Texas Water Development Board
TWDB Contract #2004-483-534

Dredging vs. New Reservoirs

December 2005

submitted by:

ALAN PLUMMER ASSOCIATES, INC.
ENVIRONMENTAL ENGINEERS - DESIGNERS - SCIENTISTS

in conjunction with:
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EXECUTIVE SUMMARY

ES.1 Introduction

The Texas Water Development Board has undertaken a cost-benefit analysis to evaluate the costs of dredging existing reservoirs as a means of developing additional water supply versus constructing new reservoirs for water supply purposes. This study conducted by Alan Plummer Associates, Inc., with the assistance of Drs. Peter Allen and John Dunbar of Baylor University, indicates that while dredging is a viable option of water supply augmentation, the costs may be twice that of developing a new reservoir. The purpose of this report is to present the findings of this study.

ES.2 Water Resources Planning

Over the past 50 years the State of Texas has enjoyed remarkable population growth (170 percent increase from 1950 until 2000). At the beginning of that 50-year period the state suffered from a severe drought that lasted from 1950 until the late spring of 1957. While the drought was not everywhere that severe, it touched on most areas of the state to include the major population centers. The water purveyors took aggressive action during and immediately following the drought of the 1950s and developed surface water supplies, often well in advance of their actual need. The large demand for water associated with the growth in population that the state has experienced since the 1950s has been smoothly accommodated, in large part because of the aggressive action of the state's water providers in developing surface water supply sources.

Prudent water supply planning typically considers both short- and long-term (e.g., 50 year) needs. Demand will continue to increase in response to population growth; thus new supplies to meet those demands must be developed. Opportunities for new water supply lakes have diminished. Today's water suppliers have to look farther into the future to find sites for water supply lakes, and even then other obstacles often arise that must be resolved. Not only have the number of water supply lake sites dwindled; but also environmental concerns, interbasin and interstate transfer issues, and parochial-based opposition stand between developing lake sites and the water suppliers. Water resource planners realize that traditional water supply will not be available and that desalination or some other water supply method will need to be embraced on a massive scale. In the interim it becomes paramount that all alternative water supply issues be carefully reviewed, and dredging should be considered a viable option for expanding existing reservoirs. Similarly basinwide management programs should be considered to limit sedimentation to the existing or newly constructed water supply reservoirs

ES.3 Dredging

The capacity of stored water in Texas is 40.5 million acre-feet. However, this capacity is being reduced by sedimentation every time it rains. The evaluations performed herein indicate that dredging may be a means of recovering 5 to 6 million acre-feet of water storage. If significant storage is to be achieved, a large volume of sediment must be removed, which may be a large undertaking. It is likely that the cost of such large scale dredging operations may not be considered practicable at this time.

Dredging can be done mechanically or hydraulically. These methods are described below.

ES.3.1 Mechanical Dredging

Mechanical dredging may involve draglines or clamshells that are mounted on barges. These operations use support barges to temporarily store dredged material. The barges are moved to shore to unloading areas where the material is loaded on trucks for disposal. This operation requires double handling of sediment and does not compare to hydraulic dredging on the basis of efficiency. Mechanical dredging can also include the use of heavy highway equipment. This excavation is accomplished by lowering the lake water or waiting until drought conditions have caused the water surface to lower sufficiently to allow access by heavy highway equipment. This latter method can be cost- effective.

ES.3.2 Hydraulic Dredging

Hydraulic dredging is conducted by pumping water from the head of the dredge back through the vessel and out a pipeline to a dewatering area. The pumped water creates a negative pressure that allows the sediment to be moved in slurry form through the pump and pipeline system. Water jets, augers, or cutterheads are used to loosen the sediment. The hydraulic cutterhead dredge is the most common of the hydraulic dredges.

ES.4 Hydraulic Dredges

Hydraulic dredges are designated by the diameter of their discharge pump. The smaller dredges are in the 10-inch range. Larger dredges reach 42-inches. Large-sized dredges have very large power plants and have high production rates. They also require large crews and usually have fairly extensive support requirements, such as support boats, tenders, and other support craft. Mobilization costs for large-sized dredges are extremely high; therefore, significant volumes of sediment are needed to make the use of large-sized dredges cost effective.

24-Inch Cutter Suction Dredge

ES.5 Comparing Dredging Costs to Construction of New Reservoirs

Dredging costs are highly variable and driven by pipeline distance to dewatering sites, land costs for dewatering sites, weather, topography, and characteristics of bottom sediments. These variables are such that dredging cost estimates need to be based on site-specific circumstances. Reservoir costs include land for the lake, embankment, mitigation lands, appurtenances to the dam, such as pump stations, and pipelines to connect the lake to the treatment plant or raw water users. Lake Ralph Hall and Lake Columbia, two currently proposed reservoirs were used herein for comparing the cost of dredging to the cost of constructing new lakes.

Costs were compared on the basis of units of storage. Since dredging is traditionally bid on a cubic-yard basis from the standpoint of production and cost, reservoirs were evaluated on the same basis. Accordingly, the evaluations contained herein include a comparison of the cost of dredging a unit volume of sediment with the cost of establishing an equivalent storage volume by constructing a reservoir.

ES.5.1 Findings

Dredging unit costs are at least twice that of securing storage in new reservoirs. New reservoir costs equate to somewhat above $1 for each cubic yard of water stored in the conservation pool. Dredging costs for large-sized dredging projects will cost over $2 per cubic yard and, depending on variabilities, could cost two, three, or more times that amount.

Dredging costs and new reservoir costs were not compared on a yield basis. If the dredging were conducted in the same meteorological region as the new reservoir, there would be no differences in yield per volume generated. If the new reservoir were located in a more prolific meteorological area than the dredging location, then the cost advantage for the new reservoir would be even greater than mentioned above. If that situation were to be reversed, the cost advantage for the new reservoir would be reduced; however, such a scenario is unlikely since most new reservoir sites are identified in East Texas areas.

ES.5.2 Alternative Considerations Regarding Dredging

Dredging should be considered a feasible alternative and compared with other water supply augmentation alternatives (reuse, water conservation, desalination, well fields, etc.). Dredging could reestablish storage in water supply lakes that could result in a percentage yield increase in existing water supplies, thereby forestalling the need for a new reservoir. In combination with other alternatives mentioned above the need for a new reservoir could be deferred for an extended period of time.

Even though dredging unit costs might be high, if the costs to develop supplemental water supply are included in the system costs (i.e. with water supply already developed) dredging costs may not significantly affect water rates since this fractional increase in water supply cost will be partially absorbed in the cost of the total volume of the water supply.

Dredging compares favorably when measured against other project criteria such as time, permit requirements, and public acceptance. Cost alone should not be the determining factor regarding dredging as a viable alternative.

ES.5.3 Water Quality

Removal of lake sediment can have a positive impact on water quality. For example, sediments can be laden with phosphate and other nutrients. These nutrients partition from the sediment into the water in the lake. The subsequent effect on water quality can represent a cost burden to water treatment for potable purposes. Additionally, it has been shown that deeper lakes are less prone to eutrophication (and algae growth) than shallow lakes. Thus, the benefits of removing the sediment should be considered among the advantages of dredging a water supply lake. These benefits could be quantified in terms of reduced expenditures for capital improvements, chemical supplies and operations at the water treatment plant.

ES. 5.4 Other Beneficiaries of Dredging

Lake aesthetics and recreation are typical reasons for dredging inland lakes in the United States. If a lake were dredged for water supply purposes, there would be benefits such as improved recreation or aesthetics that would accrue to other purposes. These benefits should be recognized. In fairness, some distribution of costs should be made to all the beneficiaries of the dredging, thus reducing the costs to the water supply function.

ES.6 Recommendations

The cost of dredging is higher than some other alternatives, but not so high as to be prohibitive as evidenced by numerous projects accomplished throughout the United States for aesthetic and recreational purposes. The quantities of sediment removed during dredging are very large and have a marked effect on the cost of the dredging operation. If the sediment could be used beneficially to reclaim land, the value of this beneficial use could offset the cost of sediment storage and dewatering. Additionally, water quality in water supply lakes could be improved by dredging, especially in those lakes that have begun to show evidence of advanced eutrophication.

Accordingly, two recommendations are presented as a result of this study.

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ES.6.1 Water Quality

Consider dredging projects among various best management practices for water quality enhancement. It is recommended a small-sized lake that has experienced eutrophication be selected for a pilot program, including construction of an aquatic wetland in its upper reaches and partial or full dredging of its accumulated sediments. The study would evaluate the effect of the constructed wetland on future sedimentation and water quality aspects as well as the effects of dredging on retarding eutrophication.

ES.6.2 Beneficial Use of Dredged Solids

Consider beneficial use of dredged solids in evaluating the economics of dredging projects. A major component of the cost of dredging is the land dedicated to permanently storing the dredged solids, which is especially the case in urban settings. It is recommended that alternative options for beneficially using the dredged solids as replacement for topsoil or other land application purposes be assessed.

CHAPTER 1

INTRODUCTION

1.1 Project Scope

The Texas Water Development Board (TWDB) has determined that it is in the best interest of the state to evaluate the costs of dredging existing water supply reservoirs to remove accumulated sediments that have been deposited in the lakes through inflow from rainfall runoff. Sediment accumulation in Texas' water supply lakes represents a significant loss of storage on a cumulative basis. With the loss of storage comes an attendant loss of dependable yield for the reservoir system. Given that reservoir construction has seen an upward shift in costs and that permitting of new reservoirs has become more difficult because of environmental and other concerns, the TWDB elected to initiate this current evaluation of dredging costs so that such costs might be compared to costs for constructing new reservoirs.

Accordingly, the TWDB contracted with Alan Plummer Associate, Inc (APAI), a Texas corporation with offices in Dallas, Fort Worth, and Austin to assess the cost of dredging reservoirs to gain additional space as an alternative to constructing new water supply reservoirs. APAI undertook the task with the assistance of Drs. Peter Allen and John Dunbar of Baylor University as both have extensive experience with reservoir sedimentation and evaluating watershed erosion and its effect on lakes.

1.2 Background

Planning for and constructing new water supply reservoirs have historically been the means for providing new water supply sources. However, the number of available sites for new reservoirs is dwindling. Competing interests for the land that would be permanently taken for reservoir construction and water impoundment makes the option for new reservoir construction a complex decision. The costs of reservoir construction have risen and continue to rise because of a recently recognized need to provide suitable mitigation for the environmental impacts of aquatic and terrestrial habitat loss that reservoir construction entails. Additionally, the price of land has often risen disproportionately to other cost factors, usually because subdividing large tracts of land into smaller tracts has resulted in a higher cost per acre. Nevertheless, the concept of dredging to establish water supply storage has generally been found to result in higher costs for a given amount of water storage than is the case for reservoir construction.

Table 1-1 was developed from data provided by the Fort Worth District, US Army Corps of Engineers (USACE). It lists the original storage volumes in selected lakes and the results of sedimentation surveys for each lake. This table demonstrates the effect that sedimentation may have on water supply reservoirs. The data were adjusted to 2004 by determining a sedimentation rate from the survey information and applying that rate to the intervening period from the date of the survey through 2004. The loss of space in the reservoirs associated with sedimentation directly translates to loss of water supply. Similarly, if the sediment were to be removed, it would represent a re-acquisition of water supply. An advantage of regaining storage space in existing reservoirs is the ability to utilize existing infrastructure to withdraw the water and deliver it to a water treatment plant. The disadvantage heretofore has been the cost of dredging.

TABLE 1-1
SEDIMENTATION IN FIVE FEDERAL LAKES – TEXAS

Lake	Year Built	Year Surveyed	Original Volume (Ac Ft)	Sediment (Year of Survey) (Ac Ft)	End of 2004 Sediment Estimate (Ac Ft)	End of 2004 Storage Loss (Pct)
Lavon	1959	1975	425,900	9,465	26,168	6%
Grapevine	1952	2002	181,012	16,310	17,269	10%
Lewisville	1954	1989	641,000	69,100	99,811	16%
Bardwell	1965	1999	54,877	8,405	9,846	18%
BA Steinhagen	1960	2004	101,814	34,654	35,424	35%

1.2.1 Water Supply in Texas

1.2.1.1 Groundwater

Groundwater represents a significant water resource for the State. For example, major cites such as Houston, El Paso, and San Antonio have relied in the past on groundwater for water supply. In addition, the Ogallala Aquifer is a major contributor to the state's economy by providing essential irrigation water for agriculture on the High Plains of Texas. However, groundwater has proven to be an inadequate resource in other parts of the State. In north central Texas, the demands of Dallas-Fort Worth (DFW), and other DFW metroplex cities outstripped the dependable yields of the Cretaceous Aquifers a half-century ago. By the 1950s, north central Texas cities were mining their aquifers and as a result, the piezometric surfaces associated with each aquifer dropped hundreds of feet. During the drought of the 1950s, the wells proved inadequate to meet the needs of the area. The cities turned to surface impoundments for water supply during and following that drought period.

In other smaller cities in Texas, ground water has proven to be a reliable and valuable resource. Drilling new wells and establishing well fields can accommodate the demand associated with increases in population, but there is a limit to the population (or perhaps more accurately, population density) that groundwater can support. Aggravating the issue of aquifer supply adequacy is the issue of groundwater quality. Groundwater resources in a large area of western Texas have become suspect due to the presence of radionuclides. High dissolved solids, nitrates, and sulfides have also caused groundwater to be of marginal water quality in various areas of the State. Because of the above factors and the fact that groundwater is a finite and limited resource, it has not been relied upon as a major water supply source by the more densely populated communities that currently utilize surface water sources. A notable potential exception may be the Roberts County project where groundwater is being marketed to large municipal customers throughout the state. This effort has not been fruitful as of this time. In its water supply investigations, the Senate Bill 1 Region C Planning Group reported the annual cost of water for the first 30 years for the Roberts County Water Supply Project to be $2.40 per thousand gallons, or $784 per acre-foot, delivered to the western portion of Tarrant County and $2.83 per thousand gallons, or $924 per acre-foot, delivered to Collin County.

1.2.1.2 Surface Water

Surface water plays the most significant water supply role in Texas. As the population of the state has increased over the years the need for water (demand) has kept pace. With the exceptions of Houston, San Antonio, and El Paso, groundwater has not been able to provide adequate supply to meet the growing demands of the state. Table 1-2 below shows the population growth by decade. Note that in the 50-year period (1950 to 2000) Texas experienced 170 percent growth. The staggering growth rate early in that period, coupled with the fact that the period 1950 through May 1957 was the drought of record for most areas in Texas (Moore, 2003), resulted in significant stress on major aquifers in north central Texas and across the state. Piezometric levels fell hundreds of feet and have not recovered to this date.

TABLE 1-2
STATE OF TEXAS POPULATION BY DECADE

Decade	Population (Millions)	Incremental Change (percent)	Change Since 1950 (percent)
1950	7.7		
1960	9.6	24.7	24.7
1970	11.2	16.7	45.5
1980	14.2	26.8	84.4
1990	17.0	19.7	120.1
2000	20.8	22.4	170.0

Source: Decennial Census of the United States, U.S. Bureau of Census, Texas State Department Center, Department of Rural Sociology, Texas A&M University

The period during the 1950's and 1960's was one of transition to surface water for many Texas locales. Those that had been through the problems that the extended drought brought forth began to aggressively develop surface water sources. In some cases, water supply lakes were developed and impounded well before their actual need. As the 20th century came to a close, the opportunities for surface impoundments had dwindled to a limited number of sites within the State. Opposition to reservoir sites had increased and the advent of the Internet, email, and rapid communications enabled those in opposition to surface impoundments to mobilize their supporters and enlist others to voice strong opposition to reservoirs. Impacts of new reservoirs to aquatic and terrestrial habitats are now given full weight, thus requiring significant costs for replacement of lost habitat. Interbasin transfers are becoming more difficult as people in basins with surplus water often present a strong parochial interest in preserving water supply for their own basins.

In the 21st Century, planning for water supplies will have to take full advantage of conjunctive methods to develop supplies. Water supply alternatives such as conservation, water reuse, reservoir system operation, aquifer storage and recovery, and water supply restoration will all have to be evaluated to identify all of the practicable measures that can be implemented before embarking on new reservoir projects, particularly those that would require interbasin transfer.

Table 1-3 depicts the total water supply reservoir storage by river basin, expressed in acre-feet, for lakes in Texas. As can be seen, the preponderance of supplies are contained in the Neches and Sabine River basins in East Texas and the Colorado, Brazos, and Trinity River basins in the central and near-west part of the State. The Red River has high dissolved solids content (e.g., chlorides and sulfates), making it marginally useful for drinking water supplies. Similarly, natural salt seeps and springs in the Salt Fork of the Brazos River basin in west Texas result in high chlorides and sulfates in the main stem of the Brazos as far downstream as its confluence with the Little River, near Marlin. A significant percentage of Brazos River basin water supply storage is located on freshwater tributaries not affected by the Salt Fork.

As can been seen, the capacity for stored water in the state is 40.5 million acre-feet. The seven basins with the highest storage represent 35 million acre-feet or almost 90 percent of the water supply storage.

TABLE 1-3
SURFACE WATER SUPPLY
TEXAS

Basin	Storage (ac-ft)
Trinity-San Jacinto	13,750
San Jacinto-Brazos	13,759
Colorado-Lavaca	16,082
Neches-Trinity	32,000
Nueces-Rio Grande	42,450
Lavaca	161,985
San Antonio	299,640
Guadalupe	427,292
Sulphur	445,595
San Jacinto[1]	572,038
Cypress	752,051
Canadian	890,967
Nueces	960,121
Neches	3,600,134
Red	3,662,687
Brazos	3,881,531
Colorado	4,562,814
Sabine	6,224,823
Rio Grande	6,528,100
Trinity	7,386,073
Total	**40,473,892**

[1]Note 1: Does not include Addicks or Baker Flood Control Reservoirs.

A volume-weighted average of storage losses due to sediment shown in Table 1-1 indicates that an opportunity may exist to recover about 14 percent of the original total storage volume shown in Table 1-3 for water supply lakes. Thus, some quantity between 5 and 6 million acre-feet could be made available by dredging, providing such action could be determined to be economically and environmentally feasible.

1.3 Study Findings

Based on literature review and interviews with organizations involved in dredging operations, dredging of water supply lakes has not been a usual practice in the United States. Dredging of lakes for other purposes, such as recreation and aesthetics has been more common, even though the cost for the dredging is often at the upper range of practicality from a water supply standpoint. Large scale dredging is conducted annually by the U.S. Army Corps of Engineers in order to maintain the inter-coastal navigation system and the inland navigable waterways.

1.3.1 Types of Dredging.

Dredging can be done mechanically or hydraulically (Peterson, M, 1997).

Mechanical dredging may involve using draglines or clamshells that are mounted on barges. These operations use support barges to temporarily store dredge material. The barges are moved to shore to unloading areas where the material is loaded on trucks for disposal. This operation requires double handling of sediment and does not compare to hydraulic dredging on the basis of efficiency. Included in mechanical dredging can be excavation using heavy highway equipment. This is accomplished by lowering the lake water or waiting until drought conditions have caused the water surface to lower sufficiently for excavation by heavy highway equipment. This latter method can be cost effective.

Hydraulic dredging is conducted by pumping water from the head of the dredge back through the vessel and out a pipeline to a dewatering area. The pumped water creates a negative pressure at the sediment that allows it to be moved in slurry form through the pump and pipeline system. Water jets, augers or cutterhead are used to loosen the sediment. The hydraulic cutterhead dredge is the most common of the hydraulic dredges.

Hydraulic dredges are designated by the diameter of their discharge pump. The smaller dredges are in the 10-inch range. Larger dredges reach 42 inches. Large size dredges have very large power plants and have high production rates. They also require large crews and usually have fairly large support requirements, such as support boats, tenders and other support craft. Mobilization costs for large size dredges are extremely high; thermocline, large volumes of sediment are needed to make the use of large sized dredges cost effective.

1.3.2 New Reservoir Unit Costs.

Two proposed reservoirs were used to develop unit costs. Lake Ralph Hall, on the North Sulphur River and Lake Columbia on Mud Creek, a tributary of the Angelina River. Since production and costs for dredging are done on a cubic yard basis, the reservoir costs were translated to cost per cubic yard of stored water. Unit costs were based on the Region C, 2001 Regional Water Plan estimated costs. Operation and maintenance costs were amortized for a 30-year period at 5 percent interest. These amortized costs were added to the land acquisition and construction costs for the reservoirs. The unit costs were developed by dividing the total cost by the water supply storage volume. The results indicate that new reservoir costs equate to just over one dollar per cubic yard of storage.

1.3.3 Dredging Unit Costs.

There is no "unit cost" applicable to dredging. The type of sediment ranging from silt to sand to clay and combinations thereof can have a significant effect on production, and therefore on unit costs. Lake bottom conditions (e.g., treed, stumps or smooth) can affect unit costs by a factor of two or four. Distance to the dredged solids dewatering site can affect unit costs. In order to maintain maximum production for distant dewatering sites it is necessary to add booster pumps with the attendant increase in energy costs and maintenance. Land costs for dewatering areas can range from $1,000 per acre to $30,000 per acre depending on the lakes setting (rural, suburban or urban). Two dollars a cubic yard would be a reasonable beginning point for estimation for large operations. But once site-specific information is available, such as sediment characteristics, bottom conditions and dewatering areas, this information should be factored into the cost equation to refine the unit cost factors.

