal sites can relieve the need to purchase new disposal site acreage, and thus the life of current disposal sites can be extended. The software developed for this project can be used for the evaluation of the cost of cutter suction dredging and specific beneficial uses such as manufactured soil and use of geotubes for erosion control.

COST AND ENGINEERING OF LONG DISTANCE PUMPING (TASK 1)

Long distance pumping of dredged material requires the addition of booster pumps located along the discharge pipeline. Cutter suction dredges have centrifugal pumps onboard to pump the dredged material through the discharge pipeline. However, if the pipeline is sufficiently long (e.g., greater than 3.2 km or 2 mi for large dredges), then the total head of the pump may not be sufficient to accomplish the task. Therefore, a booster pump station must be added to provide the additional head to transport the dredged material to the required discharge location. For very long pipes, several booster pumps may be required.

Estimating the cost of dredging is very complicated. First, the dredge production (cubic yards or cubic meters of dredged material removed) must be estimated. Important factors in production estimation include in situ sediment specific gravity, mean grain size, discharge elevation, discharge pipe length, pipeline energy losses, pump efficiency, and dredge efficiency. An engineering spreadsheet has been developed that incorporates these important factors to estimate the dredge production rate and subsequently uses the estimated production rate to evaluate the cost of the dredging project.

The main components involved in the cost of dredging are fuel and lubricant costs, dredge and land crew labor costs, routine maintenance and repairs, major repairs and overhauls, overhead costs, depreciation, profit, mobilization and demobilization, booster pumps, and capital investment. These cost items have been identified and incorporated in the development of cost estimating software for a cutter suction dredge similar to those used in dredging in the Texas GIWW.

BENEFICIAL USES OF DREDGED MATERIAL FROM GIWW (TASK 2)

Manufactured Soil

The concept of manufactured soil is one of the proposed alternatives for the long-term management of the dredged material disposal sites along the GIWW. It has been shown through a number of studies and pilot tests that manufactured soil can be created using dredged material, recyclable organic waste materials (sewage sludge), and bio-mass (cellulose or saw dust).

Research by the Waterways Experiment Station (WES) in conjunction with local USACE districts produced favorable results for the use of manufactured soil. An example of creating a manufactured soil, although not using dredged material, has been performed in Texas. The re-use of bio-solids for the creation of a manufactured soil was used in Huntsville, Texas, for a fertilizer product. These results demonstrate the feasibility of manufactured soil as a beneficial use of dredged material and suggest its broad applicability in Texas and around the country.

The main issues affecting the feasibility of manufacturing soil include: finding a market or use for the converted topsoil, determining the optimum site for the project, deciding which bio-mass should be used and from where it will come, and acquiring the bio-solid or reconditioned sewage sludge. A methodology is developed for determining the costs associated with converting dredged material to topsoil, and two beneficial use examples for manufactured soil are discussed. Excavation, transportation, and manufacturing costs are applied to each of the materials used in the creation of the topsoil. Sample spreadsheets that reflect the methodology are developed and discussed. The cost analysis is applied to two potential pilot sites along the Texas GIWW to demonstrate the methodology. The two sites, Matagorda Bay and the Bolivar Peninsula near Galveston Bay, show that manufactured soil for use in construction and landfill projects is feasible with prices ranging from \$17 to \$26 per m^3 (\$13 to \$19.9 per cy) of manufactured soil.

The results show:

- Converting dredged material is technically feasible. Studies conducted at the regional USACE districts, and by the WES, demonstrate the applicability of this new technology. Individual feasibility studies need to be performed for each site to determine if the dredged material has the properties necessary for producing a high-quality manufactured soil.

- Site selection is paramount in selecting a disposal area where excavation equipment can work. Many disposal areas are located along the coastlines, and the Texas GIWW in particular. Most sites are remote with limited land access. Alternatives to excavating the dredged material using land-based equipment should be investigated. One potential solution is to excavate the disposal area using a clamshell dredge or a dragline. Depending on the dike heights, the dredge could remove the material from the disposal area and place it in a barge or scow.

- Manufactured soil can be created and transported small distances (<40 km, < 24.8 mi) at a cost of $17 to $26 per m^3 ($13 to $19.9 per cy) of topsoil depending on the blending method, mode of transportation, and ease of excavation. This price is based on the bio-solid reconditioned to a Class B level for restricted uses and donated by a sewage treatment facility. An additional cost of $28 to $32 per m^3 ($21.4 to $24.5 per cy) is necessary if the bio-solids are reconditioned to an unrestricted Class A level.

- Although manufactured soil is more expensive than typical landfill cover and construction materials, it must be emphasized that the goal, or purpose of converting dredged material to topsoil, is to reduce the volume of dredged material placed into a disposal area. In addition, use of dredged material from the disposal site will save costs associated with the purchase of land for new disposal areas.

- It is recommended that plant-screening tests be performed on the dredged material to evaluate suitability as a manufactured soil and potential growing capacity. These tests determine the percentages of each material, dredged material, bio-solid, and bio-mass for optimal plant growth. In addition, the screening test would also be used to determine the effects of salinity on selected plant types. The change of the plant species in the manufactured soil could be studied as the salt leaches out of the system. A pilot study could then be performed at a small or medium size scale (800 to 8,000 m^3 or 1,046 to 10,464 cy of dredged material) to answer questions. Only through an actual hands-on demonstration can the many unexplored questions be addressed.

The creation of a methodology for adequately addressing costs for this new technology is essential. Previous research in the field of manufactured soil has not addressed the overall feasibility and cost effectiveness of manufactured soil. This situation is due to the donation of materials and transportation costs for the pilot tests. This study developed two methodologies to assess the feasibility and estimate project costs, and a spreadsheet is available in English and metric units to estimate the project costs.

Thin-Layer Disposal of Dredged Material

There are several dredging sites along the Texas GIWW where the thin-layer disposal method can be applied. The dredging locations that have been identified in this report as possible candidates for thin-layer disposal include Galveston Causeway to Bastrop Bayou, Freeport Harbor to Caney Creek, and San Bernard River to Matagorda Bay. For the specific dredging site, the thin-layer disposal width and thickness can be predicted by knowledge of its dredging volume, disposal thickness, and disposal width versus thickness curves.

When the thin-layer disposal thickness exceeds the desired thickness limit (currently 15 to 25 cm) for a specific dredging site, then increasing the dredging frequency and changing the dredging time schedule should be considered in order to apply the thin-layer disposal at this location. Current equipment can spray approximately 250 ft inland and retractable reels and associated pipe can be used to spray the dredged material further inland. Another possibility is to augment the thin-layer disposal with excess dredged material being discharged into the current confined disposal facilities.

Experiences with thin layer disposal have been documented at many sites outside of Texas and thin-layer disposal techniques and existing equipment have been described. Many thin-layer beneficial use projects have been successful, and it appears there are opportunities for this relatively new technique to be used for the benefit of the operation of the Texas GIWW. Additional physical and biological investigations are needed to further evaluate the acceptability of thin-layer disposal for the Texas GIWW.

Use of Geotubes to Control Erosion Along GIWW

A method for combating the erosion loss of wetlands as well as providing a beneficial use of dredged material is the placement of geotubes along the GIWW. Geotubes can provide protection against erosion and provide long-term management of dredged material. Geotubes have been used in many applications such as groins, revetments, contaminant dikes, breakwaters, reclamation works, dune reinforcement, and can be used along the GIWW. Advantages of using geotubes include providing a beneficial use for dredged material, lower cost compared to traditional coastal erosion structures, decrease in work volume, use of local materials, and lower skilled labor. However, resistance to punctures, fabric degradation, placement, variation in height, and limited guidance are possible limitations of using geotubes.

Geotubes placed along the GIWW should be designed to withstand the pressures of filling, provide sufficient permeability, contain the dredged material, and resist erosion once in place. Soil properties of the fill material must be found in order to select the material and calculate spacing for the inlets. The size of the geotextile mesh openings should be such that the material is contained and the tube is allowed to dewater. Recommendations by AASHTO and a soil-testing flowchart method from Sprague (1993) are suggested for determining the mesh opening size. The material used should be a high-strength geosynthetic that is resistant to ultraviolet rays, oils, and chemicals that may be found along the GIWW. The spacing of the inlets is based on the fall velocity of the sediments and increases as the mean sediment size decreases. A software design tool, GeoCoPS, is a verified tool that can predict the dimensions of a filled geotube and can be used in selecting geotextile material based on the filling pressures.

Scour is a problem that must be addressed before a geotube can be installed. Scour aprons can be installed using sandbags, sewn pockets, or a continuous seam that keeps the leading edge from floating. Scour aprons are a standard method to prevent scour. However, there are no criteria for calculating the width of the apron, and current practice suggests using the circumference of the tube as the scour apron width.

This report describes two geotube installation methods. One method is called the small dredge method and the other is the split pipe method. The small dredge method utilizes a small dredge that is directly connected to the filling tube. The small dredge is only used until the tube is filled. The split pipe method uses the same dredge that is doing the maintenance dredging in the GIWW, and a branched pipe from the discharge line of the dredge is connected to the geotube for filling.

A geotube can be designed for placement along the GIWW and provide a beneficial use of dredged material while preventing further inundation of wetlands due to erosion. Geotubes for this application consist of a circumference of approximately 9.14 m (30 ft) and contain about 1.53 cubic meters (2 cubic yards) of dredged material per linear foot. The case studies described in this investigation demonstrate that geotubes have been successfully filled hydraulically and used as coastal protection structures. Geotubes, designed to contain dredged material and protect further erosion of the GIWW, are more economical when installed in conjunction with maintenance dredging projects. The more cost efficient installation method is the split pipe method because mobilization costs are much less. As shown by the cost estimating spreadsheet, the cost per cubic yard (approximately $60 to $80) is much greater than placing the material in a CDF, but over time it is expected to reduce dredging frequency and wetland loss, which is an excellent beneficial use for the dredged material.

It is recommended that pilot studies, such as the examples described in this report, be conducted to determine the effectiveness of long-term dredge material management using geotubes. These pilot studies should be conducted simultaneously with a dredging project and monitored to report the condition of the geotubes and their effectiveness in preventing further erosion. The geotubes for these studies are recommended to be approximately 9.14 m (30 ft) circumference, 152 to 305 m (500 to 1000) in length, filled directly from a small dredge or branch pipe, and have a minimum scour apron width of 9.14 m (30 ft). It is also recommended that further studies be conducted regarding scour and the width of the scour aprons to maximize the structure’s effectiveness against erosion and undercutting.