1.3.4 Dredging vs. New Reservoirs.

When compared on a unit of storage to unit of storage basis dredging does not favorably compare to new reservoir construction cost. Actually the problem is one of scale. Typical new reservoir would contemplate supply storage in the hundreds of millions of cubic yards whereas typical dredging operations would involve tens of millions of cubic yards. Scaling dredging up to typical reservoir size or scaling reservoirs sizes down to dredging is not practicable. For example, if one were to opt to find an alternative to a new lake the size of Lake Grapevine, in Tarrant County (164 thousand acre-feet) one would have to find another lake, or combination of several lakes where that same volume could be dredged. Considering water supply ownership issues and availability of other lakes within the same supply area the viability of that alternative is extremely remote.

1.3.5 Dredging as a Supplemental Water Supply Source.

There are cogent reasons why dredging should be actively pursued to supplement existing water supply sources, just as there are cogent reasons to pursue reuse, water conservation, desalination and other water supply alternatives. The current water supply planning horizon as evidenced by the Senate Bill 1 planning documents demonstrates that all practicable opportunities must be employed. Many existing reservoirs could be expanded by over ten percent to their current size if volume was regained by removing existing sedimentation. The cost of the dredging may be considered high when viewed on a unit cost of the incremental yield developed by the dredging, but if spread over the entire yield of the reservoir (including the increased yield related to dredging) the unit cost of raw water shows an increase; however, it may be in a range that is considered acceptable.

1.3.6 Dredging Operations – Time.

Large volumes of sediment will entail dredging operations that will be measured in years, typically with a 24-hour-per-day operation. Large diameter floating pipeline will lead from the dredge to the shore pipe. The pipeline leading to the dewatering area and the return line from the dewatering area back to the lake will require considerations as to easements for their alignment and considerations as to whether the pipeline should be totally or partially buried for aesthetic reasons.

1.3.7 Benefits of Dredging.

Lake aesthetics and recreation are typical reasons for dredging lakes. If a lake were dredged for water supply purposes there would be benefits that would accrue to other purposes. These benefits should be recognized. In fairness, some distribution of costs should be made to all the beneficiaries of the dredging.

1.3.8 Permitting for Dredging Operations.

Dredging involves PL 92-500 permitting. Both Corps of Engineers 404 permits and TCEQ Water Quality Certifications are required. For the most part, this type permitting is reasonably routine. The variability lies in the sediment quality and sediment dewatering areas. If large areas are needed for sediment dewatering, the likelihood of impacting jurisdictional areas and impacts to aquatic and terrestrial habitat increases. While this is not fatal, it could increase the cost of dredging by the need to mitigate the impacts. If chemical impacts exist in the sediment, such as PCB’s, pesticides, herbicides or similar constituents, the requirements for handling the sediment and the land disposal requirements may render the dredging option impracticable. Dredging has been used in the United States as a remedial measure for environmentally impacted lakes and rivers. However, the costs are substantially greater and can exceed $100 to $400 per impacted cubic yard. (Blasland, Boucher & Lee, 2002; Romagnoli and Dooly, 2002)

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CHAPTER 2

LAKE SEDIMENTATION ISSUES

2.1 Water Detention Structures in the State of Texas

There are about 78,558 dams across the United States which impound an amount of water approximately equivalent to one-year's runoff from the continent (Smith, 2002). Graf (1999) cited dams as significant features of every river and watershed in the nation. In Texas, there are approximately 6,907 dams listed in the National Inventory of Dams that have storage of one-acre foot, or larger. The number of small dams in the state is quite large compared to the larger water holding structures. There are over 93 dams in Texas with a minimum storage capacity exceeding 50,000 acre-feet and 440 with more than 1,000 acre-feet of conservation storage capacity. However, the source of these statistics, the National Inventory of Dams, does not include many smaller bodies of water nor more recent urban detention structures. In a recent study by Halff Associates (2002) for the City of Richardson, Texas, seventy-one urban lakes were identified. Of these, there were 27 public lakes, 9 dry detention basins and ponds, 8 private lakes, 16 private commercial lakes, and 11 private residential (single family) lakes. A recent study by Smith et al. (2002) indicates a large number of even smaller detention ponds in the United States. In the Texas Gulf they estimate a density of 0.45 water bodies per square kilometer, representing about 0.29 percent of the land area. Texas currently has approximately 14.9 million acre-feet of storage, but only 8.6 million acre-feet may be currently used due to restrictions in infrastructure capacity, permit limits, or contracts (TWDB, 2002, p. 48)

2.2 Sources of Sediment

According to Wasson (2002), mean annual sediment yield across the globe is related to catchment area by power functions. Catchment area is a surrogate for river discharge, but perhaps more by sediment supply and transport capacity. Sediment production can be thought of as occurring between three end members, i) landsliding/debris flows, ii) sheet and rill erosion and iii) gully and channel erosion. For any size catchment, the sediment yield over time is a function of sediment production rate and sediment delivery rate for each of these processes. The problem is that allocation of sediment between the various components can change over time as a result of land use changes or changes in weather patterns. The concept of sediment supply and sediment delivery fails to accurately reproduce the distributed and time varying nature of erosion and sediment transport.

Sediment budgets describe where the sediment is coming from at a particular point in the basin. According to Reid and Dunne (1996), a sediment budget is an accounting of the sources and disposition of sediment as it travels from its point of origin to its eventual exit from a drainage basin. Sediment budget construction requires identification of erosion processes, erosion controls, and some estimate of erosive rates. Common sources of sediment and methods for evaluation are included in Table 2-1 adapted from Reid and Dunne (1996).

TABLE 2-1
SEDIMENT SOURCE AND EVALUATION

Sediment Source	Methods for Evaluation
Landslides	Field survey, air photos
Earth flows	Field survey, air photos
Debris Flows	Field survey, air photos
Gullies	Field survey, air photos
Bank erosion	Field Survey, root exposure
Surface Road Erosion	Field Survey, root exposure
Sheetwash	USLE, erosion mounds
Wind erosion	USLE (wind), mounds
Animal Burrows	Field Survey

Some generalizations can be made about erosion and sediment yield in Texas based on past studies in similar terrain after Langland and Cronin (2003).

- Basins with the highest percentage of agricultural land use will have the highest sediment yields.
- The process of urbanization can double natural erosion rates and sediment yield.
- In urban settings, channel erosion can account for over two thirds of the sediment load.
- Most of the sediment is transported when streams are at bankfull conditions.
- Sediment delivery rates have not been uniform over historic times, owing to changes in land use.

Sediment budgets have been developed routinely over the years by the National Resource Conservation Service (NRCS) in quantifying sediment sources within agricultural watersheds (Soil Conservation Service, 1966). This technique involves choosing representative areas within watersheds to evaluate the magnitude of erosion processes within that watershed. Griener (1982), in a massive study of NRCS records, categorized erosion rates by Land Resource Area and Drainage Basin within the State of Texas. Griener (1982) simplified the sediment sources for erosion by water as: sheet and rill, gully and stream bank, and miscellaneous. Results are summarized in Table 2-2 for major land resource areas in Texas. The specific Land Resource Area that correlates to the Griener Number is depicted on Table 2-3. More recently, Simon, et al. (2004) compiled suspended sediment records by somewhat similar land resource regions (Ecoregions). In order to compare the two studies, the approximate correlations between the Griener Number and Simon Number is shown on the two columns on the left side in Table 2-2.

TABLE 2-2
GROSS ANNUAL SHEET AND RILL EROSION RATES
BY LAND RESOURCE AREA ADAPTED FROM GRIENER (1982)
(TONS/ACRE)

Griener Number	Simon Number	Cropland	Pasture	Range	Urban	Forest	Misc.	Weighted Average
42	24	0.70	0.10	1.22	0.16	0.00	2.15	**1.25**
77	25	1.24	0.05	0.43	0.32	0.00	1.21	**0.98**
78	27	1.98	0.19	1.68	0.90	0.00	2.88	**1.74**
80A	27	2.12	1.43	1.03	1.58	0.00	0.57	**1.16**
80B	27	1.6	0.51	1.36	1.08	0.00	7.22	**1.36**
81	30	1.74	0.33	1.49	2.05	0.00	1.01	**1.50**
82	30	3.55	0.38	1.32	0.57	0.00	1.37	**1.49**
83A	31	2.77	0.49	0.61	0.44	0.00	0.31	**0.99**
83B	31	2.91	0.20	0.86	1.06	0.00	7.19	**0.87**
83C	31	2.38	0.08	0.56	0.10	0.00	2.01	**0.63**
83D	31	2.05	0.04	0.38	0.23	0.00	1.61	**1.33**
84B	29	6.18	1.05	2.71	1.44	0.00	6.35	**2.76**
84C	29	2.87	1.78	2.65	1.46	0.00	1.45	**1.88**
85	29	3.45	0.84	1.8	1.24	0.00	1.56	**1.90**
86	32	3.74	1.13	1.79	1.33	0.24	2.13	**2.05**
87	33	4.94	1.79	2.16	0.95	0.28	5.13	**1.87**
133B	35	5.64	1.48	2.35	1.54	0.46	3.38	**1.04**
150A	34	1.34	0.14	0.18	1.45	0.04	0.23	**0.82**
150B	34	1.42	0.14	0.11	0.56	0.05	0.39	**0.26**
152B	35	0.95	0.23	0.15	0.91	0.32	0.51	**0.35**
Weighted Average		**2.01**	**1.23**	**1.28**	**1.18**	**0.39**	**1.93**	**1.34**

TABLE 2-3
KEY: GRIENER NUMBER TO LAND RESOURCE AREA

Number	Name of Land Resource Area	Number	Name of Land Resource Area
42	Southern Desertic Basins, Plains, Mountains	83D	Lower Rio Grande Valley
77	Southern High Plains	84B	Western Cross Timbers
78	Central Rolling Red Plains	84C	East Cross Timbers
80A	Central Rolling Prairies	85	Grande Prairie
80B	Texas North Central Plains	86	Blackland Prairie
81	Edwards Plateau	87	Texas Claypan Area
82	Texas Central Basin	133B	Western Coastal Plain
83A	Northern Rio Grande Plain	150A	Gulf Coast Prairies
83B	Western Rio Grande Plain	150B	Gulf Coast Saline Prairies
83C	Central Rio Grande Plain	152B	Western Gulf Coast Flatwoods

Griener's study indicates a statewide weighted average of 1.34 tons/acre/year of sheet and rill derived sediment. The area with the second highest sheet and rill erosion rate is the Blackland Prairie (2.05 tons/acre/year), which is problematic in that it is one of the most rapidly urbanizing areas of the State. Griener went on in his study to estimate the amount of sediment at specific spots along major rivers within the State. Typically, these were associated with major reservoirs or where major streams come together and termed "yield points." To estimate the amount of sediment at a reservoir yield point, Griener used the following equation:

$$SY = [SRE*DA*SDR + GBE*DA*SDR] * RTE$$

To evaluate the amount of sediment transported through the reservoir:

$$SY = [SRE*DA*SDR + GBE*DA*SDR] * [1- RTE]$$

where:

SY = sediment yield in tons,

SRE= sheet and rill erosion in tons/ac./year,

DA = drainage area in acres,

SDR = sediment delivery ratio (applicable ratio- sheet and rill erosion/gully and streambank erosion),

GBE = gully and streambank erosion in tons/ac./year,

RTE= reservoir trap efficiency (taken as 99.5%).

For 300 yield points evaluated in the state, the total average annual gross erosion was 1.94 tons per acre of land.

Sediment loads for streams on a daily basis are derived from sediment sampling stations located throughout the state. These records have been analyzed by Coonrod, et al., (1998) for the State of Texas. Based on extensive work on analyzing suspended sediment records in Texas, the authors' findings can be briefly summarized.

- Suspended sediment load increases with increasing runoff.
- There is no apparent correlation of suspended sediment load with rainfall.
- Rainfall can be used to classify watersheds according to climate which can improve the sediment load to runoff relationship; three climate categories found to be significant were separated by areas less than 720 mm rainfall, and greater than 966 mm rainfall.
- Watersheds with no dams have higher sediment loads than watersheds with dams.
- Dams in drier parts of the state reduce the sediment load more than dams in wetter parts of the state.
- In general, sediment loads and sediment concentrations are lower for sampling points with dams in the watersheds.
- Typically, sediment concentration is highest during the warmest months.
- Infrequent high flows carry a large portion of sediment.
- Perhaps most important, most sediment rating curves vary by two orders of magnitude.

Problems inherent in using the existing sediment records for predicting sedimentation rates include the fact that all the stations have not been sampled for the same period of time or other temporal issues. In addition, there is not adequate spatial distribution of stations leading to spatial bias in using the records, e.g., one basin may have five stations and the adjoining basin none.

Multiple regression and bivariate regression equations were used to estimate sediment loads in the State and to assess the general effect of dams on sediment load within watersheds. However, the coefficient of variation (R^2) remains in the 50-60 percent level, which indicates that much of the variability in sediment transport remains unexplained. The authors concluded that a model of accurately describing how sediment varies for all conditions in Texas cannot be created with the available data**.** This conclusion is reinforced by other researchers who estimate sediment yield derived from rating curves can underestimate true yield by up to 80 percent (Walling and Webb, 1981)

As stated, Simon, et al. (2004) has also analyzed sediment records and his results are shown by ecoregion in Tables 2-4 and 2-5. The first table shows the estimated bankfull channel discharge for the Ecoregion. Simon and others found this to be the storm most effective in transporting sediment over the sediment record. The second table indicates the computed sediment load for each Ecoregion. While maximum rates are highly variable, the 50th quartile rate shows the Blackland Prairie and Central Great Plains portions of the State to have the highest sediment yields. This is consistent with Griener's study.

TABLE 2-4
COMPUTE BANKFULL CHANNEL DISCHARGE $Q = (X)(A^y)$
Q = Cubic Meters per Second
A = Square Kilometers

Ecoregion	Ecoregion Name	X	y	R^2	P Value	Number Sites
24	Chihuahuan Deserts	977.0	-.247	0.25	0.253	7
25	Western High Plains	4.864	0.231	0.349	0.002	24
26	Southwestern Tablelands	0.615	0.524	0.33	<.001	39
27	Central Great Plains	2.767	0.366	0.344	<.001	115
29	Central Oklahoma/Texas Plains	10.965	0.344	0.53	<.001	36
30	Edwards Plateau	11.995	0.353	0.94	.157	3
31	Southern Texas Plains	---	---	---	---	2
32	Texas Blackland Prairie	9.550	0.357	0.815	0.014	6
33	East Central Texas Plains	20.370	0.265	0.214	.433	5
34	W. Gulf Coastal Plain	15.276	0.612	0.569	.005	12
35	South Central Plains	4.645	0.517	0.660	<.001	16

TABLE 2-5
QUARTILE VALUES FOR SUSPENDED SEDIMENT YIELDS
(TONS/DAY/SQUARE KILOMETER.)
After Simon, et al. (2004)

Ecoregion	Ecoregion Name	Minimum	25th	50th	75th	Maximum
24	Chihuahuan Deserts	0.01	0.16	0.32	0.70	3.41
25	Western High Plains	0.02	0.06	0.29	2.84	140
26	Southwestern Tablelands	0.13	1.53	13.3	68.3	247
27	Central Great Plains	0.02	1.09	6.36	14.8	532
29	Central OK/TX Plains	0.40	2.25	13.3	27.2	268
30	Edwards Plateau	0.12	0.41	0.70	0.99	1.28
31	Southern Texas Plains	0.09	0.09	0.09	0.09	0.09
32	Texas Blackland Prairie	0.01	0.28	1.97	4.13	8.99
33	East Central Texas Plains	0.11	0.28	0.45	1.67	3.77
34	W. Gulf Coastal Plain	0.02	0.60	1.14	2.11	4.54
35	South Central Plains	0.12	0.48	1.23	3.17	9.85

As a means of comparison, both Griener and Simon procedures were used to estimate the annual sediment yield for a 1,000 square kilometer basin in the Blackland Prairie. Simon's equations yielded a total load of 719,050 tons. Griener's numbers gave a value of 506,555 tons for gross sheet and rill erosion and an additional yield of 222,390 (0.9 tons/acre/year) tons for gully and streambank erosion. Multiplying each gross erosion rate by the respective sediment delivery ratios (0.2677 and 0.6675) gave a total of 284,050 tons. It should be noted here that as was the case with the analysis of sediment from gaging stations by Coonrod, et al. (1998), prediction of sediment loads with coefficients of correlation averaging about 35 percent is problematic. Using still other regional estimates, the average for the Texas Gulf cited by Smith, et al. (2001) is 231-tons/square kilometer/year (0.935 tons/acre/year). Using this estimate, the load for the 1,000 square kilometer watershed would be only 231,000 tons. It can be seen that there is a wide variety of potential ways to formulate sediment yields within watersheds, which can vary by orders of magnitude.

A detailed study of reservoir sedimentation in the United States by Nixon (2002) summarizes the potential for using regression models alone for assessment of reservoir sedimentation. Nixon concludes that in analyzing data in the Reservoir Sedimentation Information System (RESIS) data set developed by the *Agricultural Research Service (ARS) and the National Resource Conservation Service (NRCS)* with land use and topographical inputs from Digital Elevation

Models (DEMs), the best single model for the unit sedimentation rates in the United States has a coefficient of correlation of 0.668 and a standard error of estimate of 0.921. This indicates that on average, the model can predict unit sedimentation rates within an order of magnitude. Subdivision of the United States into physiographic provinces did not appear to strengthen the regressions. For the regression most applicable to the Texas region, the coefficient of correlation was 0.619. The dominant variables were capacity watershed ratio, agriculture, mean basin slope, and rainfall intensity. Nixon states that in the entire data set, unit sedimentation rates vary over five orders of magnitude. He attributes much of the unexplained error to information concerning reservoir operational practices, the effects of changing land use and cover, and perhaps changes in weather patterns. The author summaries his work in stating that: "In this light, it seems unlikely that any reliable model for reservoir sedimentation over broad geographical areas will be developed using multiple regression analysis unless that analysis includes an immense number of variables, including those describing reservoir operation and the temporal variation of land use and land cover." (Nixon, 2002, p.110).

In addition to field methods of evaluation of sediment sources, models are increasingly being used to evaluate the magnitude of sediment generation and transport (Ward and Bergman, 1999). The major models in sediment transport by water being used in Texas for field scale assessment are the older USLE and MULSE, RUSLE2 and WEPP for sheet and rill erosion, and for basin scale estimates, SWAT and HSPF. All these models were derived by the Agricultural Research Service, USDA, except HSPF, which is a derivative of the Stanford Watershed Model and has been modified over the years by various agencies. Currently, SWAT and HSPF are part of the Environmental Protection Agencies Basins models chosen for evaluation of TMDLs. For watershed scale assessment, models are simplified in their assessment of sediment transport and deposition. The SWAT model has been run for the entire Texas Gulf Coast (Srinivasan, et al. 1998) and in more detail for specific watersheds in the State as the upper Trinity River Basin by the Water Resources Assessment Team (1995). Models are calibrated to sediment and discharge data based on available gage sites in the basin and are therefore biased in the same way as the actual gage data as shown by Coonrold, et al. 1998. While models are simplified over actual site-specific basin processes, they are still the only means to evaluate, on a watershed scale, the potential impacts of applying basin-wide management practices to reduce sediment and pollutant loads to downstream reservoirs and streams.

2.3 Sediment Deposition in Reservoirs

Sediment surveys can provide a meaningful retrospective estimate of sediment yield from a watershed provided the reservoir trap efficiency and the volume and density of the deposited sediment can be accurately assessed. There are basically four ways to estimate sediment flux (rate of sediment transport) in lakes and reservoirs (Ritchie and McHenry, 1985) and all have been done in the State of Texas. The oldest method was based on past NRCS methodologies given in Section 3 Chapter 5 of the National Engineering Handbook and involves dividing the reservoir up into segments along which surveys are conducted. At spots along the survey or range lines, sediment depth is noted with either a "spud bar" or by physically inserting a probe to estimate the pre-impoundment depth. Upon completion of all the range lines, the sediment volume is estimated by either the contour method or range method. The second method involves surveying the reservoir with a simple depth sonar device (fish-finder) and noting position by either surveying techniques or more recently GPS. The survey records depth to the water bottom. The surveys are then repeated several years later across the same general points and the difference is taken as the sediment flux. The third method, used by the TWDB and developed by Dunbar et al. (1999) involves using a more sophisticated acoustical sounding device, which is able to depict both the top and bottom of the sediment layers in the reservoir while concurrently recording the GPS location. Upon surveying the reservoir with a line spacing of from 100-500 meters, the data is downloaded, interpreted, and volumes computed giving a flux from the date of reservoir impoundment. Coring at select sites in the reservoir allows determination of sediment density as well as verifies sediment depth interpretations. The final method, which can be used with any of the above methods, is based on Cesium 137 dating techniques. Collection, analysis and age dating of reservoir sediment in Texas have been done by Van Metre and others (2004). Depending on the penetration depth of the core, Cesium 137 can provide one or more date markers within the sediment core. Worldwide fallout due to above ground nuclear testing began in 1951 and increased with much larger testing in 1952. The peak fallout occurred in the United States in 1957-58 followed by a moratorium from 1958-1961. Finally, resumption of atmospheric testing in 1961 was followed in 1963 with the end of testing and the Limited Test Ban Treaty. Van Metre dated the first occurrence of Cesium in the core at 1953 and the peak fallout in 1964. Thus, it is possible to get three sediment ages in older lakes; one for the date of impoundment, one for the 1953 beginning of Cesium deposition, and one at peak deposition. Results of sediment flux analyses for several Texas lakes are summarized in Table 2-6. The mean flux of sediment in the listed reservoirs is 2.4 centimeters per year.

TABLE 2-6
SEDIMENT FLUX FROM CORE ANALYSIS IN TEXAS
BY USGS 1992-2001
(Van Metre and others, 2004)

Lake	Constructed	Sediment Thickness (cm)	Linear Sedimentation Rate (cm/yr)
Meridith	1964	73	2.1
Fosdic	1910	105	1.4
White Rock	1912	145	1.7
Como	1889	95	2.2
Echo	1930	97	1.9
Livingston	1969	90	3.4
Houston	1955	149	3.5
Town Lake	1959	110	2.7
Lorence	1962	27	0.8
Amistad	1969	33	1.2
Falcon	1954	100	2.2
Llano Grande	---	115	5.1
Mean	1943	94.9	**2.4**

Reservoir surveys indicate an average loss in storage of 8.87 percent. The TWDB has surveyed approximately 78 reservoirs ranging in size from 84 to 1,467,283 acre-feet in conservation storage volume. These results were then used to estimate, based on prior survey information or the original lake volume, the change in storage of the reservoir. The mean change was 8.87 acre-feet of lost storage. Changes in storage ranged from a net gain of 18 percent to a net loss of 51.9 percent. (*The net gain in storage is an "apparent" gain and is due to the increased accuracy of surveying techniques. Older surveys relied on assessing reservoir volume by averaging techniques between a limited number of survey range lines cut across the reservoir. With the advent of differential GPS and improved acoustic depth sounders, reservoir volumes could be more accurately estimated. Comparison of the earlier range surveys with the newer GPS surveys often resulted in a finding of additional reservoir volume, which really indicated "no new net storage", but reflected the error in the original survey method)*

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Analysis of the reservoirs with a net loss in storage yielded the following equation.

Annual loss rate in AF = 92.8 + (0.0012)(Total Initial Storage (AF))

The coefficient of correlation was 0.46 indicating that the relationship is not able to assess all the components of reservoir trap efficiency and sediment delivery. However, the equation indicates general trend of loss rate of the surveyed reservoirs and can be a useful guide in assessing potential dredging volumes necessary to maintain existing storage levels. The annual volume deposition (or loss of storage) in the mean reservoir surveyed (179,728 acre-feet) would be 302 acre-feet (about 487 thousand cubic yards) of sediment. Assuming a dry weight of 50 pounds per cubic foot, this would require about 329,000 tons of dredging per year to maintain the original storage. The world reservoirs are losing storage at an annual rate from 0.5 to 1 percent according to Mahmood (1987) and later by White (2005). Owing to the diverse nature of sedimentation rates globally, these numbers are surprisingly similar and therefore are probably realistic long-term averages.

2.4 Problems with Estimates of Sedimentation in Reservoirs

Sediment transport varies across the watershed depending on land use, runoff, spatial variability of rainfall, soil and rock types and channel hydraulic conditions. Sediment transport varies seasonally and spatially within watersheds. Therefore, prediction of sediment loads to reservoirs is problematic. Since reservoir longevity and related economics of dredging is intricately tied to sedimentation rates, the problems are discussed in more detail below.

Reservoir sedimentation rates determined by range surveys suffered from low spatial representation of actual sediment thicknesses due to the time and labor involved with obtaining each range line. In smaller floodwater structures, even though line spacings were sparse, man months were involved in obtaining sedimentation rates. Larger reservoirs, over 200 acres or more, were extremely difficult to assess in this manner as aircraft cable was typically used to guide the survey boat along the range lines and the distances across the reservoir became too large. Using echo sounders and differential GPS allowed smaller line spacing and greatly improved the economics of surveying larger reservoirs. This more modern method of reservoir surveying began in Texas in the last 20 years. Such surveys gave reliable estimates of water volumes but were considered in error when they were expanded to assess sedimentation. The reasons for this were that the estimates of sediment flux were based on comparison of initial water volume at the time of impoundment to the resurveyed water volume. The loss of volume was attributed to sedimentation. Often flux was determined by trying to duplicate old range lines. Since sedimentation rates are often in the centimeter per year or less range and vary spatially within the reservoir depending on sediment type, this method was thought to have problems in precision and accuracy. The method now used by the TWDB as detailed by Dunbar (1999) has overcome many of these previous problems by sensing, at each survey point, the top of the sediment and pre-impoundment bottom. This is done at a high line spacing and data acquisition speed allowing for a visual image of the bottom to be produced. Interpretation of the record, when corroborated with core data, can give very accurate rates of sedimentation since the date of impoundment. The core data confirms both the accuracy of the interpreted bottom as well as the density of sediment in the reservoir. As stated, even more detail of sediment flux is possible with the use of Cesium 137 in the older reservoirs.

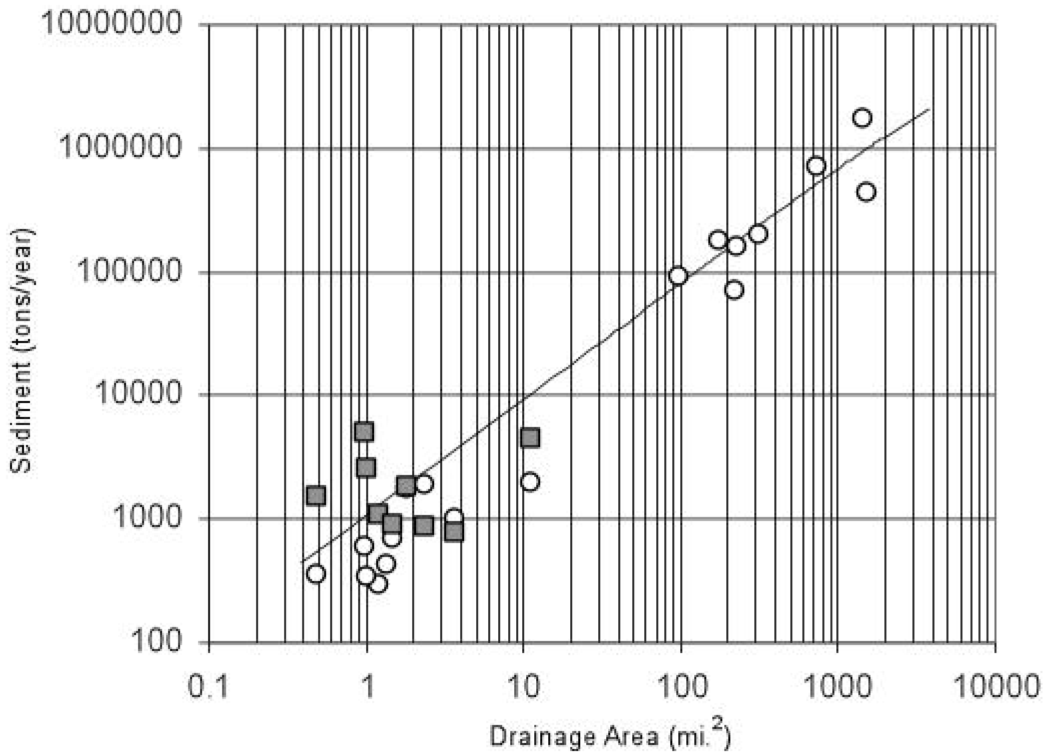
A final and not insignificant problem of the older methods of assessing sediment volume in the reservoirs was one of time and associated cost. A survey of the original Lake Waco in 1937 took 2.5 months with a six-man crew who expended 960 man-hours during the period to complete a survey of the 38,500 acre-foot lake, or about 40 acre-feet per man-hour, (Jones and Rogers, 1952). Current sediment survey rates are about 16 times greater, or about 640 ac-ft/ man-hour.

While sediment surveys can give a record of past sedimentation rates, they are dangerous to use to predict future rates owing to changing land use and perhaps climatic conditions. Models such as SWAT, calibrated to past land use/climate and sediment transported into the reservoir can be used to test the impacts of land use changes and management practices within the watersheds. (Arnold and others, 1987) One of the major problems in estimates of sediment delivery using these models in large watersheds is assessment of trap efficiency of upstream floodwater structures. There are approximately 1,944 floodwater structures (SCS reservoirs) in the State of Texas constructed under Public Law 566 (PL-566). Most of the larger PL-566 structures built by the NRCS in the 1950's and 1960's have been assumed to have trap efficiencies in the order of 95 percent or more. This is based on previous work by Heinemann (1981) or Brune (1953). Such rates were used, for example in estimating the future dredging costs in Lake Lavon (Taylor, et al. 1978). More recent evaluation of reservoir sedimentation accomplished by Dunbar and Allen for reservoirs in the Blackland Prairie has shown that assumed trap efficiency rates of 95 percent overestimate trap efficiency by up to 60 percent (Figure 2-1).

FIGURE 2-1

SEDIMENT YIELD AND RESERVOIR SEDIMENTATION

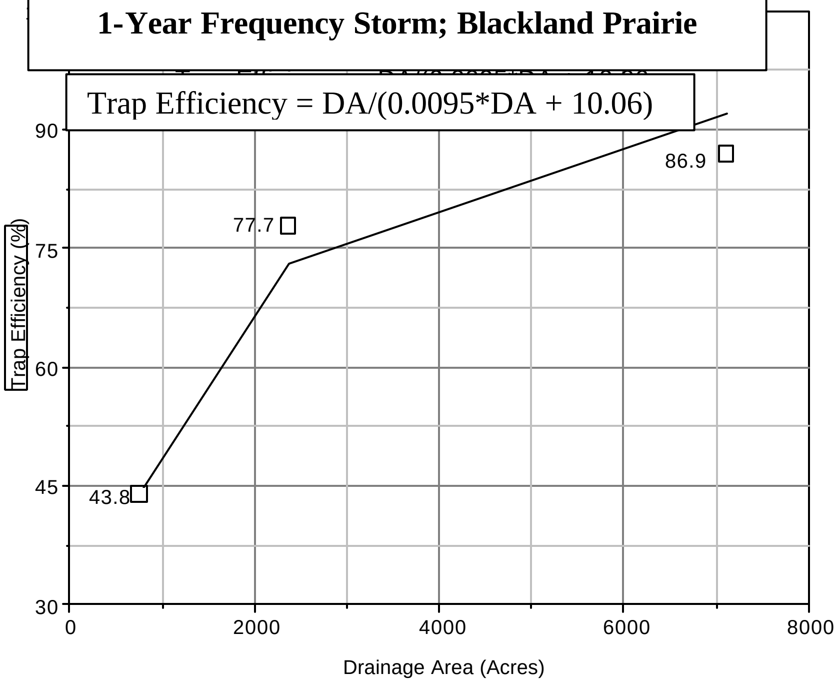
FOR THE TEXAS BLACKLAND PRAIRIE



The solid line is the predicted sediment yield for the weighted average land use in the Texas Blackland Prairie (Greiner, 1982). The circles are the observed sedimentation rates in reservoirs in the Blackland Prairie based upon modern survey results and core data. The group of reservoirs with watershed areas larger than 50 mi.^{2} are large water supply reservoirs. The group with watershed areas less than 50 mi.^{2} are SCS flood control reservoirs. Sediment yield is estimated from the reservoir data by dividing the measured trapped sediment by the expected trap efficiency. Brune's (1953) relationship was used for the large reservoirs, which had an average expected trap efficiency of 95%. Heinemann's (1981) relationship was used for the SCS reservoirs. The average predicted trap efficiency for the SCS reservoirs was 90%. The gray (solid) squares are the same SCS reservoirs, but corrected with a constant trap efficiency of 40%.

These results indicate that the sedimentation rates in large water supply reservoirs in the Texas Blackland Prairie over the last 40 years have been consistent with the sediment yield predicted by Griener (1982) and Brune's (1959) trap efficiency curve. However, the sediment trap efficiency of upland SCS flood control reservoirs has been less than half of that predicted using Heinemann's (1981) trap efficiency curve for SCS reservoirs. Similarly, a simple estimate of trap efficiency using SEDCAD 4 after Warner and others (2004) is shown using three small floodwater structures in the Blackland Prairie (Figure 2-2).

FIGURE 2-2
TRAP EFFICIENCY FOR FLOODWATER STRUCTURES
1-Year Frequency Storm; Blackland Prairie



2.5 Sediment Reduction by Application of Best Management Practices in Watersheds

A cost benefit study of a 5,000-hectare watershed in Indiana indicated that the benefits received from the Best Management Practices (BMPs) established in the 1970s did not outweigh the cost of implementing and maintaining the BMPs (Bracmort and others 2004). The Benefit-Cost ratio was 0.47 based only on sediment and phosphorous reduction from non-gully erosion as predicted by the SWAT model. The authors acknowledge that analysis of BMPs is difficult due to the limited water quality and cost data available and many of the ways to quantify benefits is problematic.

A similar evaluation of selected conservation practices in Minnesota indicated a net decrease in farm income from 1 to 3 percent and despite reducing suspended sediment by 25 percent did not reduce the negative response to established fisheries (Westra, et al., 2005).

In evaluating the total costs of a BMP, one must take into account the following four components: construction costs, maintenance and inspection costs, and land costs and any tax advantages. The benefits of BMPs will vary depending on the standards evaluated (e.g., TSS, TP, $NO_{3,}$ etc.) and the associated cost per fraction of pollutant removed. (Wossink and Hunt, 2003)

The evaluation of BMPs in the watershed upstream of reservoirs is an area that requires future study. Currently the USDA and ARS are undertaking a nationwide assessment of such practices and it is recommended that this research be analyzed prior to application of BMP practices within Texas. To reduce sedimentation in Texas reservoirs, a coordinated effort of economically prudent and environmentally justifiable methods should be studied. In addition, recent work by Vieth and others, (2004) indicate that optimization strategies in the application of BMPs shows considerable promise in reducing overall costs.

2.6 Consideration for Water Supply Lake Owner/Operators

Unquestionably reservoirs will serve to collect sediment-laden rainfall runoff that migrates to reservoir tributaries or the streams across which the reservoirs are impounded. Velocity is the causative agent; flowing water is the transport mechanism. As rainwater runoff flows over an exposed soil surface, the dynamic energy represented by the flowing water coupled with the viscosity of the water imparts a drag force on soil particles. As the runoff flows in the stream it also collects soil grains from the banks and bottom, then it abruptly loses velocity as it enters the reservoir impoundment. A reservoir constructed across a stream thereby serves as a stilling basin for inflows (USACE, EM 1110-2-142, 1997). Large-grained sediment drops out immediately once the velocity is reduced. Very fine-grained materials (clay sized particles) have an extremely slow settling velocity. Therefore, they continue on into the main body of the lake before settling to the bottom. Clay particles have high, negative charges and will not tend to settle, but tend to remain in the water column, moving in erratic paths (Brownian movement) as one particle repels another as it comes in close proximity. (Terzaghi, K, 1948)

The threat of sedimentation to reservoirs exists even in an undeveloped, natural setting. The amount of sediment that will reach a reservoir is a function of soil type, climate, meteorological events and vegetation. Beyond that, man’s practices influence the amount of sedimentation. Some areas with particularly highly erodible soil could become a major source of lake sedimentation if they were subjected to agricultural practices that removed protective soil cover (overgrazing, plowing, etc.). It would benefit the lake owner to understand the practices that are ongoing in the lake watershed and to have a certain level of influence in assuring that ongoing practices in the watershed do not result in increased erosion and, therefore, an accelerated loss of storage in the lake.

The following is a discussion of major factors that can affect the amount and rate of sediment deposition in a reservoir. These include upstream watershed practices, ground cover, climatic conditions, soil types, and development activities.

2.6.1 Upstream Watershed Practices

Even though it is inevitable that lake sediment will originate from the watershed above a lake, the amount of sediment deposited can be a variable. The entire watershed can be a source of sediment; therefore, the opportunity exists to establish practices that control sedimentation. The U.S. Department of Agriculture through its statewide organizations, such as the Natural Resource Conservation Service (NRCS) and the U.S. Forest Service (USFS) has undertaken ambitious programs for over 50 years to seek to preserve topsoil and limit erosion. This has extended to agricultural and silvicultural practices especially designed to prevent erosion of the fertile topsoil. Crop rotation, contour plowing and terracing are examples of such programs.

In the late 1940s and 1950s an NRCS predecessor also embarked on a program for constructing small lakes ("SCS Lakes") within watersheds to capture sediment-laden runoff near its place of origin. Some of these "SCS Lakes" have now filled with sediment, such that inflow is barely affected, thus rendering the lake ineffective for sediment control since the inflow travels to the spillway with little reduction of velocity and carries its load of suspended solids with it as it progresses below the dam.

Urbanization within watersheds has led to larger areas of soil disturbances and the potential for increased erosion. In the past, urbanization has also resulted in increases in stormwater runoff as pasture and forests were converted to rooftops, roadways and parking areas. Increased runoff results in increased flow in the streams and, therefore, increased erosion and higher levels of suspended solids. Disturbance associated with upland construction yields about ten times the amount of sedimentation compared to the same area in cropland use. More modern development practices and the implementation of Clean Water Act stormwater rules by the USEPA and TCEQ have begun to abate this problem in the near-term.

2.6.2 Ground Cover/Land Use

The most effective protection against erosion is ground cover. Grasses, for example, bind the soil through their root systems, and are the most effective natural erosion control practice. In addition, during rainstorms the dynamic energy of the raindrops is dissipated as the drops fall among the leaves and stems of the grass. Thus, grasses provide two levels of protection—energy absorption and soil particle binding. Data from Riesel, Texas (ARS Blackland Prairie Experimental Station records from 1939 through 1943) indicate cultivated areas had a net soil loss of 15 tons per acre compared to 0.2 tons per acre for native grass meadows (Richardson, 1993).

Trees provide a slightly lesser level of protection. The tree canopy reduces the kinetic energy of the raindrops. Additionally, fallen leaves and needles from the trees provide another layer of protection to the soil by covering the soil grains and shielding them from the impact of the falling rain and subsequent runoff. Certain tree types (invaders) do not provide suitable ground cover. For example, salt cedar trees increase the saline content of the soil retarding the opportunity to establish any grass cover. Therefore, accumulated rainfall that collects beneath the trees can have greater erosive potential. Mesquite trees and Ash Juniper tend to crowd out grasses; yet they do not contribute leaf litter to cover the area beneath the tree canopy.

2.6.3 Slope

When unprotected by vegetation, or other measures, erosion increases exponentially with slope; an area with a three percent slope has five times the erosion from and area with a one percent slope (Richardson, 1993).

2.6.4 Climatic Conditions

Climatic conditions play a major role in erosion. Rainfall across Texas varies from east to west from more than 50 inches of annual rainfall to less than 8 inches (The Handbook of Texas On-Line). In the Revised Universal Soil Loss Equation (RUSLE), the "R" factor related to rainfall impact in combination with the amount and rate of rainfall varies from 50 in west Texas to 450 in the East Texas Coastal Zone. The natural amount of vegetation is a function of rainfall. As one progresses west from the Sabine River Basin at the eastern border of Texas the amount of annual rainfall declines to the point in far west Texas that a precarious condition exists with respect to sustaining vegetation. There, full vegetative cover cannot be supported because of climatic conditions, and the bare soil is largely susceptible to erosion. While rainfall is sparse in the western part of Texas on an annual basis, it can occur in intense rainfall events, introducing significant energy into the ground as it falls. Where the ground lacks vegetative cover, the result is significant erosion.

2.6.5 Soil Types

The soil types, as described by physiographic provinces, vary across Texas as shown by Griener (1982). Aeolian deposits or alluvium cover much of the high plains of Texas. Soils in the near-west portion of Texas were derived from parent rock of older geologic ages and contain sand as a principal constituent of the soil matrix. In central Texas the soils derived from Cretaceous geologic formation tend to have high clay content. Finally, in East Texas the Tertiary aged geologic deposits contain more sand, thus, the residual soils tend to be sand or sandy loams. The type of soil has a direct relationship to erodibility and depositional pattern in lakes as indicated by Griener (1982) and variation in erodibility of soil by texture and RUSLE “L” (Hill slope Length) factor.