IDENTIFY SEPARATION TECHNIQUES APPLICABLE TO GIWW DREDGED MATERIAL (TASK 3)

The separation of sands and silts and the dewatering of dredged material can extend the life of a CDF by reducing the volume of disposed material. In addition, separated material like sand can be used for beneficial purposes such as beach renourishment.

Many separation techniques are not applicable to the high volumes associated with dredging operations, but the dewatering wheel and hydrocyclone have been identified as two potential dewatering mechanisms for use in conjunction with the disposal of dredged material resulting from maintenance dredging in the Texas GIWW. The mining and mineral processing industries use both these technologies. Limited use in the dredging industry includes West Coast mining operations using the dewatering wheel and trial tests in Michigan using the hydrocyclone. Further investigation into the operation of sand mining companies will assist in determining the operating constraints and potential problems of the dewatering wheel.

Separation techniques can also be applied to contaminated sediments. Contaminants attach themselves with clays and organic materials. If the dredged material can be divided into sand and silt fractions, the amount of contaminated material to be treated or disposed of can be decreased. While the hydrocyclone pilot study for the Miami River involves contaminated material, the actions and results of this pilot study should be studied for potential use as a separator of large particles. Further research and pilot tests should be conducted to evaluate the effectiveness of either of these technologies in dredging operations.

COST ESTIMATING SOFTWARE FOR LONG DISTANCE PUMPING (TASK 4)

The Cutter Suction Dredge Cost Estimation Program (CSDCEP) is a program that estimates the production rate of cutter head dredges and the cost of dredging projects using such dredges. The program is a non-proprietary cost estimation tool and is generalized so that estimates can be made for projects using any size dredge and any length of discharge pipeline. The theory used in the program is sound, and the practical components of the program are drawn from knowledgeable and experienced members of the dredging community. Based on the comparisons of production rates and project costs, it can be concluded that CSDCEP is an accurate and effective tool for estimating the production of a cutter suction dredge and the cost of dredging projects. The production estimation algorithm is the most important component of CSDCEP and therefore has the bulk of the theory and calculations associated with it. The Wilson et al. (1997) method of frictional head loss calculation is well respected in the dredging industry. This method is incorporated into CSDCEP and is used in conjunction with dimensionless pump characteristics curves as prescribed by Herbich (1992) to yield the production rate for any size dredge. The production rates are calculated for clean sand and then multiplied by the USACE (1988) material factor and Turner's (1996) bank factor. The production estimates given by CSDCEP were compared with other known production estimation routines. CSDCEP compared favorably with the other estimation methods and, though an option is provided in the program to use the USACE production estimate, it is recommended that the CSDCEP method be used.

The total amount of time required to complete the dredging project is calculated from the production rate, and this value is used to determine the costs of labor and equipment operation. Bray, Bates, and Land (1997) provide the bulk of the procedures used by CSDCEP to obtain these costs. The equipment capital costs and mobilization and demobilization costs are independent of the production rate and are calculated separately. These components often contribute a significant amount to the final cost. The cost estimate results given by CSDCEP were compared with actual data and government cost estimates for several completed projects. The average difference between the estimate and the actual cost was 24 percent. This average difference is a very reasonable figure considering the general nature of the CSDCEP program. In three of the four projects where a government estimate was provided, CSDCEP yielded a better estimate of the actual cost. The winning bidder was more accurate on all four, but this is to be expected due to the fact that more detailed information is known about the contractor's particular equipment and methods.

The fact that CSDCEP is a generalized program means that it will not be quite as accurate as the estimates calculated by the individual dredging contractors. This is unavoidable due to the diverse nature of dredging contracts and equipment. Many of the inaccuracies can be minimized through careful attention by the user to all potential cost-impacting aspects of a particular project. When all the important factors are taken into account and the necessary adjustments are made to the cost estimate produced by CSDCEP, the end result should be an accurate approximation of the final cost.

OPTIMUM SLURRY FLOWS (TASK 5)

The CD-CORMIX software (now called CDFATE) is a very useful tool in evaluating the sediment concentration and mixing zone boundaries for dredged material disposal in open water and can be applied to the dredged material disposal in shallow water such as that encountered in dredging in the Texas GIWW.

In the case of a submerged steady discharge that is directed vertically downward, the centerline concentration of the plume for the small dredge size is always smaller than that of a large dredge size under the same discharge conditions. This means the turbidity created is smaller for a small dredge (0.203 m, 8 in) than for a large dredge (0.61 m, 24 in). The discharge velocity closest to the critical velocity required to transport the sediment through the pipeline is the most desirable for minimizing turbidity in the water column. Recall that velocities below the critical velocity will not keep the dredged material suspended in the horizontal pipeline from the dredge to the discharge point. Also, the closer the discharge point is to the bottom, the smaller the sediment concentration.

In the case of above water discharge from 0.203 m (8 in) and 0.305 m (12 in) small dredges, the results are the same as that for the case of a submerged vertical downward discharge. For the above water surface discharge, the intensity of turbulence is stronger than that of submerged vertical downward discharge after the jet plunges into the water body, especially when the jet speed is high. So, in this case, the larger the dredge size, the more turbulence in the plume, then the sediment diffuses to a wide range and the centerline concentration is smaller.

In the case of the 45 degree or horizontally submerged discharge that is in the same direction as the ambient current, the sediment can be suspended over a wider range. The diffusion region becomes wider and the centerline concentration becomes smaller when the discharge velocity is increased. The centerline concentration or turbidity is also smaller for the smaller dredge size. Therefore, this study shows that using smaller dredges can reduce turbidity during the dredging process.

The submerged horizontal discharges show better dilution (less concentration) for the higher discharge velocities, but the concentration is still reduced by approximately one-half by reducing the dredge size from 61 cm (24 in) to 20.3 cm (8 in).

For slurry discharge above the water surface, increasing the discharge velocity reduces the centerline concentration. This is a result of the increased turbulence caused by the slurry jet as it plunges into the water. However, the smaller dredge size still results in a smaller centerline concentration or less turbidity than for a large dredge size.

Recommendations for the optimum discharge operation that reduces turbidity, mixing zone size, and deposits more of the discharged sediment on the bottom are:

(1) The ambient current velocity has an important influence on the dilution process. The smaller the ambient current, the faster the sediment is deposited. So, the disposal site should be chosen in a small ambient current field.

(2) The angle between the ambient current direction and the slurry discharge direction must not be bigger than 90 degrees. If the angle is larger than 90 degrees, then the jet produces a large turbulence with ambient water body. The sediment is suspended for a long time in the turbulence, and the diffusion region is much wider.

(3) In the same ambient conditions and the same discharge operations, the large dredge always produces higher turbidity (concentration) and a larger mixing zone region than the small size dredge for the same discharge velocity, mean grain size, and slurry concentration.

(4) The plume of the above water surface discharge is always larger than that of the submerged discharge as a result of the influence of turbulence.

(5) For the same ambient conditions and the same discharge operations, the plume sizes of slower discharge velocity are always smaller than that of a higher discharge velocity for a specific dredge. Discharging at a velocity just above the critical velocity for heterogeneous flow is the recommended operation procedure for the purpose of reducing mixing region size.

(6) The lowest centerline concentration of suspended sediment occurs at the lowest discharge velocity, so a small dredge is more desirable in the same dredging condition for small plume size and lowest concentration.

(7) The plume size of a more submerged vertical downward discharge is always smaller than that of above water discharge, 45 degrees downward submerged discharge, and submerged horizontal discharge.

ALTERNATIVES FOR ANALYZING DREDGED MATERIAL DISPOSAL (TASK 6)

Computer Model (LTFATE) for Predicting Sediment Mound Movement

The numerical model LTFATE is used for estimating the long-term response of a dredged material disposal site to local environmental forces such as waves, currents, and tides. The software was developed to determine whether an existing or proposed disposal site is dispersive or nondispersive over a period of time on the order of months to years. For a specific disposal site, the database of environmental forces is required to provide a means of defining realistic boundary conditions at a proposed or existing disposal site without requiring the collection of prototype data.

The model has the capability to predict the long-term stability of dredged material mounds as well as short-term storm surge. The results in this chapter only demonstrate an example of a long-term fate application in Galveston Bay, but the environmental data were not available for Galveston Bay so the existing data in the model were used for demonstration purposes only. Further work is needed to get the database of environmental forces (tides, waves, and currents) of the specific disposal site of interest. It is recommended that assistance from the Corps of Engineers or the authors of this report be obtained for a first-time user. This software can be downloaded from the U.S. Army Engineer Waterways Experiment Station website.

Computer Model (SETTLE) for Optimizing the Design of Confined Disposal Facilities

SETTLE is another ADDAMS tool that facilitates proper management of dredged material by providing an effective and efficient means of performing CDF design calculations. SETTLE is easy to use and encourages the evaluation of an array of design alternatives. It does not, however, preclude the need for laboratory settling tests on the dredged material to be placed in the CDF. These tests will continue to be required until reliable relationships between sediment characteristics and settling properties can be established. Further efforts are also needed to find the relations among the inflow rate, inflow solids concentration, initial storage, minimum initial storage area, dike height, effluent solids concentration, and ponded water depth.

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APPENDIX A . CUTTER SUCTION DREDGE COST ESTIMATION PROGRAM (CSDCEP) USER'S MANUAL

CUTTER SUCTION DREDGE COST ESTIMATION PROGRAM (CSDCEP)

CSDCEP USER'S MANUAL

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TEXAS TRANSPORTATION INSTITUTE

FOR

TEXAS DEPARTMENT OF TRANSPORTATION

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APPENDIX A. CUTTER SUCTION DREDGE COST ESTIMATION PROGRAM (CSDCEP) USER'S MANUAL

INTRODUCTION

General Information

CSDCEP is a useful personal computer-based tool for estimating the cost and production of a dredging project using a cutter head dredge, developed by Michael Miertschin of Texas A&M University. The program is written in Quattropro spreadsheet format and provides a very user-friendly platform for generating cost estimates.

The purpose of the program is to provide a non-proprietary cost estimation program that can be made available to anyone who wishes to use it. Because of the generalized nature of this program, a mixture of theory and practical dredging rules are used in conjunction with data from past dredging projects to generate as accurate a cost estimate as possible without detailed knowledge of the equipment to be used.

Need for Generalized Cost Estimation Software

There are many cost estimation programs in existence in the dredging industry, but each is developed by the individual company and as such is not made available to others outside the company. The need remains, therefore, for a cost estimation program that can be used by any individual who wishes to estimate the cost of a dredging project.

When estimating the cost of a dredging project, there are many considerations that need to be taken into account, including the costs of mobilization, demobilization, labor, capital investment, operation, and overhead. The amount of calculations and information involved make it virtually necessary to use a computer program to formulate the estimate.