2.6.6 Development Activities

Over the past years, urbanization and infrastructure improvement have resulted in major erosion problems. With the advent of erosion control plans (storm water pollution prevention plans) required by *The Clean Water Act* (PL 92-500), there have been effective strides toward preventing uncontrolled runoff and high erosion from construction sites. However, post-development design and practices to limit erosion and increased sediment transport have not been uniformly implemented. As early as 1964, Baird demonstrated that mean annual erosion from an area with conservation practices reduced erosion from 20 tons per acre per year to five.

2.6.7 Sediment Control Programs

The following describes a number of regulatory or voluntary programs for the control of sediment in streams and lakes.

The National Pollutant Discharge Elimination System (NPDES)

A significant result of the Clean Water Act is the NPDES program that requires the control of both “point” and “nonpoint (e.g., runoff)” sources of pollution. In Texas, responsibility for the NPDES program has been delegated to the State. In turn, the State has developed a Texas Pollution Discharge Elimination System (TPDES) program. This program requires the preparation of Storm Water Pollution Prevention Plans for many industrial-type activities and for construction projects greater than one-acre. The program is only partially effective since it satisfactorily addresses construction site activities, but it is limited when it comes to addressing site development design for the projects themselves and the post-construction period of operation. Currently, only urban cities fall under jurisdiction of the TPDES rules that pertain to site development practices. The importance of controlling rainfall runoff in a watershed in the post-construction period is that the cumulative effect of increased runoff from an altered watershed can materially affect the amount of runoff, and therefore the amount of erosion derived soil that can be transported to downstream lakes.

Programs by Water Supply Owners

The water supply owner can take proactive steps in limiting erosion throughout the watershed. The water supply (lake) owner has an economic incentive to prevent loss of water storage. To accomplish this objective, lake owners could pursue programs to purchase easements from upstream areas to limit agricultural practices that have a potential for increased erosion. Examples of this practice might include obtaining narrow easements along streams, or buying easements to restrict specific practices on discrete areas that, because of soil type, are known to be a disproportionately higher potential source of sediment. The cost-benefit of establishing BMPs has been addressed earlier in this document (Section 2.5). Essentially the application of BMPs should be developed with caution to assure that any funds devoted to BMPs can be adequately justified.

Cooperative Programs

The lake owner could also join with watershed landowners (on a financial basis) to control, or eradicate certain tree species that either reduce annual rainfall runoff through transpiration, or that prevent ground cover from being established that would otherwise prevent erosion. A tree burning or land-clearing program could be established on a priority basis. From the standpoint of preserving lake storage or increasing reservoir yield, practices such as tree burning should be carefully evaluated.

Dredging

Dredging is a common practice used to maintain the inland navigation system along the Atlantic and Gulf Coasts and throughout the many navigable rivers in the United States. Typically, dredging is performed using some form of mechanical or hydraulic dredge. Dredging is a viable and effective method to remove sedimentation that has impacted water supply reservoirs. At issue is whether dredging is an economically effective method as compared to sediment control programs or the construction of new water supplies. Another point of view is that if dredging were to be considered economically viable it would be of great benefit to stem the amount of sediment arriving from the watershed to the maximum extent possible through implementation of improved, or best management practices, throughout the watershed in order to preserve the newly restored space as long as possible. The following table (Table 2-7) summarizes the issues related to dredging. These same issues are developed in detail in the following sections, but are presented here to provide a fairly comprehensive coverage of the issues. The table is extracted from Halcrow Water, Department of Environment Transport and the Regions Sedimentation in Storage Reservoirs, Final Report 2001, Wiltshire, UK. (Some terminology has been changed and is shown in italics where words were substituted for the original.)

TABLE 2-7

LIST OF DREDGING ISSUES

Category	Examples of Possible Issues
Removal of Sediment	• Loss of Habitat – dredging reservoirs, particularly at the shallow headwaters and reservoir margins can destroy habitats and affect wetland birds, etc • Impact of desilting method adopted – if the water sustains flora or fauna of particular value, or if fish issues are important, then the dredging might be necessary to avoid lowering the water level • Temporary loss of reservoir water quality through removal of organic material • Long-term improvement in reservoir water quality through removal of organic material • Possible reduction in downstream water quality during dredging • Loss of land for containment areas to drain/treat sediment • Timing of operation with respect to bird migration or fish spawning, freezing of reservoir, etc. • Improvement in potential for recreational reservoir use
Transportation	• Reservoirs are often in remote areas – transportation on minor roads can place pressure on local communities (noise/air pollution and physical damage to roads) • The impact of transportation can be much reduced if the sediment can be effectively dewatered at or near the reservoir site using, for example, a hydrocyclone and /or a filter bed press
Disposal	• Viability of disposal to land depends on level of contaminants Contamination of groundwater by leaching
Re-use	• Examples of re-use include sand/gravel/bricks for the construction industry and *fertilizer* • Can be used to fill *abandoned* quarry areas or mines • Can be used to cap landfill sites

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CHAPTER 3

DREDGING AS AN ALTERNATIVE TO RESERVOIR CONSTRUCTION

3.1 Dredging Equipment (Petersen, 1997)

Modern dredges can be classified as either mechanical or hydraulic (or a combination of the two). Mechanical dredges lift the dredged material by means of diggers or buckets of various design, and hydraulic (suction) dredges pick up material by means of suction pipes and pumps.

3.1.1 Mechanical Dredges

Mechanical dredges remove loose soft or hard materials by a clamshell, dipper, or bucket of some type and usually operate in conjunction with disposal barges that are filled with the excavated material and then moved to a disposal site and emptied. Dipper and bucket dredges are similar in that both operate with the dipper and bucket at the end of a boom. However, the dipper is rigidly attached to the boom whereas the bucket is suspended on cables. Bucket and ladder dredges dig the material using a chain of buckets rotating around a ladder, with buckets discharging onto a conveyor belt that moves the dredged material to the disposal barge or site. These dredges are not usually self-propelled, but are moved to the work site by a tow. They can maneuver in a limited area by using spuds.

3.1.2 Hydraulic Suction Dredges

Hydraulic suction dredges are usually categorized according to the means of disposal of the dredged material (hopper, side-casting, and pipeline dredges) or according to the means for picking up the dredged material (cutterhead, plain suction, and dustpan dredges).

Hopper Dredges

Hopper dredges are deep-draft seagoing vessels used primarily for work in exposed harbors and shipping channels where traffic precludes use of stationary pipeline dredges. They are not used in shallow-draft waterways in the United States. These dredges have an internal chamber (hopper) for storing dredged solids.

Side-casting Dredges

Side-casting dredges are self-propelled, shallow-draft, seagoing vessels designed for dredging from bar channels at small coastal harbors that are too shallow for hopper dredges or wave action is too rough for pipeline dredges to operate. A side-casting dredge picks up bottom material through two suction pipes and discharges it directly overboard, to the side through a discharge pipe.

Pipeline Dredges

Pipeline dredges draw a slurry of bottom material and water through a suction line and pump the slurry through a floating discharge line, on to an overland pipeline, and finally to the disposal site. There are three-types: dredges with a plain suction intake, dustpan dredges with jets in the head that are used to loosen material, and dredges with a cutterhead at the forward end of the suction line to loosen material to be dredged.

Dustpan Dredges

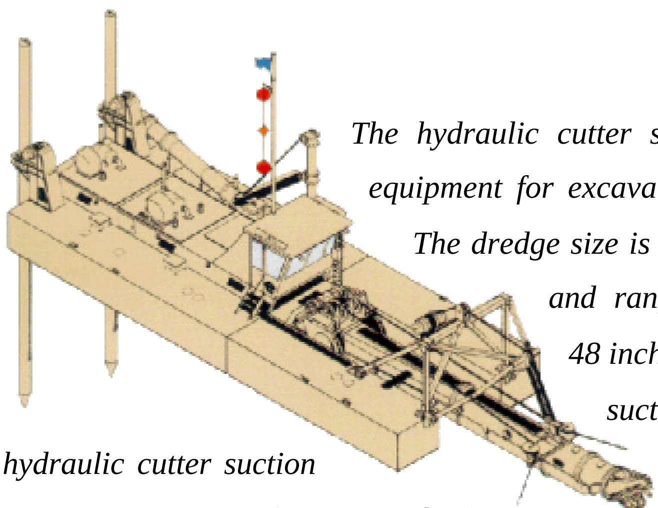
Dustpan dredges are self-propelled vessels designed for working in non-cohesive material in rivers or sheltered waters with no significant wave action. Dustpan dredges have a wide, flared, flat mouth up to 30 feet across on a rigid ladder. The dredge head is equipped with pressure water jets that loosen the bottom material and suction openings through which the dredged material and water are drawn into the suction line as the dredge is winched forward. Dustpan dredges cut a channel the width of the head and are limited to making relatively shallow cuts in repetitive passes over the shoaled area.

Cutterhead Dredges

Cutterhead dredges are the most widely used type in the United States and are generally considered to be the most efficient and versatile (U.S. Army Corps of Engineers, 1983). The cutterhead dredge has a rotating cutter around the intake end of the suction pipe and can dig and pump all types of alluvial materials and compacted deposits, such as clay and hard pan. The most common suction pipe diameters range from 8 to 30 inches.

For open-water disposal, only a floating discharge line is needed with a cutterhead dredge. A floating discharge line connects the dredge to the discharge point and is made up of sections of pipe from 30 to 50 feet in length, each supported by pontoons. For land disposal, additional sections of shore pipe of approximately 10 to 15 feet length are also needed.

For large volumes of sediment removal, the hydraulic cutter suction dredge is typically the most suitable type. The following information is from an article presented at Texas A&M University's 32nd Annual Dredging Seminar prepared by R. E. Randall, P.S. deJong and S. A. Miedema. It provides an excellent description of the hydraulic cutter suction dredge. Where the authors refer to "waterway" or "channel", the reader should substitute "lake."



The hydraulic cutter suction dredge is the most commonly used equipment for excavating and maintaining navigable waterways. The dredge size is defined by the diameter of the discharge line and range in size from 0.15 to 1.22 meters (6 to 48 inches). The most common size for a cutter suction dredge is 0.61 meters (24 inches). Small hydraulic cutter suction dredges are considered to range from 0.15 to 0.30 meters (6 to 12 inches). In the United States, the cutter suction dredges accounted for 149.1 million cubic yards of the total 271.2 million cubic yards of the dredging volume during the fiscal years 1996-98.

The cutter suction dredge consists of a large barge shaped vessel that normally doesn't have propulsion equipment and is mobilized to the job site by other vessels. It has centrifugal pumps on board that are used to pump slurry (mixture of solids and water) to a disposal location. The dredge has a ladder that supports the cutter, the cutter drive unit and the suction line leading to the suction side of the dredge pump. At the end of the suction line and cutter drive shaft is the cutterhead that is used to loosen and cut sediment that must be removed from the bottom of the waterway. The cutter may have special teeth for excavating the bottom. The excavated material *is mixed with the surrounding water and drawn up the suction pipeline due to the low pressure created by the pump on the suction side. The dredged material may consist of clay, silts, sands and gravel and the slurry may be as much as 20% sediments by volume and the other 80% is the ambient fluid. In some cases, an additional pump may be located on the ladder when dredging depth is deep (greater than 9.1 meters or 30 feet) in order to improve production due to cavitation limitations.*

On the discharge side of the main dredge pump, a long pipeline is used to transport the slurry to the disposal location that is typically a confined disposal site. The length of the pipeline may be as long as several miles. The power available and head developed by the pump or pumps must be enough to overcome the hydraulic friction losses occurring in the total pump and pipeline system. Additionally, the velocity in the pipeline on the suction and discharge side must be above the critical velocity required to suspend the sediments in the carrier fluid. This critical velocity depends primarily on sediment grain size, sediment specific gravity, and pipeline diameter. Additional pumps (called booster pumps) are sometimes needed to transport the dredged material through very long pipelines.

The dredge material lays on the bottom of the waterway and therefore, the dredge must move along the waterway (channel) to excavate the sediments. The dredge typically uses spuds, winches and anchors to move it. Spuds are large vertical cylinders that are located at the stern of the dredge. Hydraulic cutter suction dredges use two spuds arranged at a specified separation distance at the stern or with one at the stern and one in a carriage arrangement. Advancing the dredge is accomplished by alternatively raising and lowering the two spuds at the appropriate positions and consequently the dredge walks up the channel or is advanced by the spud carriage.

Winches and wires on the port and starboard side of the dredge are used to swing the dredge back and forth across the channel bottom to bring the cutter in contact with the sediment that is to be removed. The swinging of the dredge is about the one spud that is driven into the sediment. The two spud walking dredge arrangement has a production efficiency of approximately 50 percent, which means the dredge is removing sediment only half of the time. Dredges with *the spud carriage arrangement are more efficient and usually can be removing sediment 75 percent of the time. The winches must have enough power to move the cutter across the channel, and the wires must be strong enough to prevent breaking and costly downtime for the dredge. The winch wires are normally attached to anchors placed in the channel and these must be moved as the dredge moves up the channel.*

Figures 3-1 through 3-6 show examples of various cutterhead dredges.

Figure 3-1
10-inch "Dragon" Dredge[1]

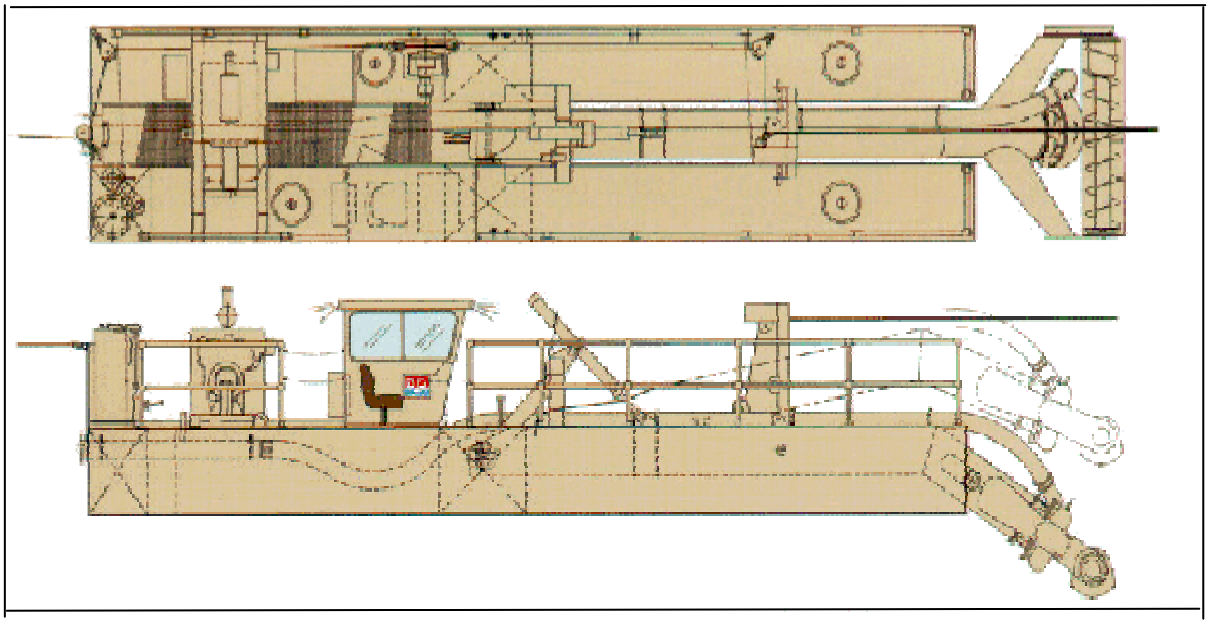


Figure 3-2
MC 2000 10-inch Auger Dredge[1]

[1]Courtesy of Ellicott Corporation

Figure 3-3
34-inch Cutterhead Suction Dredge[1]

Figure 3-4
28-inch Cutterhead Suction Dredge[1]

[1]**Courtesy of Ellicott Corporation**

Figure 3-5
24-Inch Cutterhead Suction Dredge[1]

[1] Photographs courtesy Ellicott Corporation

Figure 3-6
42-Inch Cutterhead Suction Dredge[1]

3.2 Lake Dredging

The effort required to accomplish lake dredging is affected by several variables. These factors include the sediment volume to be removed, sediment characteristics, sediment quality (i.e., the presence of toxic or hazardous materials in the sediment), lake bottom characteristics, the expected duration of dredging activities, and the impact of dredging on lake water quality.

3.2.1 Sediment Volume

Dredging to develop water supply storage is a large undertaking. The volume of sediment to be removed will have to be large if meaningful storage is to be added to the water supply. The volume of the sediment to be removed often dictates that large sized dredges be utilized in order to develop storage as efficiently as possible.

3.2.2 Sediment Characteristics

The production rate is significantly affected by the classification of the sediment. For example, clay soils are more difficult to remove and transport through the pipeline than silts. Sand represents a production difficulty level between clay and silt. Most Texas lakes have sediment that will likely be represented by combinations of clay, silts, and sands.

3.2.3 Sediment Quality

Environmental impacts caused by the presence of toxic or hazardous chemicals (herbicides, pesticides, hydrocarbons, toxic metals, PCBs, etc.) will materially affect the cost of sediment storage, since impacted sediments may require confined disposal sites that necessitate clay linings and extremely high costs for construction. Before any dredging is planned, sediment sampling and analytical testing should be accomplished to demonstrate that the sediment has not been affected by historical inflows containing contaminated sediment. References cited unit costs of above $100 to $400 per cubic yard for impacted sediment (Blasland et al., 2002; Romagnoli, et al, 2002).

Van Metre and others (1997) summarize work done on cores from White Rock Lake in Dallas, Texas stating that:

- while slow, changes occasioned by environmental regulations can successfully reduce or eliminate some toxic contaminants in reservoirs as there are large decreases noted in lead, DDT and PCB's,
- the amount of constituent in the reservoir is proportional to its use within the watershed, and
- reservoirs are traps for the toxic chemicals that will remain in the sediment long after the use has been restricted in the watershed.

Wilson (2003) notes similar trends in other reservoirs where she compares the quality of cores from three Texas Lakes from East Texas (Caddo Lake), North Central Texas (Mountain Creek

Lake, and the Texas Panhandle (Lake Meredith). Typically, sediment concentrations can be compared to sediment quality guidelines (SQGs) to indicate the degree of contamination. SQGs are based on numerous field studies and toxicity tests and have been shown to be reasonable predictors of toxicity on biota from contaminants contained in the sediments (MacDonald, and others 2000). This latter cited report shows the lake sediment to exceed the SQGs in several trace elements (Chromium, Nickel and Zinc for example) as well as some organochloride pesticides.

In a large study of urban lakes in Richardson, Texas, sediment samples were analyzed for five of the over 70 urban impoundments. Sediments were tested for metals, polychlorinated biphenols, pesticides, and herbicides. The only metals found to be above the TCEQ screening levels were lead, selenium, and silver. PCB, pesticide, and herbicide levels were below screening levels.

3.2.4 Lake Bottom Characteristics

Hydraulic dredges operate at a higher efficiency when there are no bottom obstructions or foreign objects on the lake bottom or in the sediment (fishing nets, tires, logs, etc.). Of most concern are tree stands or tree stumps left in the lakes following deliberate impoundment. Often the upper reaches of reservoirs are not cleared at the time of construction, or if cleared, stumps are left in place following the clearing. For reservoirs whose inflow contains predominately coarse-grained sediment, these same areas retain most of the sediment, specifically the portion comprised of silt or sand sized particles. In reservoirs whose inflow is dominated by fine-grained material (e.g. clay), the suspended sediment bypasses the upper reaches and settles in the deeper areas. The hydraulic dredging production rate can be reduced by a factor of two to four when dredging among trees or tree stumps (McAlester). At Lake Nasworthy in San Angelo, Texas, the dredging contractor opted to use a small dredge (10-inch dredge) to operate in the coves and upper end of the lake. The dredged material collected from the small dredge was pumped to the main body of the lake and discharged (in the lake) in the vicinity of the main dredging operations. This resulted in a “double handling” operation. In any case, an evaluation should be made as to the amount of dredging that will be needed in the shallows of a lake, especially in those lakes that have large numbers of trees and stumps left in the shallows.

From a hydrological standpoint, dredging in the shallow ends of a lake tends to regain volume in the most inefficient area of the lake. Except for short periods of flood flow, the largest lake surface area exists when the lake is at conservation pool level. At this higher elevation the lake is typically spreading out over the former flood plain and it contains fairly large areas of shallow water. Because of this larger lake surface area, evaporative losses are higher. During droughts, however, lake surface area retreats as water surface elevation drops. The remaining volume of the lake is contained within the primary river channel and flood plain. From a yield standpoint, the lake becomes more efficient as the surface area decreases. In any case, dredging in the shallows adds storage that would not be available during droughts since evaporation will have caused the lake to retreat from the shallow areas. Dredging in deep areas of the lake yields more efficient results since the deeper areas are not as affected by evaporation.

Lakes that are situated in the Blackland Prairies physical region have a larger fraction of very fine-grained sediment (silts and clay). As these materials require a long time to settle out of the water column, they tend to be spread over the lake bottom far out into the deeper portions of the lake. Lakes set in areas where more sandy soils abound will likely have deltas formed in the headwaters of the lakes, since the sandy material settles out at the first sign of quiescence. In such lakes, shallow areas of the lake will contain the majority of the sediment, thus the dredging operation may have to be accomplished in the least efficient areas and in the areas of most difficulty regarding trees and tree stumps. Conversely, in lakes situated in Blackland Prairies (high clay fraction), the shallower areas can be avoided and significant storage can be regained in the deeper areas of the lake less likely to contain trees and stumps.

As to dredging in the deeper areas, one caveat remains. Often the water supply intake or outlet works invert is set at some elevation above the bottom of the lake. Thus any volume below the invert, whether water or sediment, is “dead” storage. Removing sediment from elevations below the lake operator’s ability to withdraw water is not a prudent endeavor.

3.2.5 Duration of Dredging Operations

The dredging production rate is a function of the dredge size, the characteristics of the material being dredged, and the amount of trees and stumps in the lake bottom. The sediment volumes to be dredged from Texas lakes can be significant. Table 3-1 depicts likely durations of dredging required to remove sediment volumes of 5,000 acre-feet to 50,000 acre-feet. The 24-inch dredge is the most prevalent dredge used in the United States (Randall, et al), Accordingly, dredges in that size range were examined to assess the duration of dredging projects. Table 3-1 reflects the duration of dredging operations for dredges of 20-, 30-, and 36-inch sizes. Results are based on a sediment mixture consisting of sand, silt, and clay, as well as a lake bottom devoid of obstructions such as tree stumps.

TABLE 3-1
DURATION OF DREDGING PROJECT
(MONTHS)

SEDIMENT VOLUME (Ac-Ft)	SIZE DREDGE			
	20 Inch	24 Inch	30 Inch	36 Inch
5,000	30	20	12	9
50,000	300	200	127	90

3.2.6 Water Quality Aspects of Hydraulic Dredging

Dredging operations could conceivably agitate bottom sediments and increase the turbidity and amount of fine suspended sediments within the water column of the lake. Cutterhead hydraulic dredges, when well operated, produce among the lowest resuspension rates of common dredge types. Control of cut depth, swing speed, cutter head rotational velocity, and flow rate can reduce resuspension. Silt curtains, when used in the right setting, have been shown to be very effective at controlling the loss of re-suspended materials (Schroeder, 2001). Generally, a quiescent lake setting (low subsurface velocity) is an ideal location for silt curtains.

3.3 Disposal of Dredged Material

For many years, the material removed in dredging operations was considered a waste material, except when used as fill for commercial or industrial development, or to fill in dike fields and old bend-ways in rivers. However, in recent years, the environmental effects associated with the disposal of dredged material have become highly suspect in the public view, and much controversy has ensued **(**Platz, C., 2002; Pebbles, V., 2002; Abood, K and Rein, 2002, Marlin, J., 2002).

The major problems associated with disposal of dredged material are:

a. Availability of sufficient disposal area for initial and future maintenance dredging within a reasonable (economically feasible) distance to dredging operations.

b. Potential adverse environmental effects associated with disposal of dredged material, including increased turbidity, resuspension of contaminated sediments, and decreased dissolved oxygen levels.

There is also increasing interest in the use of dredged material as a resource as the amount of material dredged each year continues to increase, because urbanization and industrial development have made it difficult to locate new sites for dredged material disposal in many areas. Environmental regulations have also restricted disposal options. The cost of dredged material disposal has increased rapidly in recent years due to the lack of suitable disposal sites, which results in greater distances from the dredging site to disposal areas.

The U.S. Army Corps of Engineers (USACE) has addressed the issue of dredged material reuse on numerous occasions. The USACE program for dredging federal navigation projects yield some 4,000,000 cubic yards of dredged sediments annually. Because of this large volume the USACE has looked to using the dredged material beneficially. This has ranged from:

- habitat restoration/enhancement (using dredged solids as substrate for habitat development,

- Parks and recreation land,
- Agriculture, horticulture, and forestry,
- Strip mine reclamation and landfill cover, and
- Industrial/commercial development fill

The major issues for reuse involve assessment of physical suitability, logistics considerations, and environmental suitability. General physical properties of dredged material are given in USACE EM 1110-2-5026. These properties are based on laboratory testing for grain size, plasticity, organic content, compaction, consolidation, and shear strength. Engineering properties are critical to determining the types of beneficial uses possible.

Logistical characteristics involve:

- distance to the proposed beneficial use site,
- site accessibility,
- required equipment to dredge the lake,
- equipment required to move the dredged material,
- material handling requirements,
- size of the project versus intended beneficial use,
- timing of operation with weather, or
- site conditions, among others.

Environmental suitability involves evaluation of the organic and inorganic toxicity of the material with regard to its intended use. This determination must ensure all applicable standards are met. For example guidance see MacDonald, et. al., (2002). There is considerable interest in using dredged material outside of confined placement options and efforts are underway to alter the undesirable characteristics by adding organic materials, manure, or other biosolids. The cost of addressing environmentally impacted sediment generally will preclude its consideration for adopting a dredging option to increase water supply.

3.3.1 Sediment Handling

Hydraulic dredging requires copious amounts of water in order to move sediment in a pipeline. In order to preserve water supply, it is necessary to return the water to the lake once the sediment has been removed. The most economical and typical procedure is to pipe the dredged material to settling basins where the hydraulic residence time provides ample opportunity for the sediments to fall out of suspension. In order to take advantage of gravity to return the water back to the lake, it is necessary to locate sediment dewatering basins at elevations higher than the lake surface. As a condition of its dredging permits, the USACE requires that any water returned to the lake be prevented from flowing over the ground. Thus, it is necessary to route the water directly back to the lake or to a tributary stream of the lake by pipeline.

Availability and cost of land for sediment basins will significantly affect dredging cost. The distance and elevation change between the lake being dredged and the sediment dewatering basin(s) determine the pump sizes and the need for booster pump stations. Information to follow in Chapter 4 shows the effect of pipeline distances on the cost of dredging operations.

The logistics of laying a pipeline from the lake shoreline to the dewatering basin is also a major consideration. If the dredge size is very large, the pipeline diameter will also be large and will be difficult to install. Road crossings will require boring or tunneling, or if bridges are nearby it may be possible to obtain permission to run the pipeline through the bridge openings. Easements for crossing private lands will certainly be needed, at a cost to the project.

Other means are available to dewater sediment, such as centrifuges, polymer addition followed by belt press, and large Geo-textile bladders. Given the large volume of sediment to be removed in a water supply storage recovery operation, these methods are not recommended if land is available for the construction of dewatering basins.

3.3.2 Sediment Dewatering Basins

Dewatering basins for large-scale projects require considerable land (ASCE Guidelines, 1997). The depth of sediment to be stored in a basin affects the total amount of land required. For example, if 50,000 acre-feet of sediment were to be removed and stored in basins with an ultimate sediment depth of three, five, or ten feet, approximately 12,000, 7,000, or 3,500 acres of land would be required, respectively. These acreages are based on the assumptions that the sediment in the basins will achieve a density of approximately 70 pounds per cubic foot, which is higher than the "natural" density of sediments residing on a lake bottom (i.e. 50 pounds per cubic foot). The acreage requirements as stated do not take into account need for buffers for construction of berms and other purposes.

Berm height requirements can be considerable. For large volumes of sediment, the necessary berm heights could be on the order of 15 to 20 feet. The dewatering basin must have sufficient volume to provide the necessary residence time to allow the solids to settle, space for storing accumulated sediment, and freeboard. Because of the size of the berms, they must be developed based on sound engineering design and subjected to quality control during construction. Interior berms and flow control devices are also necessary to provide effective controls during the dewatering process.

The ultimate use of the dewatering area may have an impact on the design of the basin, and can also affect land acquisition costs. For example the land could be leased, rather than purchased and subsequently returned to some beneficial use (e.g. pasture, park, forest area, etc.). At Springfield, Illinois, sediment dredged from a lake was stored in upland basins that were eventually returned to farming acreage after the sediment dried.

Intuitively, the greater the basin depth available for sediment storage, the lower the unit cost of the dredging operation since the land cost will be minimized. Storing 10 feet of sediment results in a unit cost associated with land acquisition that is approximately one-half that for five feet of storage. If land must be purchased, the economic decision as to the depth of storage or the amount of land to purchase must take into account the initial land price, adjusted by the present worth of the land value following the dredging operation. If the land will have no future beneficial use, the future value should be considered as zero.

3.4 Regulatory Issues Associated with Lake Dredging

Any proposed dredging activity might involve requirements for permits or coordination with regulatory agencies. The applicability of laws or regulations depends on the dredging methods, disposal measures and chemical nature of the dredged material. Table 3-2 summarizes various laws and regulations that could affect a lake-dredging project.

TABLE 3-2
FEDERAL ENVIRONMENTAL LAWS AND REGULATIONS

Statute	Regulation	Agency	Remarks
Clean Water Act Section 401	40 CFR 121	TCEQ	Dredge and Fill discharges to waters of U.S.
Section 402	40 CFR 122	TCEQ	Stormwater discharges
Section 404	33 CFR 320-30	USACE	Dredged and fill discharges to waters of U.S.
R& H Act 1899	33 CFR 403	USACE	Navigable waters of the U.S.
Coastal Zone Management Act	15 CFR 923	Texas	Dredging, disposal of solids in water in coastal zone
NEPA	40 CFR 1500-1508	USEPA	Federal action or permit issuance
Fish & Wildlife Coordination Act	16 CFR 661-667e	USFWS	Federal agency projects and federal permits
Endangered Species Act	16 CFR 1531-1544	USFWS	Activities that could impact threatened or endangered species
RCRA	40 CFR 257-258	USEPA	Storage, treatment and disposal of hazardous waste
TCSA	40 CFR 761	USEPA	Handling or disposal of PCB-contaminated sediments
National Historic Preservation Act	36 CFR 800	THC	Requires survey and investigation for pre- and historic sites

3.4.1 Clean Water Act, Section 404

Section 404 of the Clean Water Act of 1972 (PL 92-500), as amended, is the primary federal statute regulating the discharge of dredged or fill material into waters of the United States. Section 404 applies to the disposal of dredged or fill material into lakes, rivers, and wetlands. It also applies to any return water from an upland disposal site. Because hydraulic dredging uses large volumes of water that are returned to the water body, the presence of this return water assures that a 404 permit will be required. Section 404 does not apply to placing dredged solids in upland areas, unless the upland areas contain jurisdictional waters of the United States. Section 404 permits are issued through USACE district offices. The regulations that have been promulgated for the 404 programs are contained in 33 CFR 320-330 (Regulatory Programs of the Corps of Engineers).

3.4.2 Clean Water Act, Section 401

Section 401 of the Clean Water Act provides the State of Texas authority to issue certification that proposed dredge and fill disposal activities will not violate applicable state water quality standards. Part 230.10(a)(5)(b) of the State rules indicates that no discharge of dredged or fill material shall be permitted if it causes or contributes to violations of any applicable state water quality standard. A Section 401 certification is required for any discharge regulated under Section 404. The 401 certification is not, in itself, a permit, but its denial has the same effect as a negative permit determination.

3.4.3 Clean Water Act, Section 402

Section 402 of the Clean Water Act established the National Pollution Discharge Elimination System (NPDES) permit program for point source discharges. NPDES permitting responsibility has been delegated by the USEPA to the State of Texas. Section 402 is applicable to storm water discharge from construction of and maintenance of dewatering basins. The USACE policy related to return of dredge water is that Section 401 is applicable to dredging return flow, not Section 402.

3.4.4 Clean Water Act, Section 307

Section 307 of the Clean Water Act directed the USEPA to develop pretreatment standards for industries. Local municipalities and sanitary districts are responsible for the management of pretreatment programs for wastewater treatment systems. Unless return flows or other discharges for the dredging operation are routed to a publicly owned treatment works there is no requirement for addressing Section 307.

3.4.5 Rivers and Harbors Act

Any structures or work that impact the course, capacity, or conditions of a navigable waterway of the United States must be permitted under Section 10 of the Rivers and Harbors Act of 1899 (33 CFR 403). This permit program is managed by the USACE, and where Section 10 permitting is required it is handled jointly with section 404 requirements. The USACE coordinates Section 10 permits with the Coast Guard.

3.4.6 Coastal Zone Management Act

The Coastal Zone Management Act of 1972, as amended (16 USC 1451 et seq.) requires that federal actions (including federal licensure and permitting) address the consistency of proposed actions with approved coastal management programs. Of necessity, the proposed action would have to be located where it could reasonably be expected to affect land or water use or natural resource of the coastal zone. The act affirms a national commitment to the effective protection and rational development of coastal areas.

3.4.7 National Environmental Policy Act

Section 309 0f the 1970 amendments to the Clean Air Act (PL 91-604) and the National Environmental Policy Act (NEPA) of 1969 (PL 91-190) require a detailed statement on significant federal actions impacting the quality of the human environment. A dredging project conducted by a federal agency or with federal funds would require NEPA compliance. In addition, the issuance of a permit under a federal regulatory program requires NEPA compliance. NEPA is not a permit program, and cannot deny any particular dredged material management decision. However, by requirement that the environmental effect be considered and documented, NEPA brings the factors into open review and provides coordinating agencies and regulatory agencies more comprehensive information upon which recommendations and decisions can be made.

3.4.8 Fish and Wildlife Coordination Act

The Fish and Wildlife Coordination Act of 1934, as amended, requires consultation with the U.S. Fish and Wildlife Service (USFWS) and the fish and wildlife agencies of the states (Texas Parks and Wildlife Department, in this case) where the "waters of any stream or other body of water are proposed or authorized, permitted or licensed to be impounded, diverted or otherwise controlled or modified" by any agency under a federal permit or license.

3.4.9 Endangered Species Act

The Endangered Species Act of 1973 provides for the conservation of ecosystems upon which threatened and endangered species of fish, wildlife, and plants depend, both through federal action and encouraging the establishment of state programs. Dredging, per se, may not affect aquatic species; however the location of dewatering facilities has to account for nesting grounds for a number of birds and migratory waterfowl. Similarly, a vegetative and habitat evaluation will have to be accomplished for endangered plants, animals, and reptiles.

3.4.10 Resource Conservation & Recovery Act (RCRA)

The Resource Conservation and Recovery Act (PL 94-580) covers a large category of solid waste. It specifically does not apply to solids or dissolved material in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges. Absent the findings of hazardous or toxic contaminates in the dredged solids, it is concluded that RCRA imposes no restrictions on dredging operations, including dewatering sites.

3.4.11 Toxic Substances Control Act (TSCA)

The Toxic Substances Control Act of 1976 (PL 94-469), as amended, regulates the disposal of a limited number of toxic substances, one of which is polychlorinated biphenyls (PCBs). In the amendments published in Federal Register 35384-35474, June 29, 1998, dredged materials containing PCBs are considered a "PCB remediation waste" and must be managed based on the concentration of PCBs present. Disposal requires incineration, land filling, or other risk-based alternatives specifically approved by the USEPA. Low-level concentrations (less than 50 ppm) can be disposed of under conditions prescribed by a 404 permit.

3.4.12 National Historic Preservation Act, 1966, Section 106 and 110 (36 CFR 800)

This act requires federal agencies to preserve and protect sites that may be eligible for registration as "historic". The issuance of a federal permit is a basis for the federal agency to require an archeological investigation. Texas has a similar, yet separate requirement: The Antiquities Code of Texas**, (**Section 191 of the Texas Administrative Code, Title 9). The need to protect this country's heritage guides this policy, which states that it is in the public interest to locate, protect, and preserve all sites, objects, buildings, and locations of historical, archeological, educational, and scientific interest. These sites have been defined to include prehistoric and historical American Indian campsites, dwellings, and habitation sites. Investigations at land disposal sites or dewatering areas would require a permit from the Antiquities Committee for survey, excavation, or restoration.

3.4.13 Summary of the Effect of Regulations on Potential Lake Dredging Projects

As shown, there are a number of federal and state regulatory requirements that must be addressed in the dredging process. In general, these regulations apply to three specific areas: dredging itself, location of dewatering basins, and land application of dredged solids and contaminated sediments.

Dredging has the potential to increase turbidity at the dredging site. If this occurs, the use of silt curtains around the dredging site should alleviate the problem. If water is to be returned to the lake or to a tributary stream following dewatering of the sediment, then state water quality standards must be met in the receiving water body (Section 401). Typically, a condition of a 404-permit requires a maximum suspended solids concentration of 300 mg/L in the return flow. This requirement can be met by providing sufficient residence time at the dewatering site. Residence time is a function of hydraulic capacity of the dewatering basins.

Dewatering basins for large scale dredging operations require large expanses of land. Assessment of the site for federal jurisdictional areas (waters of the United States, including wetlands), or other factors such as habitat for rare or endangered species or historical sites will be required. If impacts are noted, the site will have to be relocated or mitigation measures will need to be taken.

Contaminated sediments are a concern. At some point, depending on the level of contamination, the cost of handling contaminated sediment will preclude dredging as an alternative. Even if the sediment is only marginally contaminated, the lake owner may have to purchase the area where the sediment is to be permanently stored, since a landowner may not desire to take a risk that the testing results have identified a problem concentration, or that rules in the future may cause the classification of the material to require storage in a confined storage facility, thus making the landowner liable for removing and transporting the material to some alternate location. In any event it will be necessary to perform a threat analysis to the lake's sediment based on historical operations and land use in the watershed. Sampling and analytical testing of sediments in major arms of the lake should be taken and tested for the probable contaminants related to operations conducted in the watershed. As a minimum, sediment should be tested for toxic metals, PCBs, herbicides, pesticides and hydrocarbons.

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CHAPTER 4

EVALUATING THE COST OF DREDGING VERSUS NEW RESERVOIR CONSTRUCTION

4.1 Methodology

In evaluating the cost of lake dredging versus new reservoir construction, APAI used technical publications, information available from state and federal agencies, and personal contacts.

4.1.1 Technical Publications Dredging

Three technical publication sources used herein are the U.S. Army Corps of Engineers (USACE), the World Bank, and Texas A&M University.

The U.S. Army Corps of Engineers (USACE)

The USACE has published several documents, usually in the form of technical papers or technical memoranda on hydraulic dredging. Included in this documentation are descriptions of hydraulic and mechanical dredging equipment and cost factors that apply to dredging operations. These latter include depreciation factors for the dredges, pipelines and ancillary equipment, as well as cost factors for operations and maintenance. The USACE provides the maintenance dredging for navigable rivers and the Intracoastal Waterway. Accordingly, records of these projects are easily obtained, particularly annual contract and production information. These data were reviewed to determine the annual change in dredging costs and to discern typical dredging costs for large volume operations.

The World Bank

The World Bank commissioned studies to evaluate alternative strategies for managing sedimentation in storage reservoirs as a contribution to promoting conservation of water storage worldwide. A two-volume document authored by Shigekazu Kawashima, Tamara Butler Johndrow, George Annandale and Farhed Shah was published in 2003 entitled, *Reservoir Construction, The RESCON Approach (Vol I)* and *RESCON Model and User Manual (Vol. II)*. This document includes, among other pieces of valuable information, the following approximation of hydraulic dredging costs:

$$\text{Cost Dredging} = 6.61588727859064 \text{ X } (\text{Vol Dredged}/10^6)^{-0.431483663524377}$$

The number of significant figures is not understood for such a gross approximation. The equation was recalculated using figures with only two significant figures and the results compared favorably to the above equation. Generally, the two versions of the equation varied by approximately one (1) cent per cubic yard of sediment removed. As such, it is recommended that a value of 6.62 be used for the constant in the equation and 0.43 be used for the exponent. That minor amendment notwithstanding, the above equation represents a reasonable estimation of the cost of dredging. Calculated costs compare well to actual bids that have been obtained for various sized dredging projects.

Texas A&M University (TAMU)

TAMU operates a department that is extensively involved in dredging operations. Excellent cost data are available from TAMU. In addition, the Cutter Suction Dredge Cost Estimation Program (CSDCEP) developed by the Ocean Engineering Program/Civil Engineering Department, Texas A&M University is a generalized cost estimation tool for use in estimating the cost of a cutter suction dredging project. The model consists of a series of linked Excel spreadsheets that allow the user to input numerous variables, such as sediment classification, lengths of pipeline, specific gravity of dredged material, dredge size, and other factors such as crew size. Based on user input, the program calculates an estimated production rate, in terms of volume of material dredged per time (typically cubic yards per hour), and then uses this information to calculate an overall cost for the project.

The production rate directly affects the time required to complete a project, and therefore the cost of labor, equipment, and fuel. CSDCEP uses sediment transport theory, non-dimensional pump curves, and empirical factors derived from experienced dredging companies to estimate the production rate as accurately as possible. The program also has the capability to predict the need for a booster pump in the discharge line.

Calculated project costs using the CSDCEP also compared well with actual bid data. The results are discussed later in this section. A direct comparison to the RESCON model is also provided.

4.1.2 Agency Contacts

U.S. Army Corps of Engineers

The USACE was the principal agency used for reference in this project. Various USACE Districts, such as Fort Worth, Galveston, Kansas City, and Omaha were contacted to get their experience, if any, on dredging inland lakes.