Benefits of CSDCEP

CSDCEP provides the following:

- cost estimates for any cutter head dredging project, for any size dredge,
- production estimates taking into account the type of sediment, size of dredge, and length of pipeline, and
- a convenient method of changing parameters to suit the specific project if detailed information is available.

System Requirements and Installation

CSCDEP operates in the Microsoft Windows 95 environment, in Quattropro version 6.01 spreadsheet format. This program can not be converted into Microsoft Excel or any other spreadsheet, so it is necessary to have Quattropro installed on your computer.

To install CSDCEP on your computer, simply insert the CSDCEP program disk into your floppy drive and copy the file "CSDCEP.wb2" to the hard drive in the desired directory. CSDCEP can now be started by opening the file from the Quattropro program, or simply by double clicking the file from the program manager in Windows.

PROGRAM OPERATION

Organization

The program is divided into six main sections:

1. Main input and output page (Figure A-1 and Figure A-2) – primary input area and display of program results.
2. Defaults page (Figure A-4) – default values of variables used in the program, which can be changed by the user.
3. Mobilization and demobilization page (Figure A-5 and Figure A-6) – costs are calculated on this page for the process of preparing and transporting the dredging equipment to and from the job site.
4. Project execution page – costs are calculated on this page for all aspects of the dredging project carried out at the job site.
5. Database page – data on labor rates, crew sizes, equipment costs, etc. are kept on this page and are accessed by the program.
6. Production estimation pages – calculations are executed on these pages to estimate the production of the dredge under the given circumstances.

Throughout the program, cells intended for input by the user are denoted by a green color (this manual is black and white only, so the color green is denoted by gray). Though the bulk of the user input is entered on the main input page, there are also input cells on the defaults page, the mobilization/demobilization page, and the project execution page.

Main Input and Output Page

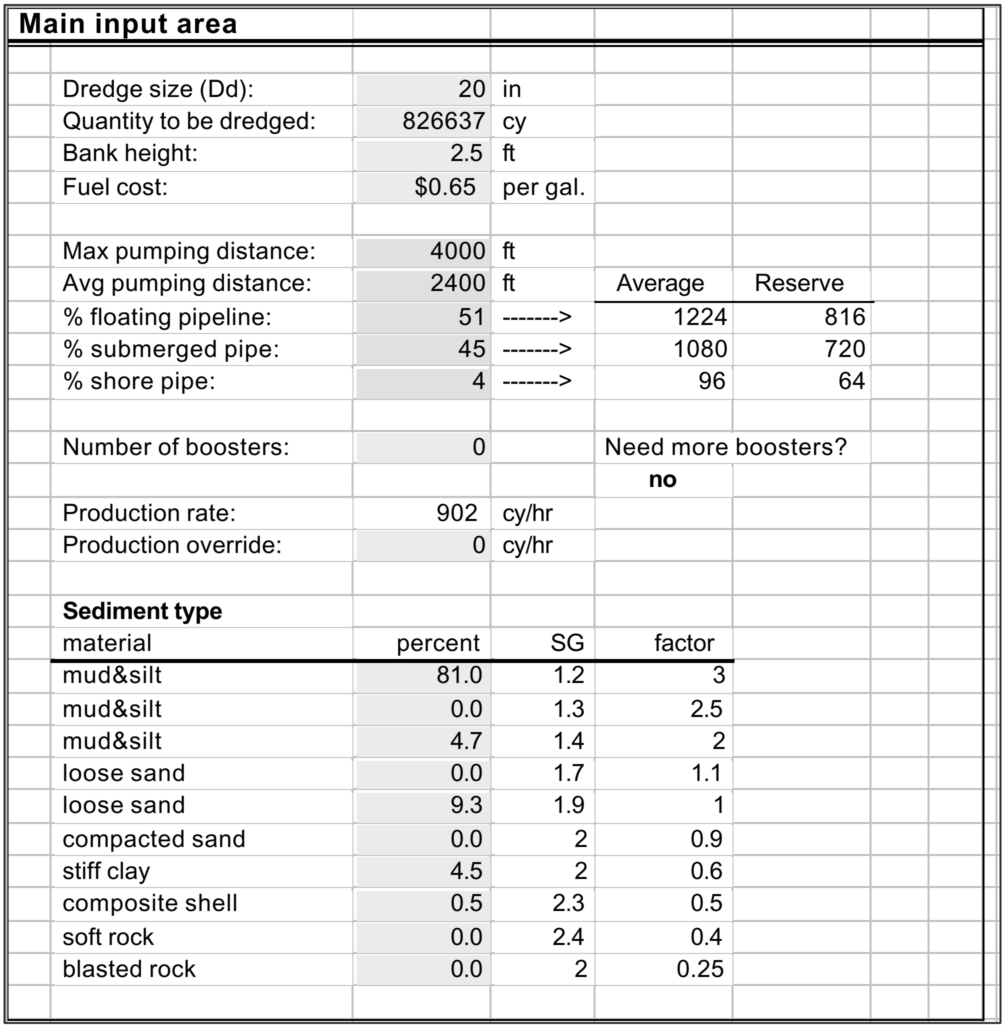
The main page is divided into two areas called the "Main Input" (Figure A-1) area and the "Cost Estimate Results" (Figure A-2). The main input section is where the user enters the basics of the dredging project.

Dredge Size

This is the size of dredge to be used on the project, measured by diameter of the discharge pipeline in inches. This number is used in all areas of the program and is the basis for determining crew sizes, dredge production rates, and equipment costs.

Quantity to Be Dredged

The quantity to be dredged is the volume in cubic yards of dredged material to be removed. It is assumed that the pay is based upon the volume of material removed from the channel, not the volume placed in the disposal area.



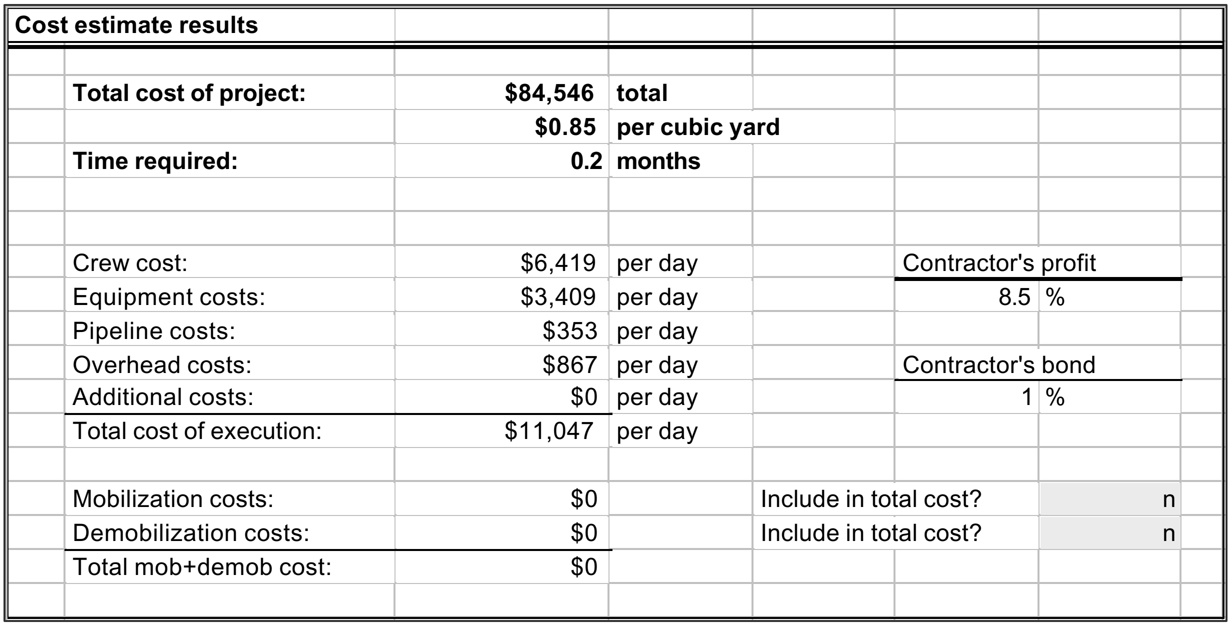
Main input area

Dredge size (Dd):	20	in		
Quantity to be dredged:	826637	cy		
Bank height:	2.5	ft		
Fuel cost:	$0.65	per gal.		
Max pumping distance:	4000	ft		
Avg pumping distance:	2400	ft	Average	Reserve
% floating pipeline:	51	------->	1224	816
% submerged pipe:	45	------->	1080	720
% shore pipe:	4	------->	96	64
Number of boosters:	0		Need more boosters?	
			no	
Production rate:	902	cy/hr		
Production override:	0	cy/hr		

Sediment type

material	percent	SG	factor
mud&silt	81.0	1.2	3
mud&silt	0.0	1.3	2.5
mud&silt	4.7	1.4	2
loose sand	0.0	1.7	1.1
loose sand	9.3	1.9	1
compacted sand	0.0	2	0.9
stiff clay	4.5	2	0.6
composite shell	0.5	2.3	0.5
soft rock	0.0	2.4	0.4
blasted rock	0.0	2	0.25

Figure A-1. Main Input Section of CSDCEP.



Cost estimate results					
Total cost of project:	**$84,546**	**total**			
	$0.85	**per cubic yard**			
Time required:	**0.2**	**months**			
Crew cost:	$6,419	per day		Contractor's profit	
Equipment costs:	$3,409	per day		8.5	%
Pipeline costs:	$353	per day			
Overhead costs:	$867	per day		Contractor's bond	
Additional costs:	$0	per day		1	%
Total cost of execution:	$11,047	per day			
Mobilization costs:	$0		Include in total cost?		n
Demobilization costs:	$0		Include in total cost?		n
Total mob+demob cost:	$0				

Figure A-2. Main Output Section of CSDCEP.

Bank Height

The bank height is the average depth of the cut to be made in the channel. The bank height is used to determine the "bank factor" (Figure A-3) that is a factor applied to the dredge production based on the ratio of the cutter head to the bank height. If the bank height is equal to or greater than the cutter diameter, optimum cutting efficiency is achieved, and the factor is approximately equal to one. However, if the cutter diameter is greater than the bank height, the cutter does not take in as much material as it is capable of, and a factor of less than one must be applied to the estimated production rate.

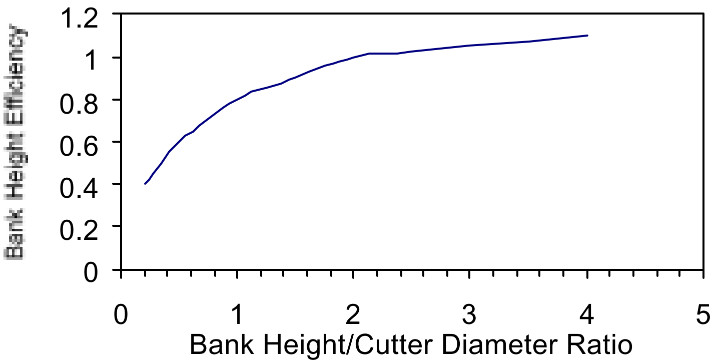


Figure A-3. Bank Factor Determination Chart (Scott, 1997).

Fuel Cost

The current price of bulk diesel fuel per gallon.

Average Pumping Distance

This is the average length of pipe through which the dredged material is pumped to the containment area. This value is used to determine production rates, the need for boosters, cost of pipeline wear, and preparation time for mobilization and demobilization.

Maximum Pumping Distance

This is the maximum length of pipe used on the job. This number is not as significant as the average distance, but it adds to the cost as a result of pipeline on standby and preparation time for mobilization and demobilization.

Percent Floating Pipe, Percent Submerged Pipe, Percent Shore Pipe

This is the percent of the total line length of each respective type of pipeline. This impacts the final cost based on the fact that floating pipe is more expensive than shore pipe, and submerged pipe is the most expensive.

Number of Boosters

This is the number of booster stations desired in the pipeline. If the pipeline is too long for the chosen dredge pump to maintain the necessary velocity, a booster pump must be added. The program determines if this is necessary in the production estimation routine. If another pump is required, it is stated to the right of the input box. Also, it may be desirable to have more booster pumps than are necessary in order to increase dredge production and lower the total cost. The optimum number of boosters can be determined by varying the number entered here and observing the effect on the total cost.

Production Override

The dredge production can be entered manually if the production estimate is unsatisfactory. This input is provided in case the user has experience with the particular dredge in the given circumstances. If the value is set to zero, the calculated production is used.

Sediment Type

This is a very significant factor in the determination of the production rate. A fine-grained silty material is easier to pump than larger grained sediments or clay. There are 10 sediment types listed, and the user may input percentages of each type that is encountered in the channel to be dredged.

The cost estimate results are displayed below the main input section. The primary results of cost per cubic yard, total project cost, and time required are highlighted and displayed at the top of the section. Daily execution costs are displayed and broken down into the following categories: crew, equipment, pipeline, overhead, and additional costs. Also, the total costs of mobilization and demobilization are given.

Defaults Page

On the defaults page (Figure A-4) are listed a number of values used in the program that are typical for current equipment and today's economy. These values will probably not need to be changed in the near future, but the capability exists in the program if differing conditions call for it. The defaults are grouped into four categories: general, mobilization and demobilization, execution, and production.

General

This section includes general calculation parameters, such as contractor's profit and bond, typical crew shift length, and typical hours per day of equipment operation.

Mobilization/Demobilization

This section includes typical values for calculations on the mobilization and demobilization page. Daily costs are listed here for supplies and small tools, support equipment (with operators), fuel, subsistence (per man), and tug boat cost. Other values listed here include towing speed, number of tug boats, and travel expenses (per man).

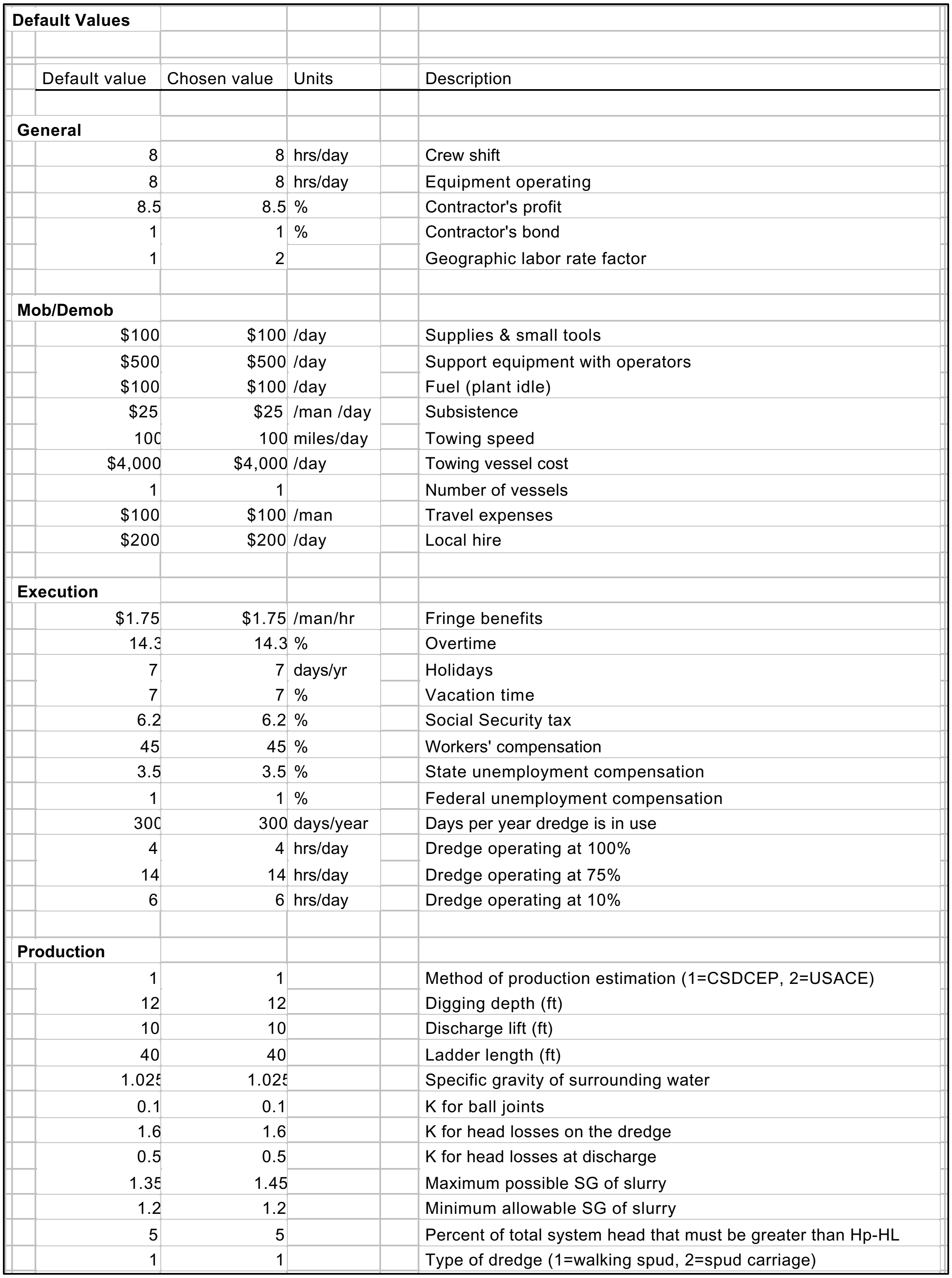
Execution

This section includes values used in the project execution calculations, including labor and equipment. Labor costs are the first values that may need to be changed, since taxes and benefits mandated by the government and unions change frequently. Some of the values used in the labor cost calculations include fringe benefits, overtime, holidays, vacation time, federal taxes, workers' compensation, and unemployment compensation. Equipment variables include hours per day the dredge works at 100 percent and days per year that the dredge is in use.

Production

Values here are given for the production estimation pages. As with the other sections on this page, most of the values are self-explanatory, but some need further clarification.

- **Method of production estimation** – If a 1 is entered here, the program uses its own production estimation algorithm, and if a 2 is entered, then the USACE method of production estimation is used.



Default Values

Default value	Chosen value	Units	Description
General			
8	8	hrs/day	Crew shift
8	8	hrs/day	Equipment operating
8.5	8.5	%	Contractor's profit
1	1	%	Contractor's bond
1	2		Geographic labor rate factor
Mob/Demob			
$100	$100	/day	Supplies & small tools
$500	$500	/day	Support equipment with operators
$100	$100	/day	Fuel (plant idle)
$25	$25	/man /day	Subsistence
100	100	miles/day	Towing speed
$4,000	$4,000	/day	Towing vessel cost
1	1		Number of vessels
$100	$100	/man	Travel expenses
$200	$200	/day	Local hire
Execution			
$1.75	$1.75	/man/hr	Fringe benefits
14.3	14.3	%	Overtime
7	7	days/yr	Holidays
7	7	%	Vacation time
6.2	6.2	%	Social Security tax
45	45	%	Workers' compensation
3.5	3.5	%	State unemployment compensation
1	1	%	Federal unemployment compensation
300	300	days/year	Days per year dredge is in use
4	4	hrs/day	Dredge operating at 100%
14	14	hrs/day	Dredge operating at 75%
6	6	hrs/day	Dredge operating at 10%
Production			
1	1		Method of production estimation (1=CSDCEP, 2=USACE)
12	12		Digging depth (ft)
10	10		Discharge lift (ft)
40	40		Ladder length (ft)
1.025	1.025		Specific gravity of surrounding water
0.1	0.1		K for ball joints
1.6	1.6		K for head losses on the dredge
0.5	0.5		K for head losses at discharge
1.35	1.45		Maximum possible SG of slurry
1.2	1.2		Minimum allowable SG of slurry
5	5		Percent of total system head that must be greater than Hp-HL
1	1		Type of dredge (1=walking spud, 2=spud carriage)

Figure A-4. CSDCEP Defaults Page.

- **K for ball joints, etc.** – K is the minor loss coefficient for certain parts of the dredge/pipeline system.

- **Maximum/minimum SG of slurry** – these are the values that set the operating range of specific gravity for the dredging operation in question.

- **Type of dredge** – if a walking spud dredge is to be used on the job, a 1 should be entered here. For spud carriage dredges, a 2 should be entered. The vast majority of dredges currently in operation in the United States are walking spud dredges, so “1” is the default. The dredging efficiency value in equation 7 is 0.5 for a walking spud dredge and 0.9 for a spud carriage dredge.

Mobilization/Demobilization Page

Mobilization and demobilization costs are perhaps the most difficult to accurately estimate in a program of this type. The main problem lies in the fact that no two dredges have to travel the same distance to arrive at a job site. Also, different dredges are always in different stages of readiness to mobilize. For example, contractor A may be completing a project 10 mi away from the site being considered, while contractor B may have a dredge not in use 100 mi away. In this example, contractor A has less distance to travel to the job site, but has more preparation to do before moving his operation. Also, contractor A’s mobilization costs are basically included in the demobilization costs for the last project. Contractor B, however, has little preparation to do but must travel a greater distance. In this scenario, contractor A would likely have substantially less costs associated with mobilization, and would therefore give a lower bid price for the project. Many times the contractors are not compensated for demobilization costs and therefore do not include them in their bids. For this reason an option is provided in the program to leave the demobilization costs out of the estimate.