Texas Water Development Board (TWDB)

The Texas Water Development Board is a resource for information on Texas lake storage volume and sedimentation for selected lakes. The TWDB is the agency designated to implement Senate Bill 1 water supply planning, which includes development of water supply sources and strategies for water user groups. As a part of this effort, planning-level cost estimates have been developed for construction of water infrastructure (e.g., reservoirs, pipelines, treatment facilities, etc.).

4.1.3 Personal Communication

Lake Owners

Lake owners who have performed dredging operations were contacted and debriefed concerning their experiences. Typically, owners may have contracted for hydraulic dredging, or purchased a dredge and used hired labor to accomplish the dredging. One issue was common among lake owners; for the contracting option, the quantity of dredged material removed from the lake was difficult to determine. Sediment deposited in a lake resides in various stages of consolidation. Near the bottom of the deposit, sediment is denser than sediment nearer the top. Once the sediment has been removed, it is stored in a dewatering basin where the density (consolidation) may or may not be the same as in the lake. Thus, disagreements can arise regarding the quantity dredged versus the quantity stored. Some concern was also voiced that the contractor may tend to operate in areas of the lake most favorable to dredging until the contracted quantity has been achieved. This approach leaves other areas, such as coves and shallows, undredged. This practice causes boaters and landowners to be dissatisfied because the dredging did not provide access to shore for boats, or improve vistas of homeowners.

Lake owners were also concerned with upstream watershed practices. Some were very active in working with local and state governments, and property owners concerning the effect of land use activities in the lake watershed on sedimentation rates and lake water quality.

Dredging Contractors

Dredging contractors voiced their opinion that each lake is different and that unit prices could vary substantially based on the type of sediment, amount of trees and stumps left in the lake, depth of water, and other factors. Ranges of two to four were given as factors by which difficult bottom conditions could affect standard unit pricing. Dredging contractors also commented that quantities of dredged material were often a point of variance between the lake owner and the contractor. Contractors did not have universal trust in lake surveys as a basis for payment.

Other methods were considered more reasonable, such as pumping rates and duration of pumping.

Dredge Manufacturers

Dredge manufacturers provided useful information regarding production rates for their dredges. Data were provided that specified expected production rates as they vary with sediment type and pipeline distance. Ellicott International, Baltimore, MD was particularly helpful concerning capabilities of dredges.

Others

The following entities provided specific resources that were referenced in the study.

- Western Dredging Association (WEDA): provided lists of contractors and technical references.

- International Association of Dredging Companies (IADC), the parent organization of the WEDA: provided resources for international papers and lists of contractors.

- American Society of Civil Engineers provided reference material on dredging, including technical papers presented at conferences or in booklets or books, such as <u>Guidelines for Retirement of Dams and Hydroelectric Facilities, written by the</u> ASCE Task Committee on Guidelines for Retirement of Dams and Hydroelectric Facilities.

- Waterways Experiment Station (USACE) and the U.S. Environmental Protection Agency provided references related to the disposal of sediments and the beneficial uses of dredged solids.

4.1.4 Development of Cost Curves for Dredging

Historical Data

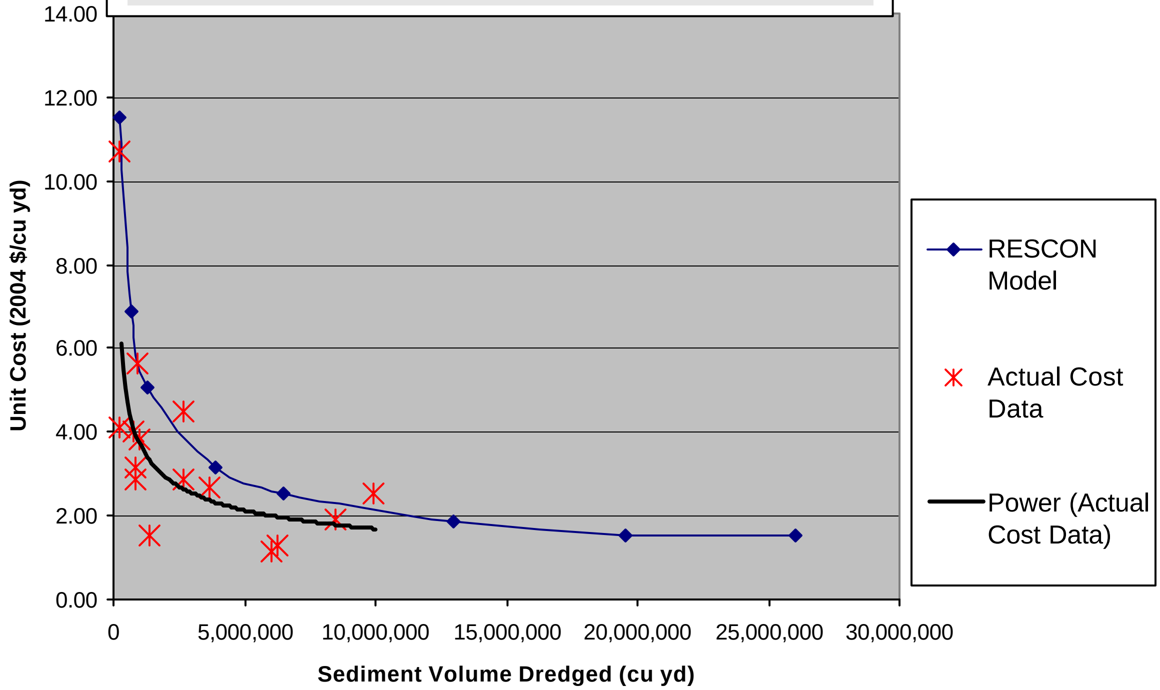
Historical data were selected from actual projects throughout the United States. Dredging costs were determined on a cost per cubic yard basis. Costs were adjusted to current (2005) prices using USACE EM 1110-2-1304 Civil Works Construction Cost Index System (CWCCIS), revised as of 30 September 2004. Adjustments were also made based on location using state adjustment factors found in the same publication.

The USACE document based its indexes on Engineering News Record, RS Means Company publications on cost indexes, OMB updating factors and Bureau of Labor Statistics Product Price Indexes. Accordingly, these dredging costs per cubic yard are considered to be up-to-date. The actual USACE dredging costs increases from 1992 through 2003 yield much higher cost differentials than the CWCCIS reference indicates should be the case. However, non-USACE dredging costs referenced at lakes within the United States do not reflect such high cost differential. The large cost differential (over time) for the USACE dredging projects is attributed to disposal requirements at coastal locations. Wetlands protection requirements have altered the disposal methods and have resulted in higher cost differentials than labor and equipment cost increases would otherwise indicate.

RESCON Model

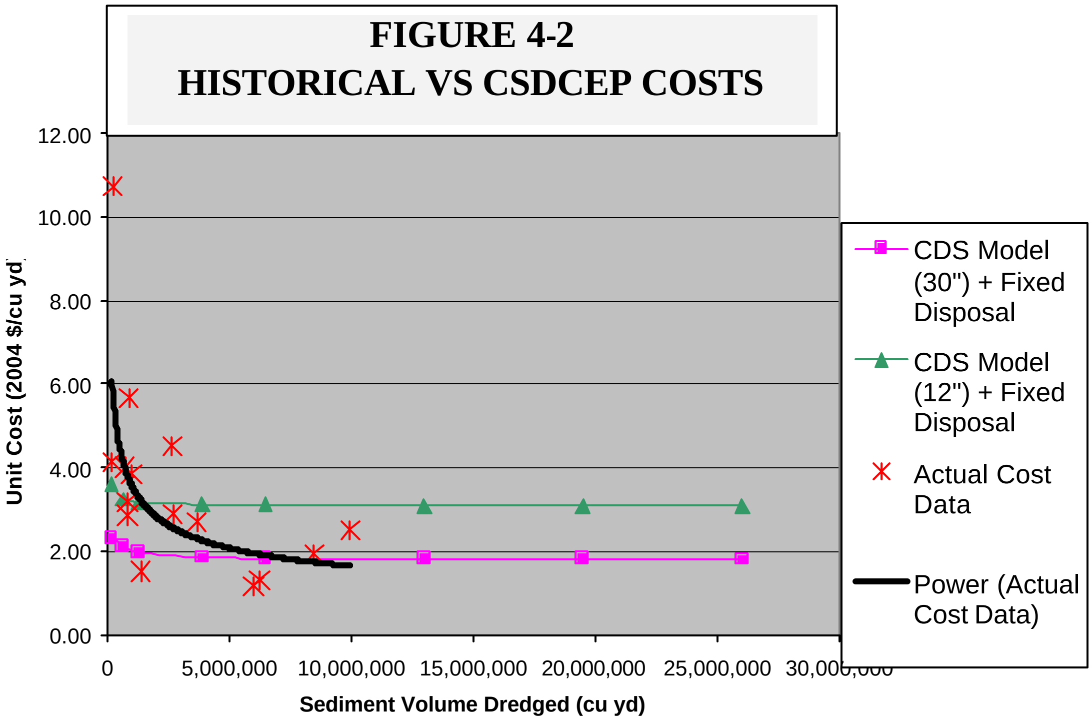
The simplified dredging RESCON equation was used to evaluate costs of dredging for various quantities. Figure 4-1 displays those costs relative to historical actual costs. The results are fairly consistent with actual experience, especially for small volume operations. It is recommended the RESCON Model be utilized for general planning type operations or studies.

FIGURE 4-1
HISTORICAL VS RESCON COSTS



CSDCEP Model

The CSDCEP model was used to assess the same production scenarios as the RESCON model. In addition, the costs generated by the CSDCEP model were adjusted to include the costs of obtaining land and constructing dewatering structures, since this cost component is not included in the CSDCEP model. The calculated costs are compared to historical actual cost data in Figure 4-2. For projects requiring the removal of a large volume of sediment, a larger dredge diameter would be expected to result in a more efficient operation. In general, lower unit costs can be achieved with a larger diameter dredge if the reduction in costs associated with the shorter time period required for removal exceeds the additional annual debt service required for the larger equipment. For comparison purposes, Figure 4-3 displays calculated cost curves associated with both a 12-inch dredge and a 30-inch dredge.



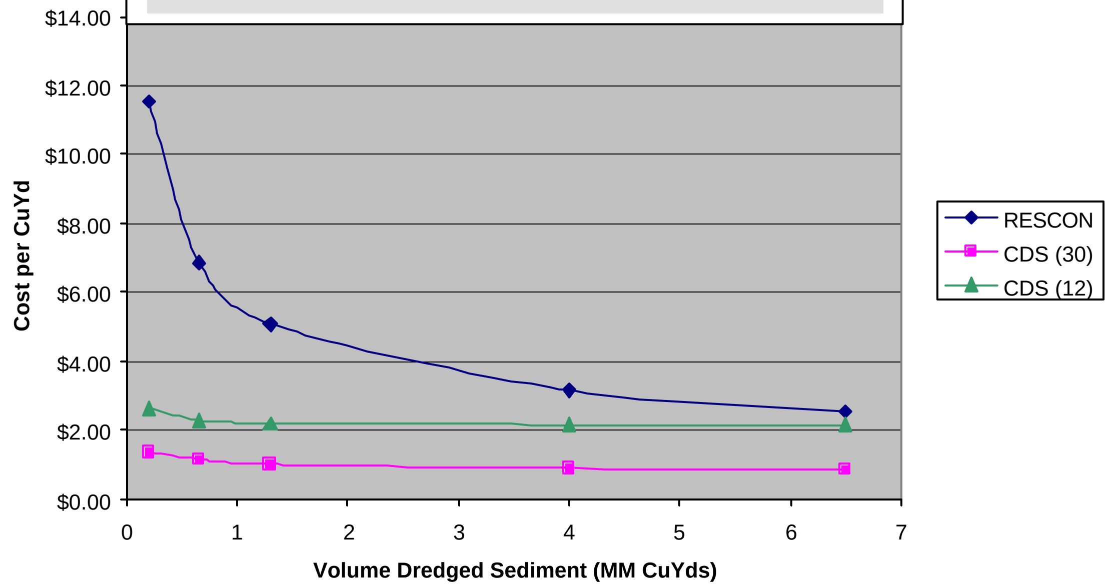
Comparison of CSDCEP Model and RESCON Model

Figure 4-3 displays the results of both the RESCON and CSDCEP models for various production scenarios. As depicted in the figure, the modeled CSDCEP costs were not adjusted to account for dewatering basin needs so as to compare the results of the two models on the same basis. The variability between the models is most pronounced at the extremes of the production range. For low quantities of sediment removed, the RESCON

model approaches much higher unit costs as the volume of dredged sediment diminishes. Based on unit cost data that have been developed in the Dallas-Fort Worth area for small dredging operations of less than 100,000 cubic yards, the RESCON results are realistic.

FIGURE 4-3

RESCON VS CSDCEP COSTS



At the other end of the scale, the RESCON model appears to produce continually decreasing unit costs with increasing production volumes. By contrast, the CSDCEP model calculates unit costs that approach a constant, and remain constant above a certain production volume. This approach is considered more appropriate. For production volumes greater than a given value, the only variable is time (i.e., how long it will take to complete the project). All other factors are constant. For a particular dredge, the crew size and operational costs are the same day after day. The pipeline to the dewatering site is a fixed distance, and the same power costs are involved in delivering the dredged slurry to the dewatering site. Depreciation schedules account for the serviceable life of the equipment. As such, pipeline replacement due to “wear-and-tear” has no effect on the unit cost since the depreciation of short-lived items, such as pipes, has been included in the estimation. Because the CSDCEP model allows for different size dredges, varying sediment types, distances to dewatering sites and elevation differences, it is more versatile and, therefore, a more valuable tool. Also, the CSDCEP model allows for variations in input that are specific to the site, such as fuel costs, crew salaries, etc. The CSDCEP model’s failure to produce conservative estimates at low production volumes is not considered important for the scenarios of interest because most water supply dredging projects will not involve small quantities of sediment. As the CSDCEP model appears to be the most appropriate model for cost estimation of water supply dredging operations, it is recommended for use in comparing the cost of dredging to increase water supply to new reservoir construction when specific projects are being considered.

4.1.5 Dewatering Basins

The selected CSDCEP model does not address disposal areas. To develop unit costs for dewatering basins, a basin geometry consisting of interior and exterior berms, flow controls, an outlet structure, and 10 feet of sediment storage capacity (to reduce land costs) was assumed. Construction cost factors were selected from construction unit costs shown in Region C, Senate Bill 1 documents for embankment construction.

Table 4-1 displays the impacts of land costs for dewatering basins on dredging unit costs.

TABLE 4-1

IMPACT OF LAND COSTS ON DREDGING UNIT COSTS

Land Cost/Acre	**$1500**	**$3000**	**$5000**	**$8000**	**$10000**	**$20000**	**$30000**
Land Cost/CuYd	0.08	$0.16	$0.26	$0.42	$0.52	$1.04	$1.56
Berm Cost/Cu Yd	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50
Total Cost/Cu Yd	**$0.58**	**$0.66**	**$0.76**	**$0.92**	**$1.02**	**$1.54**	**$2.06**

Land costs vary depending on locale with respect to urban settings or rural locations. For example, lakes in urban areas will have land available only in areas that are competing for commercial or residential developments. Therefore, the cost for those lands will be very high. Lakes situated in rural areas, however, will have a much lower unit cost for land. For large dredging operations, considerable land will be needed (hundreds or thousands of acres). As such, some difficulty in siting dewatering basins may be encountered when attempting to avoid permitting and mitigation requirements associated with wetlands or jurisdictional streams under Section 404 of the Clean Water Act.

4.1.6 Dredging and Disposal Cost Curves

Having selected the CSDCEP model as appropriate for the cost estimation, a family of cost curves was developed to depict the variation in unit cost with distance to the dewatering basin(s), sediment type, and dredge size. The results were plotted as a family of curves depicting unit costs as they vary by distance to the dewatering area for each of four different types of sediment. Figures 4-4 through 4-6 display the results for dredge sizes ranging from 12-inch diameter to 30-inch diameter. In analyzing the results, the efficiency of the large diameter dredges is apparent, as is the decrease in production rate associated with dredging clay as opposed to mud or silt.

4.2 Cost of New Reservoirs

To compare dredging costs to reservoir construction costs, the reservoir costs must be expressed as a unit cost per volume of storage. Reservoir costs include land for the lake, embankment, mitigation lands, appurtenances to the dam, such as pump stations, and pipelines to connect the lake to the treatment plant or raw water users. Two currently proposed reservoirs were selected for use in this comparison: 1) Lake Ralph Hall on the Sulphur River in Fannin County and 2) Lake Columbia, on Mud Creek a tributary to the Angelina River in Cherokee and Smith Counties. Based on Senate Bill 1 Regional Water Planning documents that provide detailed planning estimates for these lakes, the unit cost to develop storage in those two lakes is estimated at about $1.00 to $1.15 per cubic yard. Table 4-2 shows the steps taken in making this comparison.

FIGURES 4-4 THROUGH 4-6

Figure 4-4: Unit Dredging Cost (UDC) Using 20" Cutter Suction Dredge vs. Distance to Sediment Depository (D) for Dredged Sediment Volume of 5,000 Acre Feet

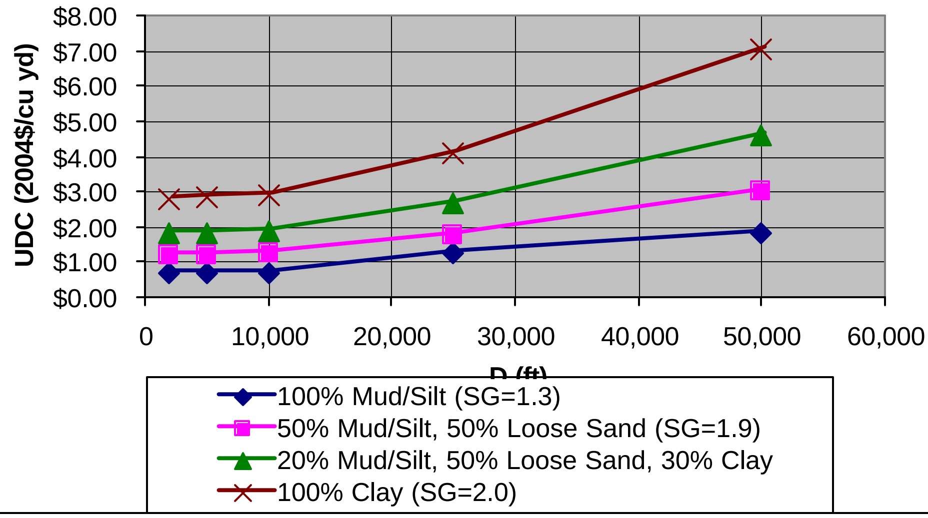
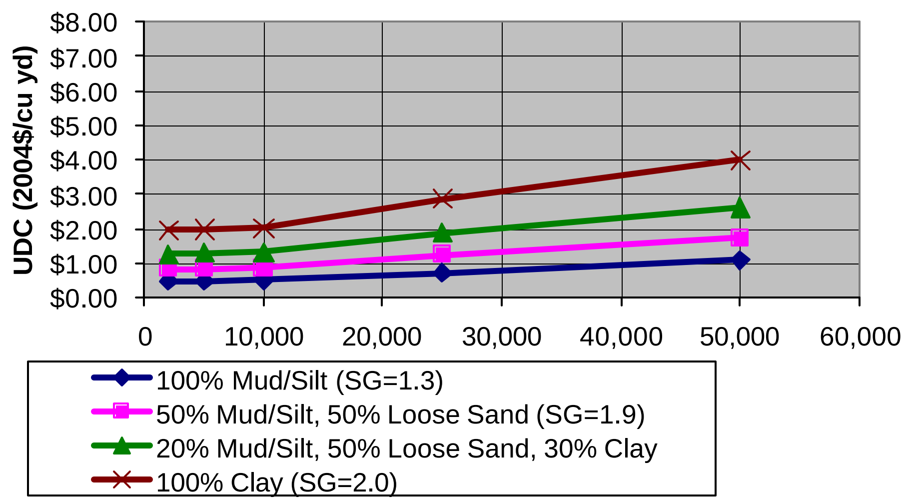


Figure 4-5: Unit Dredging Cost (UDC) Using 30" Cutter Suction Dredge vs. Distance to Sediment Depository (D) for Dredged Sediment Volume of 5,000 Acre Feet