The calculations on the mobilization/demobilization page (Figure A-5 and Figure A-6) are based on the assumption that all dredges are not in use immediately prior to transfer to the job site. The main factors, therefore, in determining costs for this portion of the dredging project are the distance to and from the job site, the size of the dredge, and the length of pipeline used on the job. The page is broken down into five main sections: the mobilization and demobilization input parameters, the working rates for labor and equipment, standby rates for equipment, and the calculations.

Mobilization Input Parameters

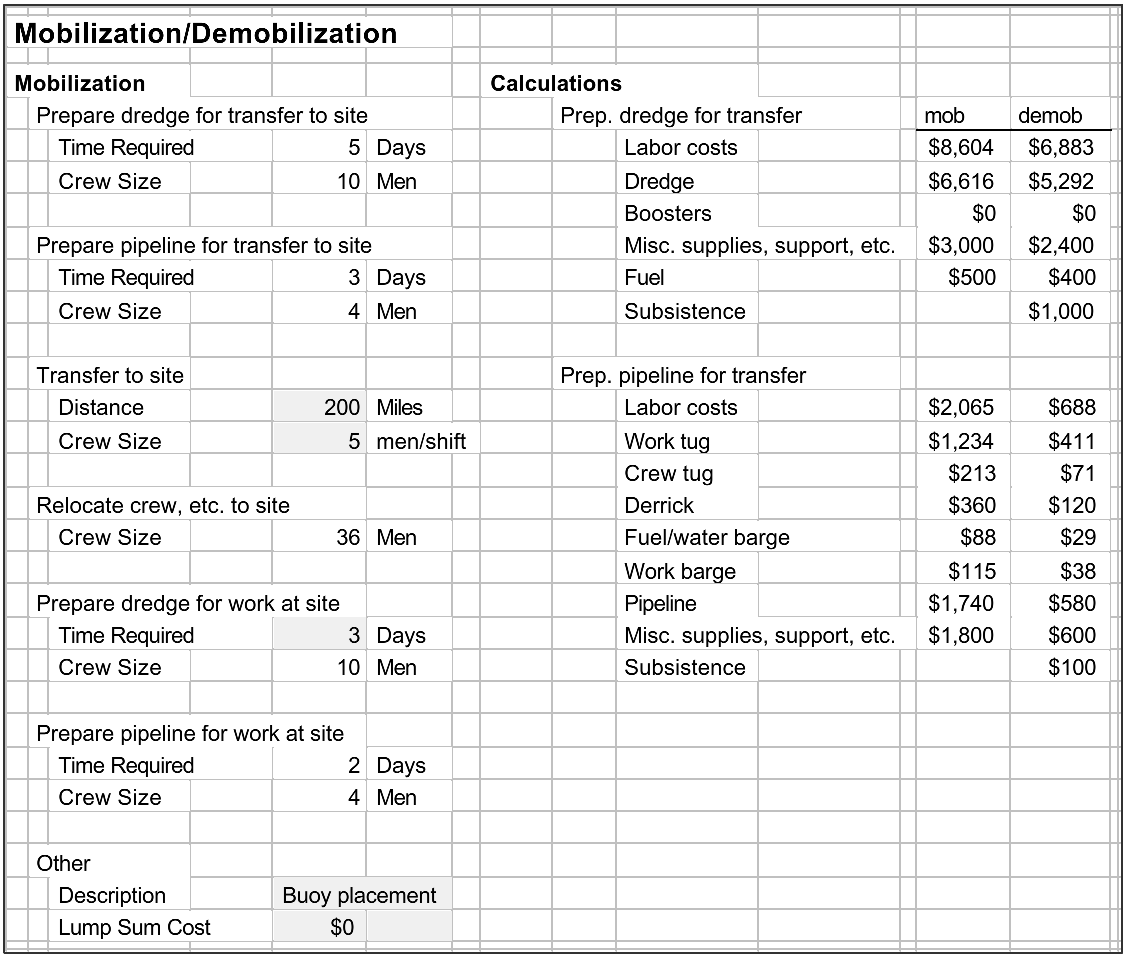
The only manual inputs in this section are the distance to the job site, the number of crew needed for the tow to the site, and an input for any lump sums required by the site, such as cost of buoy placement, etc. The other parameters in this section are calculated based on size of dredge and length of pipeline. These calculations yield values for the length of time and number of crew required for the preparation and transfer of personnel, pipeline, and the dredge itself.

Demobilization Parameters

The distance of relocation and the lump sum value are the only manual entry values in this section. Other values are taken from the defaults page or calculated. These parameters describe only the length of time necessary for transfer and preparation for storage of the dredge and pipeline.

Working Rates

Cost per hour of the tugs and barges in operation as well as hourly labor rates are calculated here. The monthly working rates for the tugs and barges are taken from the database and divided by the hours operating time per month. The labor rates are calculated on the execution page.



Mobilization/Demobilization

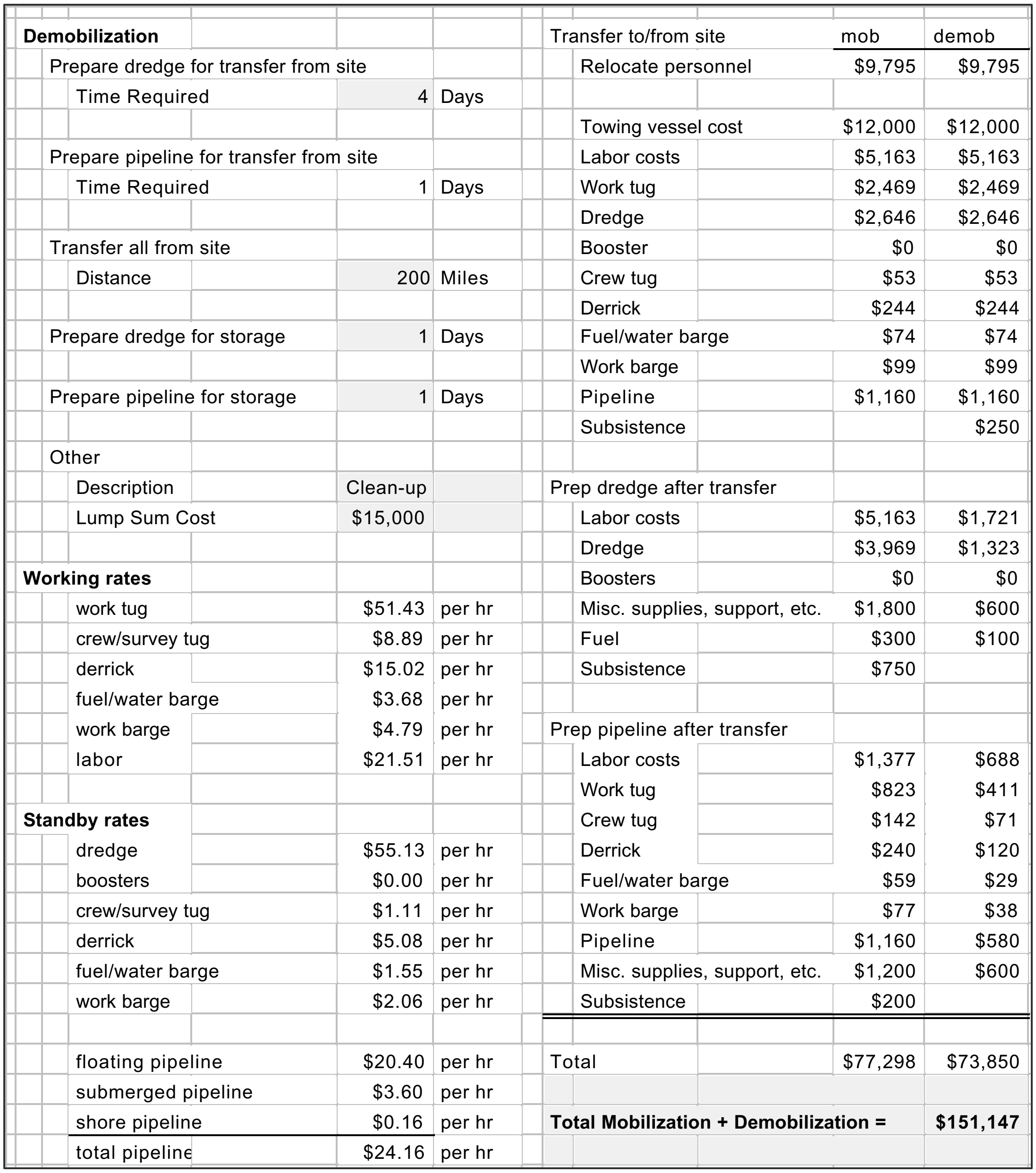
Mobilization

Prepare dredge for transfer to site		
Time Required	5	Days
Crew Size	10	Men
Prepare pipeline for transfer to site		
Time Required	3	Days
Crew Size	4	Men
Transfer to site		
Distance	200	Miles
Crew Size	5	men/shift
Relocate crew, etc. to site		
Crew Size	36	Men
Prepare dredge for work at site		
Time Required	3	Days
Crew Size	10	Men
Prepare pipeline for work at site		
Time Required	2	Days
Crew Size	4	Men
Other		
Description	Buoy placement	
Lump Sum Cost	$0	

Calculations

Prep. dredge for transfer	mob	demob
Labor costs	$8,604	$6,883
Dredge	$6,616	$5,292
Boosters	$0	$0
Misc. supplies, support, etc.	$3,000	$2,400
Fuel	$500	$400
Subsistence		$1,000
Prep. pipeline for transfer		
Labor costs	$2,065	$688
Work tug	$1,234	$411
Crew tug	$213	$71
Derrick	$360	$120
Fuel/water barge	$88	$29
Work barge	$115	$38
Pipeline	$1,740	$580
Misc. supplies, support, etc.	$1,800	$600
Subsistence		$100

Figure A-5. Mobilization/Demobilization Page (Part 1).



Demobilization		
Prepare dredge for transfer from site		
Time Required	4	Days
Prepare pipeline for transfer from site		
Time Required	1	Days
Transfer all from site		
Distance	200	Miles
Prepare dredge for storage	1	Days
Prepare pipeline for storage	1	Days
Other		
Description	Clean-up	
Lump Sum Cost	$15,000	
Working rates		
work tug	$51.43	per hr
crew/survey tug	$8.89	per hr
derrick	$15.02	per hr
fuel/water barge	$3.68	per hr
work barge	$4.79	per hr
labor	$21.51	per hr
Standby rates		
dredge	$55.13	per hr
boosters	$0.00	per hr
crew/survey tug	$1.11	per hr
derrick	$5.08	per hr
fuel/water barge	$1.55	per hr
work barge	$2.06	per hr
floating pipeline	$20.40	per hr
submerged pipeline	$3.60	per hr
shore pipeline	$0.16	per hr
total pipeline	$24.16	per hr

Transfer to/from site	mob	demob
Relocate personnel	$9,795	$9,795
Towing vessel cost	$12,000	$12,000
Labor costs	$5,163	$5,163
Work tug	$2,469	$2,469
Dredge	$2,646	$2,646
Booster	$0	$0
Crew tug	$53	$53
Derrick	$244	$244
Fuel/water barge	$74	$74
Work barge	$99	$99
Pipeline	$1,160	$1,160
Subsistence		$250
Prep dredge after transfer		
Labor costs	$5,163	$1,721
Dredge	$3,969	$1,323
Boosters	$0	$0
Misc. supplies, support, etc.	$1,800	$600
Fuel	$300	$100
Subsistence	$750	
Prep pipeline after transfer		
Labor costs	$1,377	$688
Work tug	$823	$411
Crew tug	$142	$71
Derrick	$240	$120
Fuel/water barge	$59	$29
Work barge	$77	$38
Pipeline	$1,160	$580
Misc. supplies, support, etc.	$1,200	$600
Subsistence	$200	
Total	$77,298	$73,850
Total Mobilization + Demobilization =		**$151,147**

Figure A-6. Mobilization/Demobilization Page (Part 2).

Standby Rates

It also costs the contractor to have his equipment sitting idle while it could be earning money, so standby rates must also be taken into account. Once again, the values for the tugs and barges are taken from the database, this time with the addition of pipeline standby rates.

Calculations

For each of the following sections costs are calculated for both mobilization and demobilization.

- **Prepare dredge for transfer** – standby costs are calculated for the dredge and booster pumps. Also, labor costs, subsistence, fuel, and miscellaneous supplies are considered.

- **Prepare pipeline for transfer** – here standby costs are calculated for the pipeline, as well as for the tugs and barges. The additional costs listed above are also calculated for this section.

- **Transfer to and from site** – towing vessel, relocation of personnel, subsistence, and labor costs are calculated. In this section, working rates are used for the work tug, but for all other equipment standby rates are used.

- **Prepare dredge after transfer** – for mobilization purposes, this section computes costs of preparation for work. For demobilization, this section computes costs of preparation for storage. Miscellaneous supplies, fuel, subsistence, and labor costs are calculated, as well as standby costs for the dredge and boosters.

- **Preparation of pipeline after transfer** – for mobilization, this section yields the cost of laying the pipeline at the job site and preparing it for work. For demobilization, this cost is simply preparation for storage. The tugs and barges are once again considered, as well as the miscellaneous costs listed above.

Project Execution Page

The bulk of the calculations in the cost estimation program are carried out in the project execution page. With the possible exception of very small jobs, the project execution costs far outweigh the mobilization and demobilization costs, and therefore the most attention to detail is focused on this page. There are four main components to the project execution page: the production calculations, the labor and crew costs, the equipment costs, and the pipeline costs.

Production Factors

The production rate is determined on the production estimation pages for a loose sand of median grain diameter of 0.4 mm in ideal pumping conditions. Since very few dredging operations fit this description, a number of factors must be applied to compensate for the difference.

- **Material Factor.** Both the built-in production estimation program and the Corps of Engineers method yield production rates for a slurry composed entirely of clean sand with a median grain diameter of 0.4 mm. Since the characteristics of sediments vary widely and have a great influence on the actual production rates, the Corps has introduced the concept of a "material factor" to account for the difference (USACE, 1988). This factor takes into account different viscosities, grain sizes, and in situ consolidation to provide a description of relative ease of pumping. For instance, silt is easily excavated and, due to its tendency to remain in suspension, easily transported. On the other hand, compacted clay is difficult to excavate and, once excavated, is difficult to pump through the line due to its tendency to consolidate and create "clay balls." Since the sediment at a particular job site is seldom composed of a single type, the user is allowed to enter percentages of the whole of 10 different sediment types to create a composite material factor. This factor is then applied to the calculated production rate. Therefore the silt mentioned above has a factor of greater than one while the clay has a factor of less than one (medium-sized sand has a factor of one).

- **Other Factors.** In order to calculate the bank factor, the ratio of the cutter diameter to the bank height entered in the main page must be determined. This value is then used in conjunction with Figure A-3 to obtain the bank factor. Two cells are left open for additional factors to be entered manually. Typical factors that may be necessary depending on the job site conditions are wind and wave factors. All of these factors are then applied to the production rate to yield the final production rate estimate.

Labor and Crew Costs

A dredging operation requires the services of many different personnel. A typical project calls upon a number of crewmen and laborers, both salaried and hourly. For a typical job, there is one each of the following salaried workers: a captain, officer, chief engineer, and an office worker. Depending on the size of the dredge being used, the number of the following hourly paid workers will vary: levermen, dredge mates, booster engineers, tug crew, equipment operators, welders, deckhands, electrical engineers, dump foremen, cooks, and winchmen. Data for the number of crew and their respective pay rates are taken from the database. Adjustments are then made to the wages using the values from the defaults page for fringe benefits, overtime pay, holidays, vacation time, taxes, and workers' compensation. The resulting total hourly rate is multiplied by the hours per day each crew member works to obtain the total daily cost of labor. These adjustments are not made to the salaried workers.

Equipment Costs

After the labor and crew costs, the equipment costs are the largest part of the total project cost. The capital costs of the dredge, boosters, tugs, and barges are obtained from the database along with the number of each needed for the project. Bray, Bates, and Land (1997) provide the method for computing each of the following:

- **Routine maintenance and repairs.** For all of the equipment listed above, it is recommended to multiply the capital value by 0.00014 to obtain the daily costs for minor repairs that can be carried out while the dredge is operating.

- **Major repairs.** For the average daily cost of repairs requiring the dredge or any other piece of equipment to be shut down, it is recommended to use a value of 0.0003 times the capital value.

- **Insurance.** Multiply the capital cost by 0.025 and divide by the average number of working days per year to calculate the cost of insurance.

- **Fuel cost.** In order to calculate the fuel consumption, one must determine the effective hours per day that the dredge operates at 100 percent power. The defaults page provides the user with the option of entering the hours per day of the dredge operating at 100 percent power, 75 percent power, and 10 percent power. From these values the effective hours at 100 percent are determined. The fuel cost per day is then taken as the item's horsepower times the hours per day at 100 percent times the fuel cost per gallon times 0.048079. This is another value recommended by Bray, Bates, and Land (1997).

- **Cost of lubricants.** It is suggested to use 0.1 times the fuel cost to obtain this value.

- **Depreciation.** To calculate this value, the useful life of the piece of equipment in question must be known. These values are contained in the database and accessed here by the program. The depreciation is then calculated as the capital cost divided by the useful life and the number of days per year in operation.

Pipeline Costs

The total capital cost of the pipeline is determined by multiplying the total number of pipe sections by the cost per section obtained from the database. The same methods used above are used to calculate depreciation and repair costs, keeping in mind that the useful life of a section of pipe is much shorter than the equipment items due to the constant abrasive wear of the material being pumped through it. The average pumping distance entered on the main page is used to determine the costs of the main pipe lengths. The remaining length of pipe suffers less wear and therefore has a longer useful life and needs fewer repairs than the main pipe length.

After the equipment and pipeline costs are determined, the overhead costs are then taken to be 0.09 times the total daily costs of equipment and pipeline. At the bottom of the page are several cells left open where additional specific costs can be entered and added to the daily cost of execution. The time required to complete the project is calculated based on the production rate and the hours per month that the dredge is in operation. This value is then multiplied by the daily costs to obtain the total cost of execution.

Database Page

The database contains information about equipment and labor involved with typical dredging projects. This information was obtained from the U.S. Department of Labor and the U.S. Army Corps of Engineers. All of the data is listed as a function of the dredge size, and as such can be easily accessed from the main program.

Equipment Database

The first part of this section contains the dredge production versus line length data. Data for the tugs, barges, and boosters follows this and includes the capital costs and, where applicable, the horsepower of the unit and the quantity needed. Pipeline data is also contained in this section. Pipe section length, capital cost, and useful life are listed here.

Working Rates and Standby Rates

This section contains values for the monthly working rates of the tugs and barges and hourly standby rates for the tugs, barges, and pipeline.

Labor Database

For all the crew members listed on the execution page, this section gives the number needed as well as the hourly rates or monthly salary, depending on position.

Charts

There are also charts on the page that are used to determine the bank factor, dredge capital cost, and time required to prepare the pipeline for mobilization. The bank factor chart was taken from Turner (1996), and the capital cost chart was taken from Bray, Bates, and Land (1997). The pipeline preparation chart is an intuitive formula that is put into chart form for use with this program.

Production Estimation Pages

The production estimation routine combines friction head loss theory from Wilson et al. (1997) with dimensionless pump characteristics curves described by Herbich (1992) to provide the results needed by the program.

Determination of Critical Velocity

As a grain of sediment travels through a pipeline, there is a certain velocity that the fluid around it must maintain in order to prevent the grain from falling to the bottom of the pipe and becoming stationary. If this velocity is not maintained, much of the sediment will settle and clog the pipeline. This condition is very undesirable, because it means shutting down the operation while the line is being unclogged. This “critical velocity” is a function of the specific gravity of the sediment, the grain size, and the diameter of the pipe. Wilson et al. (1997) have presented a convenient method of determining the critical velocity using a nomograph (Figure A-7). This nomograph has been entered into the spreadsheet and yields the critical velocity based on an assumed specific gravity of 2.65 (quartz) and median grain diameter of 0.4 mm. Even though optimum pump efficiency and production rates occur at higher velocities, contractors tend to operate near this critical velocity, because the lower velocities inflict less wear on the pipes.