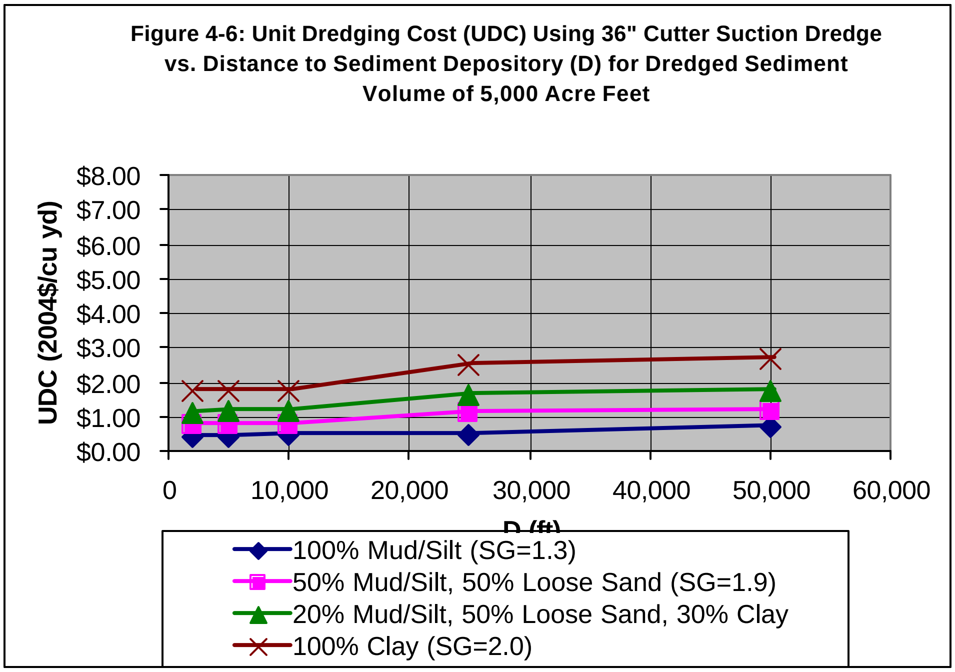


Figure 4-6: Unit Dredging Cost (UDC) Using 36" Cutter Suction Dredge vs. Distance to Sediment Depository (D) for Dredged Sediment Volume of 5,000 Acre Feet
UDC (2004$/cu yd)
$8.00
$7.00
$6.00
$5.00
$4.00
$3.00
$2.00
$1.00
$0.00
0
10,000
20,000
30,000
40,000
50,000
60,000
D (ft)
100% Mud/Silt (SG=1.3)
50% Mud/Silt, 50% Loose Sand (SG=1.9)
20% Mud/Silt, 50% Loose Sand, 30% Clay
100% Clay (SG=2.0)

TABLE 4-2
EVALUATION OF UNIT COST FOR NEW RESERVOIRS

Item	Lake Ralph Hall Fannin County Sulphur River			Lake Columbia Cherokee & Smith Counties Mud Creek-Angelina River		
	acre-feet	**cubic yards**	**acres**	**acre-feet**	**cubic yards**	**acres**
Storage	160,235	258,512,467		187,839	303,046,920	
Lake Area			7,650			10,000
Project Area			11,200			
COST ESTIMATE						
Item			**Estimate**			**Estimate**
Embankment and Appurtenances			$127,589,000			$140,567,000
Pipeline			$36,568,000			$59,902,000
Intake Pump Station			$6,831,000			$18,588,000
Construction Total			**$170,988,000**			**$219,057,000**
Land and Mitigation			$22,781,000			50,469,000
Interest			$17,384,000			26,653,000
First Cost			**$211,153,000**			**$296,179,000**
Capitalized O&M Cost			$50,960,000			$41,200,000
Total Cost			**$262,113,000**			**$337,379,000**
Unit Cost Per Cubic Yard of Storage			**$1.01**			**$1.11**
Note: Totals include engineering and environmental studies and allowances for contingencies						

4.3. Effect of Energy Cost and Land Cost on Evaluation of Lake Dredging vs. New Reservoirs

The cost of energy and land are significant factors in developing additional water supplies by either dredging existing reservoirs or constructing new reservoirs. The following is an evaluation of the relative effect of energy and land costs on each of these water supply alternatives.

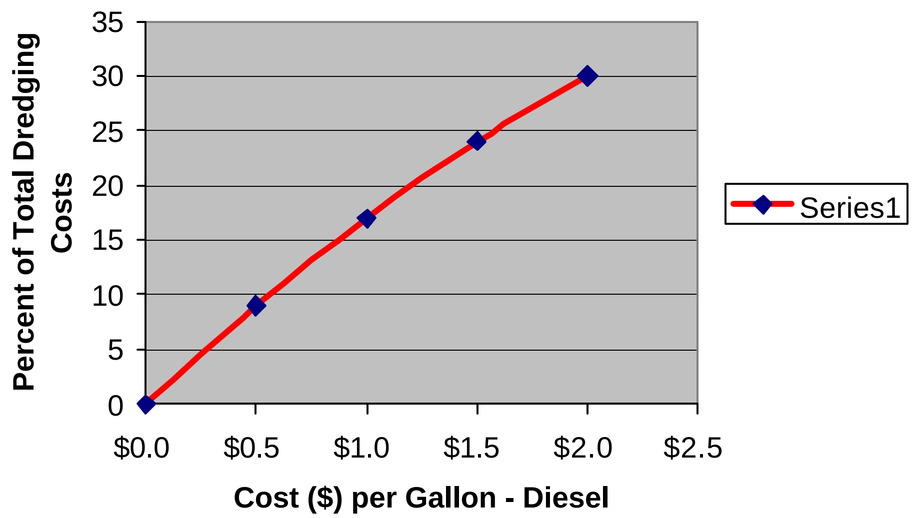
4.3.1 Energy

Dredging typically requires a greater amount of energy than reservoir construction to develop an equal amount of storage. Therefore, dredging will be more expensive in terms of energy than constructing a new reservoir. Furthermore, based on expenditures of energy, dredging will always cost more irrespective of the future costs of energy (lower or higher). The differences in energy expenditures have to do with the greater efficiency in creating water supply storage by constructing an embankment to store water up-gradient of the embankment as compared to dredging an existing reservoir.

For example, a new reservoir typically requires work to build the embankment (dam) and pipeline leading to a water treatment plant. Using engineering information developed for Lakes Ralph Hall and Columbia, the total amount of fill material necessary to build an embankment and the amount of excavation necessary for pipelines was estimated and compared to the volume of water stored at conservation pool level. The results of this estimation showed that water storage volume created was about fifty times the volume of the dam embankment and pipeline excavation. In general, the energy required to construct the embankment and implant the pipelines can be assumed to be proportional to the cubic yards of material moved. Based on the above-mentioned information, the volume of storage created is about fifty times the volume of the embankment plus the volume of pipeline excavation. Ignoring local differences in horizontal and vertical distances to move material, the energy equation becomes 50 units gained for one unit spent.

To generate the same water storage volume the hydraulic dredge must dredge the entire amount of gain in water supply storage (i.e., one volume of dredged material for each volume of water supply storage created). In terms of energy expended (efficiency) new reservoir construction is far more energy efficient, and therefore will be less costly. If fuel costs continue to go up, this will work to the detriment of dredging. Fuel costs are significant components of the overall dredging costs. A unit cost for dredging silty sediment and a 5,000-foot pipeline was developed using the CSDCEP model for a 20-inch dredge operation. If diesel fuel had cost nothing, the base cost of dredging would be \$1.19 (not including land or sediment basins construction). If diesel fuel cost \$2.00 per gallon, the dredging cost would be \$1.69 per cubic yard, an increase of 42 percent over the base dredging cost. At \$2.00 a gallon, the fuel cost would represent \$0.50 of the total cost of each cubic yard dredged. This represents 30 percent of the total cost of dredging (\$0.5/\$1.69X100 = 30 percent.) Figure 4-7 reflects the effect of diesel fuel cost on dredging for the dredging conditions listed above.

FIGURE 4-7
IMPACT OF FUEL COSTS- DREDGING



4.3.2 Cost for Land

New reservoirs occupy large tracts of land. Dredging operations also require large areas for dewatering basins. However, penalizing a dredging operation for the total cost of a dewatering basin is not always appropriate since it is possible that, if the dewatering basin were properly planned, the land would have potential for other uses after the dredging was complete. Also there are alternatives to gravity dewatering systems that could minimize land requirements. Centrifuges could be used to partially dewater the sediment and belt presses could be used to further dewater the sediment. Such mechanical dewatering would require large expenditures of energy to accomplish the dewatering and fleets of trucks to move the partially dried sediment to upland areas for disposal. Mechanical dewatering alternatives substitute supplied energy for gravity. There is a significant cost increase to such an alternative.

In comparing land required for dewatering dredged material to land required for a new reservoir, the proposed Ralph Hall Reservoir was again used as an example. The proposed Ralph Hall Reservoir has conservation pool storage of about 260 million cubic yards. The lake project lands for the conservation and flood pool amount to about 12,000 acres. If one were to dredge 260 million cubic yards of sediment (to compare to a Ralph Hall Reservoir), the dredging operation would require a dewatering area of about 12,000 acres if the sediment were stored to depths of 10 feet. If sediment were stored to depths of 20 feet then a dewatering area of over 6,000 acres would be required. The comparison illustrates that at best dredging would need an amount of land equivalent to one-half of the area required for a new reservoir. Again, it is possible that the sediment would have value, and the land could be used for grazing or other agricultural purposes after completion of the dredging. However, from a practical standpoint, the availability of land in the quantities contemplated for such a massive scale dredging operation would be unlikely.

4.3.3 Summary of Energy and Land Cost Considerations

As energy and land costs are significant parts of both dredging and reservoir construction projects, the above comparison was made to compare these costs on an equal basis. Energy costs work to the detriment of dredging on a comparative basis. Land costs needed for dredging dewatering basins versus land needed for reservoirs could favor dredging, but not to the degree that energy costs work to the detriment of dredging. In comparing the unit costs of dredging to those of new reservoir construction, it is concluded that dredging (even under the best conditions) is more expensive by a factor of two or more than the estimated $1.00 to $1.15 per cubic yard ($1,610 to $1,855 per acre-foot) of storage for construction of reservoirs. If the lake site to be dredged is in an area where land costs are high, if dewatering sites are distant from the dredge site, if bottom conditions include stumps and trees, and/or if the dredged material is preponderantly clay the unit cost of dredging will be three, four or more times the unit cost of reservoir storage.

4.4 Additional Considerations in Evaluating Dredging versus New Reservoir Construction

Despite the apparent cost advantage of reservoir construction, conducting dredging for supplemental water supply as a conjunctive solution to water supply has fewer impediments than new reservoir construction and has a large number of benefits. The following additional considerations are worth evaluating.

4.4.1 Proximity

A reservoir site or feasible project must be available in order to make the comparison. If a reservoir site is not within an “economical” distance to the entity, and if there is an uncertainty that the new reservoir can be constructed, then consideration for dredging should be made on its own merits, or compared to other water supply alternatives.

4.4.2 Political Considerations

If the reservoir in question could be problematic due to political opposition or other factors, it must be reevaluated to determine if it is a valid alternative.

4.4.3 Timing

Timing may be the most critical factor that should be considered. The benefit of dredging a water supply lake may not be its cost compared to the cost of a new reservoir, but its value in a conjunctive supply role. Dredging might provide about 10 percent more storage (yield) in an existing lake. This could postpone the need for a new reservoir. Assuming that the population increases in Texas are sustained past present planning horizons, then it becomes prudent to develop (or in the case of dredging to re-develop) as many water supply sources as possible. If a “minor” water resource can be developed, and it is affordable, then it should be pursued. If such actions postpone the need for new reservoirs, significant benefits could accrue. Some regions in Texas are experiencing population growths that have outstripped planning estimates. The addition of a 10-year buffer in time would be of great value in order to accomplish permitting, design and construction of new water resources in an orderly manner.

4.4.4 Opportunity Cost of Land

In general, for the purposes of this report, the unit cost of a dredging operation has included the cost of land for sediment storage. Some of the historical cost information obtained from lake operators did not include land costs since the lake owner had lands available to use for sediment storage. The costs, therefore, only included the cost to dredge and deliver the material to the dewatering site. The true cost of dredging should include a cost for land used in dewatering, since there is an opportunity cost for land. To evaluate the true cost of dredging, the total cost should account for the opportunity cost of land used for sediment storage relative to the value of that land were it to be used for some other purpose.

4.4.5 Equivalency

The comparison of dredging versus new reservoir construction can be hampered by both opportunity and scale. In order to compare costs, the two alternatives should be of the same scale. If 50,000 acre-feet were available from a dredging operation, should its cost be compared to cost of constructing a 50,000 acre-foot reservoir (Bardwell Lake, Proctor Lake, and Granger Lakes are of that size)? What if, instead, a new reservoir site were available that had an optimum water conservation pool of 200,000 acre-feet. That same volume of sediment might not be available for dredging in the same water supply area. Thus, the opportunities are different, and the scales are different.

An attempt at equivalency is frustrated by the dissimilarities in the projects. Of course, it is conceivable that the water supplier could need only 50,000 acre-feet of storage (or its equivalent in annual yield). In this case, the water supplier might be a partner in the larger reservoir project for a percentage of the project, and the equivalence test could be met. However, this probability requires the coincidence that such a situation existed. This circumstance might not defer construction of the new reservoir since the remaining reservoir partners could look to others to acquire the storage or redistribute the storage among themselves, if one partner opted for dredging its water supply lakes instead of joining in the new reservoir.

4.4.6 Affordability

Perhaps comparing alternatives purely on the basis of costs passes up the opportunity to make a decision based on other factors. One test would be to assess the affordability of an option. The water supplier must translate costs of developing water resources into the rate that customers are charged. Good stewardship involves providing water supply resources at affordable costs. If one examines dredging, or any other alternative, on the basis of the system operations, it can be demonstrated that seemingly high unit costs for a single alternative (e.g., dredging) might have only a minor impact on the overall cost of water. In the simplest form, it can be assumed that the value of water in a reservoir is represented not by its cost to develop many years ago, but the cost to bring the next reservoir on line (the cost of the new reservoir). If dredging could create an additional 10 percent of storage at a cost per cubic yard four times that of the value of the existing storage, the impact would be to change the overall value of the water by around 27 percent (assuming that 100 storage units exist that have a value of one dollar per unit. If dredging generated ten more units at a cost of four dollars per unit, the revised unit cost would be (100 units x $1 + 10 units x$ 4)/110 units = $1.27 per unit). This level of consequence would not rule out dredging as a viable option. In terms of customer rates, the cost of treatment and delivery would remain unchanged, thus, the increase in raw water cost would be dampened in the overall cost of delivery of treated water.

4.4.7 Other Benefits/Uses

Other project considerations may also need to be evaluated on the basis of economics. If the recreational and aesthetic benefits of the lake would be improved through dredging operations, some of the cost of the dredging budget could be allocated to those purposes, thereby reducing the unit cost of dredging applicable to water supply. Even if the project were already considered feasible, the allocation of costs to various benefits could be made in order to preserve future water supply revenue for other capital projects.

4.4.8 Conjunctive Supply

A fair evaluation of alternatives would be to consider all available methods for providing water supply. This is not to say that only one would be selected. In fact, all could be selected and perhaps only the order of bringing the alternatives on line would be the main consideration. Table 4-3 lists some considerations that apply to potentially available resources that could augment existing supplies.

TABLE 4-3
COMPARISON OF ALTERNATIVE WATER SUPPLY OPTIONS

Alternative	Cost Relative to New Reservoir	Impact on Water Supply	Increase in Revenue	Time to Develop	Dependable
New Reservoir	NA	Major	Yes	30+ yrs	Yes
Dredge Exist WS Lake	Two or more times	Minor	Yes	5 yrs	Yes
Water Conservation	Equal	Minor	No	10 yrs	Not all measures
Well Field	Less	Minor to Major	Yes	5 yrs	Depends on locale
Saline or Brackish Water	Probably greater	Minor	Yes	10 yrs	Depends on locale
Aquifer Storage and Recovery	Less	Peaking Reduction	Yes (Offset WTP expansion)	5 yrs	Depends on locale
Reuse	Less	Minor to Major	Yes	5 yrs	Yes

4.5 Evaluation Model

It is offered that the appropriate method to evaluate alternatives, especially dredging, is to examine the alternative against the range of other possible alternatives. “Pair Wise” is a simple planning tool that aids in evaluating alternatives against various criteria. It was developed by a group of scientists and engineers at Sandia Base, New Mexico. It is presented as an example of “a” system to weigh the various components in arriving at a prioritization of alternatives.

4.5.1 “Pair Wise” Model

The Pair Wise evaluation process described below uses an Excel spreadsheet with various linked worksheets. The basis for the system is to isolate and rank the criteria that will be used to evaluate alternatives. In the example shown below, it was assumed that: (1) cost, (2) time and (3) probability of success were appropriate criteria. The last criterion takes into account both the probability that the alternative may not be implemented (e.g., a permit could not be obtained) or that the alternative might not produce the necessary supply (i.e., water conservation).

4.5.1.1 Ranking the Criteria

To assess the criteria, a matrix is formed and each criterion is measured against the others in terms of perceived importance. Table 4-4 provides the numerical scores that are to be used in discerning the value of one criterion when measured against the other criteria. Table 4-5 is an example of a Pair Wise ranking of the above criteria.

TABLE 4-4
NUMERICAL GRADING FOR CRITERION

Importance of Criterion 1 vs. Criterion 2		**Importance of Criterion 2 vs. Criterion 1**	
Much Greater	5	Much lower	1
Greater	4	Lower	2
Same	3	Same	3
Lower	2	Greater	4
Much Lower	1	Much Greater	5

TABLE 4-5
PAIR WISE COMPARISON – CRITERIA

		Cost	**Time**	**Probability of Success**	**Sum**
1	Cost		1	3	4
2	Time	5		4	9
3	Probability of Success	3	2		5

In this example "Cost" was measured against "Time to Implement" and "Probability of Success" using a score system shown in Table 4-4. Thus, when "Cost" is compared to "Time" it was assumed that time was critical and, therefore, "Cost" held a much lower value. Having assigned a value of "1" to "Cost" compared to "Time", the next row in the matrix is automatically calculated for "Time" versus ""Cost" and assigns a "5."
Table 4-5 shows this relationship.

When "Cost" was compared to "Probability of Success" a more balanced relationship was assumed, thus, a score of three was entered. Again, on the third row, the system automatically calculated the reverse of this relationship, "Probability of Success" to "Cost" and a score of 3 resulted.

Finally, "Time" was measured against "Probability of Success". In this case, it was assumed that time was still a greater (but not "much greater") concern than "Probability of Success", thus, it was given a score of 4. This resulted in a score of 2 when comparing "Probability of Success" to "Time".

The ratings result in an overall sum for each criterion, which is computed in the last column. This sum will be subsequently used to provide "weighting" to adjust raw rating scores for alternatives.

4.5.1.2 Comparing Alternatives

The next process in the Pair Wise Program is to rate each alternative against the remaining alternatives as pertains to an individual criterion. Since three criteria were used, there will be three separate calculations made as shown in the Tables 4-6 through 4-8.

TABLE 4-6
COMPARING AND RANKING ALTERNATIVES RELATIVE TO COST

		New Reservoir	Dredging	Reuse	Water Conservation	Well Field	SUM	WT	RANK
1	New Reservoir		5	2	3	4	14	56	2
2	Dredging	1		1	2	2	6	24	5
3	Reuse	4	5		4	4	17	68	1
4	Water Conservation	3	4	2		3	12	48	3
5	Well Field	2	4	2	3		11	44	4

TABLE 4-7
COMPARING AND RANKING ALTERNATIVES RELATIVE TO TIME

	New Reservoir	Dredging	Reuse	Water Conservation	Well Field	SUM	WT	RANK
New Reservoir		1	1	1	1	4	36	**5**
Dredging	5		4	2	4	15	135	**1**
Reuse	5	2		4	3	14	126	**2**
Water Conservation	5	4	2		2	13	117	**4**
Well Field	5	2	3	4		14	126	**2**

TABLE 4-8
COMPARING AND RANKING ALTERNATIVES RELATIVE TO PROBABILITY OF SUCCESS

		New Reservoir	Dredging	Reuse	Water Conservation	Well Field	SUM	WT	RANK
1	New Reservoir		2	2	3	2	9	45	4
2	Dredging	4		3	4	2	13	65	2
3	Reuse	4	3		4	2	13	65	2
4	Water Conservation	3	2	2		2	9	45	4
5	Well Field	4	4	4	4		16	80	1

As can be seen from the above tables, the ratings for each alternative compared to the others resulted in a ranking of importance on scale of 1 to 5, with five being the most important and one being the least. The numerical scores in each row were added, and the result was entered in the column "SUM". The sum was then adjusted by multiplying it times the appropriate factor that was determined in Table 4-5, which assessed the relative value of the criteria. This resulted in weighted values that were entered in the column "WT".

4.5.1.3 Ranking The Alternatives

Tables 4-6 through 4-8 showed rankings among alternatives for each criterion. The next and final result is shown on the Table 4-9, with the overall ranking based on the results of all comparisons.

TABLE 4-9
FINAL COMPARISON

		Cost	Time to Implement	Probability of Success	SUM	RANK
1	New Reservoir	56	36	45	137	5
2	Dredging	24	135	65	224	3
3	Reuse	68	126	65	259	1
4	Water Conservation	48	117	45	210	4
5	Well Field	44	126	80	250	2

This final comparison lists each alternative and its relative score for each of the three criteria. In this case, the individual scores were summed, and a rank assigned based on the highest numerical score receiving a rank of one and the remaining scores ranked accordingly. This type procedure is normally accomplished with a group of stakeholders making the assessments of the individual comparative values.