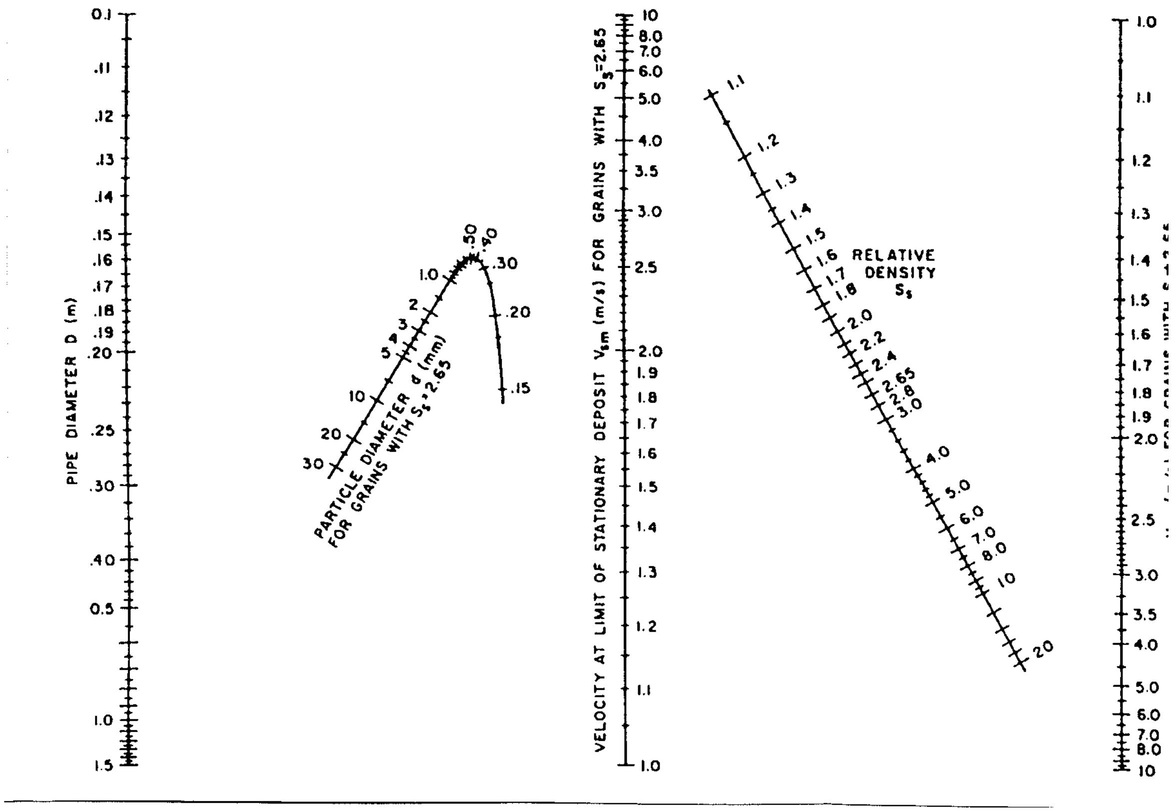


Figure A-7. Nomographic Chart for Critical Velocity, from Wilson et al. (1997).

Determination of Head Losses

It is important to calculate the head losses for the system because this is how the maximum pumping distance for a particular pump is determined. The major component of the head losses of a system is the frictional head loss. There are also minor losses due to pipe joints and bends, but when you are dealing with thousands of feet of pipe, the frictional losses far outweigh the rest. Head losses due to friction are determined in the program by the procedure outlined by Wilson et al. (1997). The head losses per unit length (feet of head per feet of pipe) are given by:

$$i_m = \frac{fV^2}{2gD} + 0.22(S_s - 1)V_{50}^{1.7}C_v V^{-1.7} \qquad \textbf{(A-1)}$$

$$w = 0.9V_t + 2.7\left[\frac{(\rho_s - \rho_f)g\mu}{\rho_f^{\ 2}}\right]^{\frac{1}{3}} \qquad \textbf{(A-2)}$$

$$V_{50} = w\sqrt{\frac{8}{f}}\cosh\left[\frac{60d}{D}\right] \qquad \textbf{(A-3)}$$

where i_m is the head loss due to friction per unit length, d is particle diameter, D is pipe inside diameter, ρ_s and ρ_f are density of solid and fluid, respectively, V is mean velocity of mixture, f is the friction factor for water, g is acceleration due to gravity, μ is dynamic viscosity of fluid, S_s is specific gravity of solids, C_v is the delivered concentration by volume, and V_t is particle terminal velocity.

Dimensionless Pump Characteristics Curves

In order to create a dredge production program that can be applied to any size dredge pump, Herbich's (1992) method of using dimensionless parameters in the pump characteristics curves is incorporated. A typical set of pump characteristics curves displays the pump head, brake horsepower (or shaft horsepower), and pump efficiency as a function of discharge rate. In a dimensional format, these curves are valid only for a pump with the same specifications that is operating at the same speed. However, when translated into a dimensionless format, the values of head (H), horsepower (P), and discharge (Q) may be calculated for any similar pump operating at any speed (Figure A-8). Since efficiency (η) is a percentage, it is already dimensionless. The dimensionless values are determined by:

$$H_{\dim} = \frac{gH}{\omega^2 D^2}$$
$$Q_{\dim} = \frac{Q}{\omega D^3} \qquad \textbf{(A-4)}$$
$$P_{\dim} = \frac{P}{\rho \omega^3 D^5}$$

where the subscript "dim" indicates a dimensionless quantity, g is the acceleration due to gravity, D is the impeller diameter, ω is the pump speed in radians per second, and ρ is the fluid density.

The curves that are used in the program were created by transforming a number of dimensional curves provided by Georgia Iron Works and Mobile Pulley and forming a composite set of dimensionless curves from them. With this set of dimensionless curves it is now possible to obtain the values of pump head, brake horsepower, discharge, and pump efficiency simply by entering any one of the values listed along with an impeller diameter and pump speed.

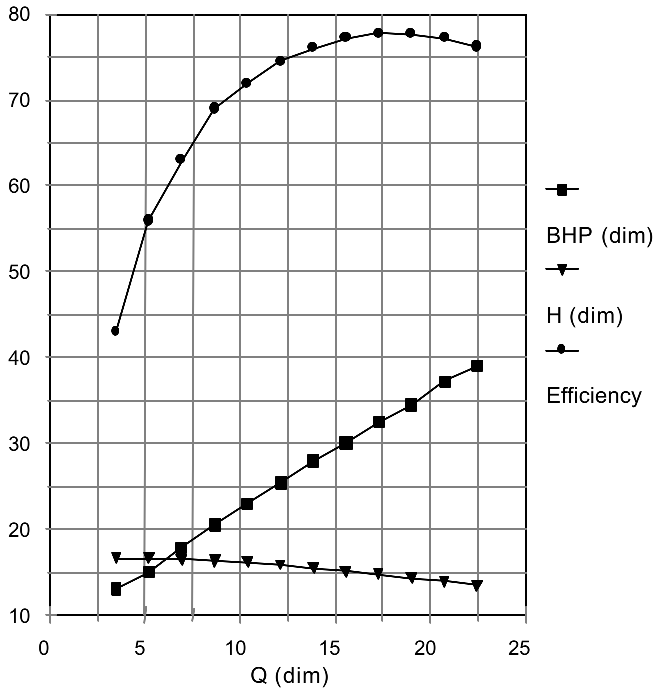


Figure A-8. Dimensionless Pump Characteristics Curves Used in CSDCEP.

Determination of Production Rate

The production rate of a cutter suction dredge can be calculated using the following equation:

$$P(cy/hr) = Q(GPM) \times C_v \times 0.297 \times PF \times DE \qquad \textbf{(A-5)}$$

where DE is dredge cycle efficiency (~ 0.5 for a walking spud dredge); P is the production rate in cubic yards/hour; C_v is the maximum concentration of solids by volume; PF is the production factor that accounts for material differences, bank height, and other factors; and 0.297 is a units conversion factor. In order to calculate the production using the above method, the following four values are needed.

Specific Gravity of the Mixture

This value is assumed to be 1.4 initially, but may become smaller if the friction head losses are too large at this value. It is desirable to pump at the highest possible specific gravity, because this means a greater concentration of solids by volume, which results in a higher production rate. This number changes incrementally down to a value of 1.2 in order to reduce head losses. It would be very inefficient to pump at a lower specific gravity than this, and a booster should be added at this point.

Impeller Diameter

From examining the dimensionless pump curve equations, it is obvious that the impeller diameter of the pump must be specified in order for the user to obtain the proper values. The problem here lies in the fact that a number of different sized impellers may be used in any given pump. Contractors will usually change the impeller depending on the length of pipeline used on a job. It is common practice to use a smaller impeller for shorter line lengths, thus conserving horsepower, and larger impellers for longer pipe lengths, thereby maximizing pump head. In order to simplify the input for this program, a list of typical impeller diameters is incorporated into the program, with different diameters listed for each dredge size and pipe length. These values were obtained from pump specifications listed in various pump manufacturers' catalogues. No selection needs to be made by the user for this quantity, because the program determines the appropriate value.

Pump Speed

This value is equally as important as the impeller diameter for the calculations. Each pump has its own most efficient operating speed, and this value does not vary nearly as much as the impeller size. Another table of typical values is accessed by the program in order to obtain a suitable pump speed for its calculations. These values were obtained by examination of the pump characteristics curves provided by Georgia Iron Works and Mobile Pulley.

Discharge Rate

This is another quantity that, much like the specific gravity, is varied by the program in order to obtain the best possible operating conditions. From Figure A-8, you can see that the pump head decreases with increasing discharge rate. The first choice of discharge rate is about 20 percent higher than the discharge corresponding to the critical velocity. The pump head is then obtained from the dimensionless pump curves. If there is insufficient pump head to overcome the head losses, the chosen discharge velocity is incremented downward and the new pump head is determined. This process is repeated until either the pump head is found to be more than 5 percent greater than the head losses, or until the discharge corresponding to the critical velocity is reached. If the latter should occur, the program prompts the user to add a booster to the system.

The addition of a booster increases the head of the total system by the amount of pump head achieved by the booster. The above process is then repeated for the new system configuration. Once an acceptable number of boosters has been selected, the pump efficiency is obtained from the curves and the production is calculated using the equation stated above.

Corps of Engineers Production Estimation Method

Based on previous dredging experience, the Corps of Engineers has compiled a database of typical dredge production rates based on dredge size and pipeline length. The program calls three values of pipeline lengths and their corresponding production rates from the database based on dredge size. Using the pipeline length entered on the main page, a production rate is interpolated from these values. If the resulting production rate is insufficient for an efficient operation, a message lets the user know that another booster must be added. After adding a booster, the line lengths corresponding to the production rates are multiplied by a “booster factor” that is roughly equal to one plus the number of boosters. This works on the principle that pumps in series simply add to the head of the system. Or, simply stated, the length that pumps in series can pump is equal to the sum of the lengths that each can pump individually. Thus, the production rates in the table remain the same, but the line lengths are multiplied by the booster factor. This process repeats until a suitable number of boosters is reached and a sufficient production rate is obtained.

SENSITIVITY ANALYSIS

Example calculations were made and graphed using CSDCEP to show the effect of varying certain parameters while holding all others constant. In each example, four dredge sizes are displayed for the sake of comparison. The following parameters are held constant in each of the graphs except for the graph in which the particular value in question is varied:

- The volume of the material to be dredged is one million cubic yards.
- The discharge pipeline length is 3,000 ft.
- The sediment is 100 percent medium grained (0.4 mm median grain diameter) loose sand.
- The bank height is four feet.

Figure A-9 shows the effects of varying the bank height when all other parameters are held constant. As can be seen from the results on the graph, the bank height plays a significant role in the cost of the dredging project, due to the effect on the dredge production. This provides evidence for the argument that smaller dredges, and therefore smaller cutters, should be used on projects with a only a thin layer of sediment to be removed.

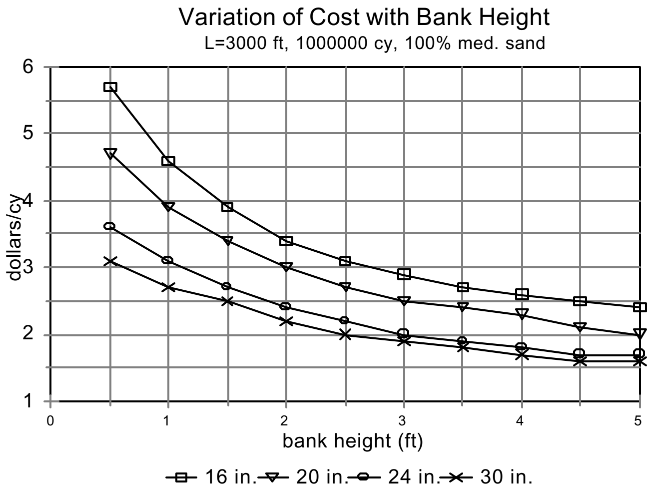


Figure A-9. Variation of Cost with Bank Height.

Figure A-10 shows the effects of varying the length of the discharge pipeline. As expected, the longer the pipeline is, the more the project costs. From the graph it can be seen that for every mile of pipeline used, the price increases by about 1.8 dollars per cubic yard. Figure A-11 shows the effect on the cost of varying the volume to be dredged. The results displayed here are fairly intuitive, showing that it is cheaper to excavate large volumes of sediment using a larger dredge than a smaller one. One should note, however, that with smaller volumes, the smaller dredges become more economical. This trend can be seen developing in the graph.

Figure A-12 and Figure A-13 show the effect on the cost of pumping different types of sediment. Figure A-12 shows the increasing cost of the operation as the amount of clay in the sediment increases. On the other hand, Figure A-13 shows that the costs can be substantially lower if the material is mostly silt or mud. The smaller grain size of the silt and mud make it more easily suspended in water and easier to transport, thus reducing the costs. Clay, even though it has the smallest grain size of any sediment, is difficult to dredge because it is very cohesive and difficult to excavate, and once it is in the pipe, it has a tendency to ball up and roll along the bottom of the pipe.

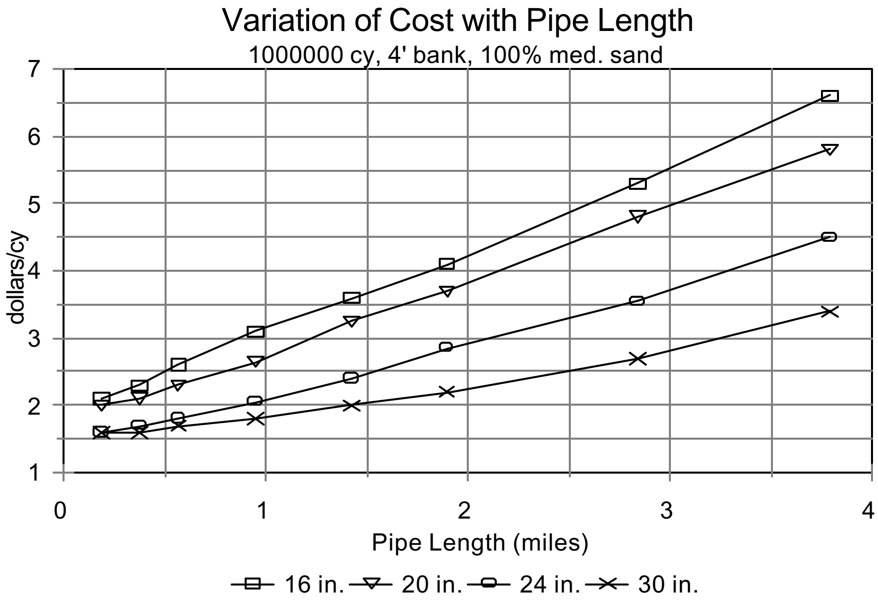


Figure A-10. Variation of Cost with Discharge Line Length.

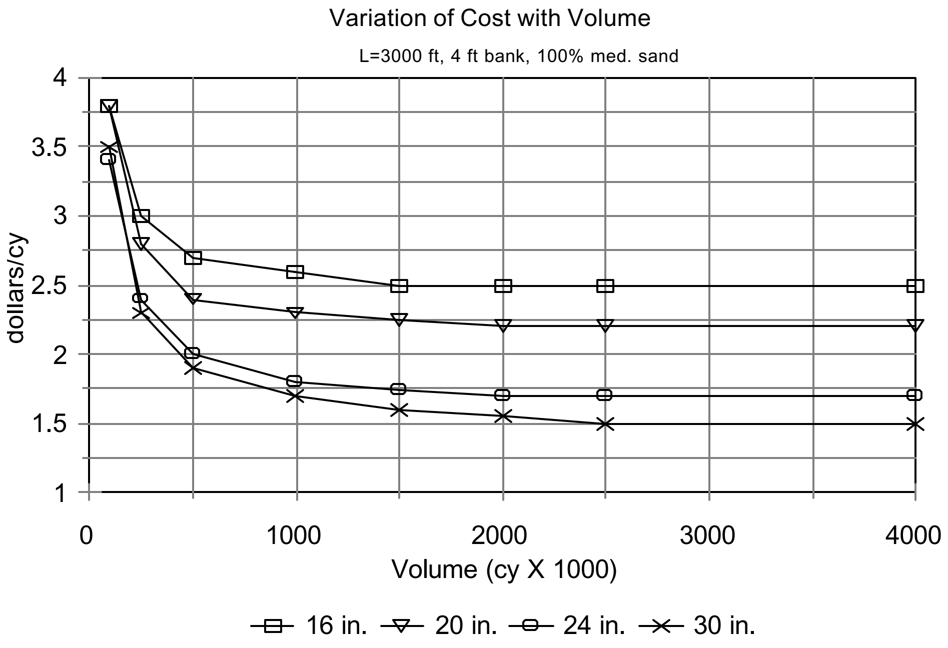


Figure A-11. Variation of Cost with Volume of Dredged Material.

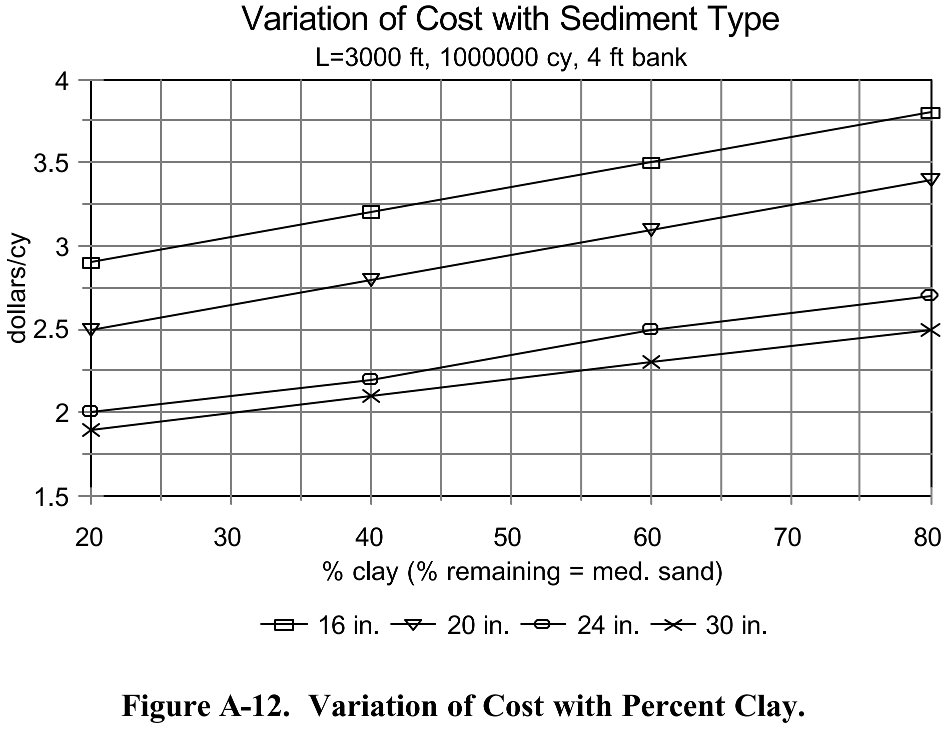


Figure A-12. Variation of Cost with Percent Clay.

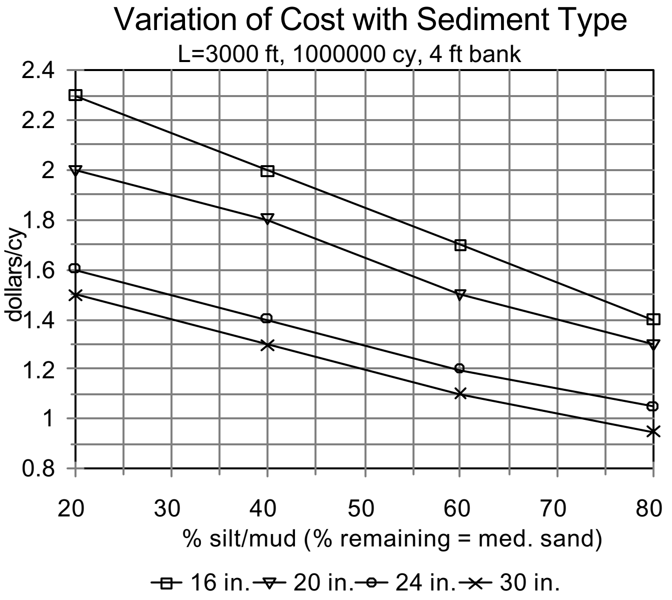


Figure A-13. Variation of Cost with Percent Silt/Mud.