In the example case, the scoring resulted in reuse having the highest rating, thus it would be the preferred alternative. Dredging came out in the middle and new reservoirs had the lowest priority. This example is for illustrative purpose only, but it demonstrates a method for comparing the values, consequences, or importance of various alternatives for meeting an objective.. In the hypothetical case, "Time" was a driving force. Because the new reservoir could not be brought on-line as quickly as the other alternatives, it fell to lowest priority.

4.5.1.4 Adjustments to the Protocol

To give the system a greater number of dimensions, it could be run iteratively with adjustment in relative criteria. For example, cost could be considered as a variable, such that it could be evaluated at various degrees of cost differentials. A base cost could be evaluated, then other evaluations made with the cost at incrementally higher values (e.g., two times base cost, three times base cost, etc). At some higher level, cost would dominate over all other criteria. The same iterations could be done on time. Time differentials in 5- or 10-year increments could be assessed. Similarly, "Probability of Success" could be expressed in quantifiable terms and evaluated at different degrees of success. This would establish criteria boundary conditions, points of general quantification, where a threshold is established that makes one criterion a decision point in itself. For example, if the cost of an alternative caused an unsustainable increase in water rates to the public, the alternative would be dismissed on that single criterion if its cost reached that proportion.

Having developed certain boundary conditions, then the individual alternatives could be better assessed based on the conditions of cost, time and probability of success pertinent to that location and the planning horizon being assessed.

CHAPTER 5

WATER QUALITY CONSIDERATIONS IN EVALUATING DREDGING VERSUS NEW RESERVOIR CONSTRUCTION

Despite the apparent cost advantage of reservoir construction, conducting dredging for supplemental water supply as a conjunctive solution to water supply has been shown to have fewer impediments than new reservoir construction and has a large number of benefits. The following addresses the benefits of improved water quality related to dredging.

5.1 Water Quality

Dredging can improve the water quality of the lake. Sediments are frequently deposited at depths conducive to anaerobic decomposition. Also, successive deposits cover initial sediment deposits such that the lower levels of sediment tend to become anaerobic even if the overlying water is aerobic. Anaerobic conditions cause the propensity for phosphates and other nutrients to become soluble and partition from the sediment to the water. Removing sediments containing phosphates and other nutrients will tend to decelerate the rate of eutrophication of the lake. This reduction in nutrients in the water column could have an effect at the water treatment plant and could forestall the need for capital expenditures and operational costs for advanced treatment processes. Existing lakes that have experienced severe eutrophication or that have been beset by large expanses of virulent aquatic vegetative growth might be candidates for dredging from the standpoint of water quality alone, notwithstanding any potential gains in water supply. As is the case of water supply purposes, if a lake were selected for dredging on the basis of water quality improvements the cost/benefit evaluation should take into account the other beneficiaries, such as water supply, aesthetics and recreation as stated in paragraph 4.4.7 and 5.3.

5.2 Water Quality - Innovative Design

Water quality can be addressed by dredging to remove sediments in the lake. In some cases it could be possible to use dredging methods to establish constructed wetlands in the upper reaches of a water supply lake for the purpose of isolating nutrients and sediment by storing the dredged solids in areas separated from the main lake water body. The design of this concept could be accomplished to form constructed aquatic wetlands in the headwaters that would improve the efficiency of nutrient removal

5.3 Example Water Quality Project

As stated previously, there can be many purposes for dredging a lake in addition to water supply. Recreational boaters and fishermen would benefit by dredging the shallows of lakes that have filled in through with sediments to such an extent that the upper reaches and tributary arms are no longer accessible to boats. These same areas can be zones of the lake that contain high organic content within the sediment and also contain phosphates and other nutrients. Thus, dredging those areas could improve vistas, increase boating and fishing access and improve water quality within the lake.

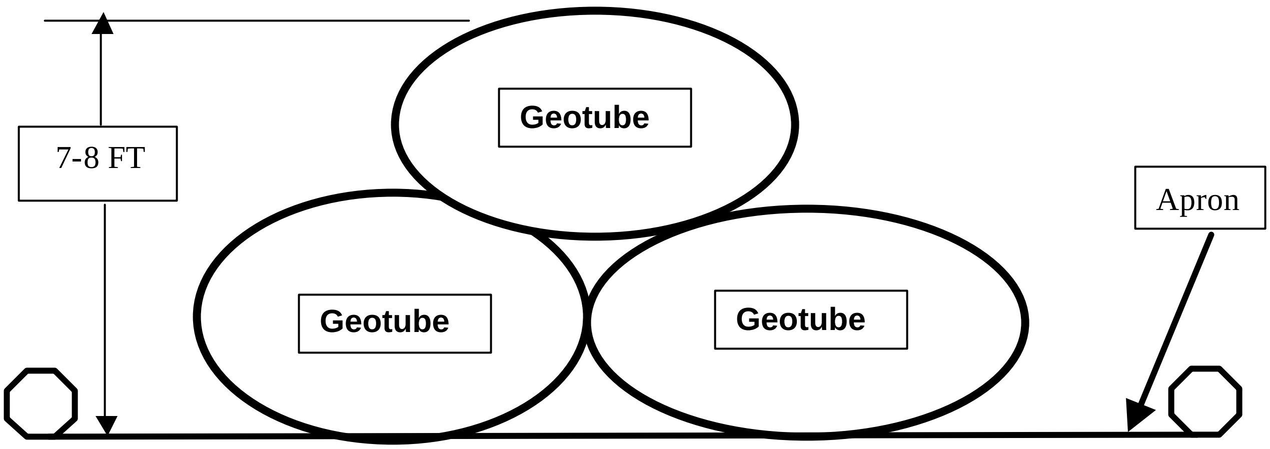
Notwithstanding the beneficial purposes enumerated above for dredging the upper reaches of lakes, there is another scenario that could be pursued. That is, dam-off upper reaches of the lake and form constructed wetlands in the upper reaches using dredged material as fill, such that a fairly uniform depth of shallow water could be realized. This would have the advantage of providing a permanent residence for a portion of the lake's sediment within a short distance of the dredging activity, as well as establishing an area of aquatic vegetation to receive incoming flow to remove sediments and nutrients from the water to the benefit of water quality of the main body of water in the lake. Of course, this might also eliminate an area of the lake to which boaters would want continued access. Thus, not all users or residents of the lake would support conversion of portions of the lake to constructed wetlands.

In order to isolate the areas where the constructed wetlands would be located it would be necessary to construct a weir or dam in the headwaters to establish the boundaries of the constructed wetlands. These structures could be constructed as an earthen embankments planted with switchgrass, sheet pile weirs, or Geotubes® dams. Geotubes® are large, woven polyester or polypropylene bags (bladders) that are filled with dredged solids. The solids consolidate in the Geotubes® expelling the water from the bag during the consolidation process.

For example, a small lake in an urban setting was considered. For the purposes of the example, the lake was assumed to be 3,200-foot long, and a 7- to 8- foot high dam would be constructed using a combination of three Geotubes® as shown on Figure 4.8.

FIGURE 5-1

CROSS-SECTION GEOTUBE DAM



To illustrate an alternative wherein dredging could be used for (1) removing a majority of the lake's sediment for water quality purposes while increasing water supply by the amount of storage space gained, (2) providing for a constructed wetland only, and (3) a combination of the first two alternatives. (See the following example.) A hypothetical setting was developed for "Lake Wanna B' Dredged."

Surface	1,200 acres
Volume (initial)	19,470 acre-feet
Sedimentation	18 percent, or 3,630 acre-feet
Yield Initial	4,500 acre feet/year
Yield Current	3,690 acre-feet/year
Land Cost	$10,000 per acre
Sediment Type	Silt and sand
Dam Length for Wetlands	3,200 feet

Table 5-1 below depicts the various outcomes for the three alternative schemes. Dredging costs were developed using the CSDCEP Model for dredging and pipeline costs for delivering dredged solids to a sediment dewatering basin at a distance of 5 miles for Alternatives A and C, and a distance of 1,000 feet to the constructed wetland for the constructed wetland alternative scenario. Acreage for the dewatering basin was based on storing sediment to a height of 10 feet with a resident density in the basin of 70 pounds per cubic foot as compared to a density in the lake of 50 pounds per cubic foot. A basin with a berm height of 15 feet constructed with side slopes of three horizontal to one vertical was assumed. A buffer strip was also assumed outside the berms.

The cost was assessed on a cost per acre-foot and a cost per thousand gallons for the actual amount of yield developed by the dredging. This unit cost was restated based on distributing the cost of dredging to the entire yield of the lake following dredging.

From the standpoint of water supply, Alternatives A (dredging the entire lake) and C (dredging the entire lake and constructing a wetlands in a portion of the lake's headwaters) address water supply in addition to water quality. The incremental cost per thousand gallons for the raw water supply developed amounts to something over three dollars. However, if distributed over the entire lake's supply, the added cost to the raw water is on the order of 60 cents per thousand gallons. Water quality improvements are not insignificant and have value. For example, Alternative A would generate an additional 810-acre feet per year (0.72 MGD) yield at a cost of $12.5 million. The improvements in water quality (taste and odor) plus the possible avoidance of capital and O&M costs at the water treatment plant should be quantified to determine what portion of the $12.5 million might be offset by the improvements in water quality occasioned by the dredging operation.

TABLE 5-1
EXAMPLE – COMPARE DREDGING FOR WATER QUALITY

	ALT A	ALT B	ALT C -Combine A & B	
Project	**Dredge Entire Lake WQ/WS**	**Dredge for Wetland Only WQ**	**Dredge Lake (-) WQ/WS**	**Dredge for Wetland WQ**
Volume ac-ft	3,630	500	3,130	500
Volume CuYd (Millions)	5.85	0.81	5.05	0.81
Dredging Unit Cost/CuYd	$1.32	$2.14	$1.32	$1.32
Unit Cost Land & Basin/CuYd	$0.82	N/A	$0.82	N/A
Unit Cost Lake Weir (Dam)	N/A	$0.62	N/A	$0.62
Increase Yield ac-ft/yr	840	None	725	None
Total Cost (Millions)	$12.5	$2.39	$12.4	
Annual Cost (Thousands) (30 yrs @ 5.5%)	$860	$164	$853	
Water Supply Cost/ac-ft/yr	$1,025		$1,175	
Water Supply Cost/1000 Gallons	$3.14		$3.61	
Increase raw water cost in lake per 1000 gallons	$0.59	$0.14	$0.60	
Water Quality	Remove nutrient laden sediments	Polish incoming water during low and moderate flows	Remove nutrient laden sediments and polish incoming water during low and moderate flows	

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study lead to determining that there were practicable opportunities for performing hydraulic dredging, perhaps not on the same scale as constructing a new reservoir, but other opportunities were found to have viability. The study also addressed sedimentation. While sedimentation is inevitable, the amount of sedimentation can and should be minimized in order to extend the life of existing reservoirs, or spread out the schedule between dredging events if dredging is to be used to recover capacity in reservoirs. The conclusions are as follows:

6.1.1 Dredging vs. New Reservoirs

Dredging is not competitive with the construction of new reservoirs when compared on an equal volume basis. While the unit costs for dredging are extremely variable, even under the most favorable conditions, the unit costs for dredging are about twice the cost for developing a unit of storage in a new reservoir. The study found that the cost for new reservoirs in terms of capacity created was above $1.00 per cubic yard of capacity. This figure included the pipeline costs as well as the amortization of O&M costs for a thirty-year period. Dredging costs can be highly variable. A general floor of $2.00 per cubic yard of dredged material was determined, with variabilities of sediment type, bottom conditions, distance to dewatering sites, land costs, and other factors increasing the unit cost by factors of two, four, or more.

A rough comparison of energy costs favors reservoir construction over dredging. Dredging requires displacement of one unit of sediment to create a unit of storage, while one unit of embankment for a reservoir yields twenty to eighty units of storage. This relationship works to the detriment of dredging and portends that dredging will always be at a disadvantage.

6.1.2 Dredging As A Supplemental Water Supply

Even though the cost of dredging does not compare favorably to the cost for constructing new reservoirs, dredging should still be considered a viable alternative for supplementing water supply. Hydraulic dredging can re-establish the original yield of a water supply lake and could conceivably postpone the need for a new reservoir for years. The unit cost of dredging when applied to the entire yield of the water supply lake does not result in unacceptable unit costs for raw water.

6.1.3 Dredging Benefits Other Than Water Supply

Dredging has been used frequently in inland lakes in the United States to improve boating, other recreation activities and aesthetics. If dredging were accomplished to increase or supplement water supply, the cost of dredging should also be distributed to all the beneficiaries of the lake in order to evaluate cost-effectiveness of dredging.

6.1.4 Dredging for Water Quality Purposes

Improving water quality is a special benefit for dredging. Removal of lake sediment also removes organics that are associated with the sediment. Eutrophication can be reversed and/or delayed through dredging.

6.1.5 Cost Variability for Dredging

The cost of dredging can be highly variable and is influenced by the type of sediment, chemical quantity of sediments, bottom conditions, depth of water, distance to and topographical setting of solids dewatering areas and the cost of land for dewatering basins. Land costs in urban areas can be $20,000 to $30,000 per acre, which has a significant effect on unit costs if de-watering basins are used. Texas A&M University has developed an excellent modeling tool for estimating the cost of dredging operations. This tool addresses all variables from mobilization through discharge. The model does not account for land costs for the dewatering area or the construction of the dewatering facility itself. This model, the Cutter Suction Dredge Cost Estimation Program (CSDCEP) is recommended for use in evaluating site-specific dredging alternatives.

6.1.6 Watershed Management

The rate of sedimentation can be predicted within a certain low tolerance of accuracy. From a relative basis it can be demonstrated that urbanization and cropland farming contribute disproportionate amounts of sediment to lakes. On-going programs to minimize erosion should be continued.

6.1.7 Permits

A PL 92-500 Section 404 permit is required for hydraulic dredging. A TCEQ 401 Water Quality Certification is also required. Depending on the land needs and surface modifications, cultural resources, threatened and endangered species, and jurisdictional waters of the United States must be addressed.

6.1.8 Constructed Wetlands

Large portions of sediments, particularly sand and silt-sized grains are often trapped in the shallow headwaters of lakes. An innovative concept would be to isolate these shallows from the lakes' main bodies and use dredging operations to fill the shallow areas so that aquatic wetlands are formed. These wetlands could be used to polish the incoming flows and remove sediments from the inflow, especially during times of low to moderate inflow. This would diminish the amount of nutrients traveling to the main body, thus the quality of the main body (water supply) would be less susceptible to eutrophication or taste and odor problems. Additionally, it has been shown that deeper lakes are less prone to eutrophication (and algae growth) than shallow lakes. Thus, the water quality benefits of restoring depth to the lake should be considered among the advantages for dredging a water supply lake.

6.2 Recommendations

The evaluation has addressed various items related to comparing dredging versus constructing new reservoirs. One important consideration was the need to address the watershed in order to limit the amount of sediment that is delivered to the water supply lakes (whether newly constructed, or dredged). There are several watershed initiatives and programs in the United States and within Texas. Other than a need to support such initiatives, there are no specific recommendations made on the basis of this report. Instead two specific recommendations are submitted.

6.2.1 Beneficial Uses for Dredged Solids

It is recommended that beneficial uses for dredged solids be considered in order to minimize the cost of dredging especially in urban or suburban settings. Generally large expanses of land would be required (on the order of thousands of acres) if dredged solids were used to replace or build up topsoil. The practicability of such an endeavor should be investigated. The Texas Department of Agriculture and the Agricultural Extension Service administered by Texas A&M University are agencies that are well suited to develop practicable concepts for re-distributing large volumes of sediment back on the landscapes of origin. Other agencies or not-for-profit organizations such as the Texas Farm Bureau could also make contributions in this area. The intent is to find a cost-effective manner in which to place recovered sediment in upland areas, rather than permanently dedicate land as repositories for dredged solids. The literature on the subject of beneficial uses of dredged material generally focuses on contaminated material, rather than land application or restoring topsoil.

6.2.2 Pilot Water Quality Project

A small-sized lake should be selected as a study project incorporating dredging of the main body and establishment of a constructed wetland in the shallows. The effects on water quality, particularly eutrophication, should be examined. Because this is best done on a pilot scale basis it is recommended that an urban lake be identified for the pilot project. The City of Fort Worth has evaluated three of its small, non-water supply lakes because of legacy pollutants. The United States Geological Service has conducted analytical sampling and age tests of the sediment. Because of the amount of data developed it is suggested that one of these lakes be considered for a pilot program. Other small-sized lakes through out the State should be evaluated as candidate sites. Essentially the candidate site should have experienced some degree of eutrophication and have inlet areas that would be suitable for conversion to wetlands areas.

APPENDIX A

EXAMPLES OF DREDGING PROJECTS

APPENDIX B

DISCUSSION OF DREDGING COST ELEMENTS

APPENDIX C

COPY OF EXECUTIVE ADMINISTRATOR’S COMMENTS

APPENDIX A

EXAMPLES OF DREDGING PROJECTS

Extensive dredging has been accomplished along the navigable rivers and inter-coastal waterways, primarily by the U.S. Army Corps of Engineers. Dredging has also been conducted at small lakes throughout the United States. The majority of inland lake dredging has been motivated by recreation or aesthetic purposes. In Dallas, White Rock and Bachman Lakes have recently been dredged and in Abilene, Lytle Lake dredging is being completed. None of these lakes are water supply lakes; however, aesthetics and boating were of sufficient public interest to warrant expenditure of funds to deepen the lakes and improve their headwaters. A limited number of water supply lakes have been dredged to enhance water supply or recover storage lost to sedimentation.

Irrespective of the purpose for dredging, such as channel deepening for navigation purposes, recreation, aesthetics or water supply, the components of dredging are similar. The following are examples of dredging accomplished in both inland waterways and inland lakes.

Corps of Engineers. Table A-1 provides typical dredging costs for USACE projects.

TABLE A-1
CORPS OF ENGINEERS EXPERIENCE

Year	Project	Cu Yd	Cost/Cu Yd
2003	Neches River	2,700,000	$2.88
2003	Embrey Dam	251,384	$10.72
2004	Mobile River/Theodore Ship Channel	750,000	$4.00
2004	Miss River Pass-A-Loutre	6,250,000	$1.31
2003	Trinity River - Ch to Anahuac	212,000	$4.13
2003	Ohio River	1,000,000	$3.84
2003	Red River – Vicksburg	6,000,000	$1.17
2002	Trinity River -	894,882	$5.66
2000	McClellan Kerr Ark River	835,000	$3.17

<u>Lake Trafford, Florida</u>. Lake Trafford is an approximately 1,500 surface acre lake some 20 miles southeast of Fort Myers, Florida. A lake survey determined the lake had accumulated about eight and one-half million cubic yards of loose, flocculent organic material. A hydraulic dredging plan was proposed that would have an ultimate cost of $17.5 million, to be shared between the State of Florida and the federal government.

The following cost elements estimated for the project are pertinent.

TABLE A-2
ESTIMATED COSTS – LAKE TRAFFORD – FLORIDA

Item	Quantity	Estimated Cost (millions)	Cost/Cuyd
Dewatering Site	Sediment Basin	$2.5	$0.21
	449 Acres	$0.7	$0.085
Dredging	8.5 MM Cu Yd	$11.5	$1.35
Eng/Admin/Env		$1.2	$0.14
TOTAL		**$15.2**	**$1.79**

The above estimate considered hydraulic dredging with a 14-inch cutter suction dredge. The dewatering area was located on 449 acres less than one mile from the dredging operation and was estimated at $1,600 per acre. Sediment depths of up to 9 feet were estimated.

<u>White Rock Lake, Dallas Texas.</u> White Rock Lake is a 1,015-acre, scenic lake operated by the Dallas Parks and Recreation Department. The Dallas Water Utilities (DWU) originally constructed it as a water supply lake, but abandoned it as a water supply source because its yield was minimal compared to the DWU demand. The lake is virtually a “downtown” lake. Because of its proximity to a large residential base and its beauty, it is widely used for a number of activities including fishing, sailing, birding and picnicking. The City underwrote the dredging operation funded by municipal bonds. The unique feature of this dredging operation was the disposal of the dredged solids. An abandoned quarry, located almost 20-miles south of the site was used to store the solids. Thus, the water used in dredging and to maintain the solids in a slurry condition were wasted (i.e., the water was not returned to the lake following dewatering of the sediments). Based on conversation with Renda Marine, the dredging contractor, the dredged solids were recovered in slurry of about 30 percent solids to 70 percent water. This was further diluted to about 20 percent solids for pumping. One hundred four thousand feet of 24-inch steel pipe was used to transport the slurry. The dredge was equipped with a 2,000 horsepower pump, and two 1,500 horsepower pumps were used in series to boost the slurry to the disposal area.

Three million cubic yards of sediment were dredged at a cost of $18 million, including pipeline and pumping costs. This equates to $6 per cubic yard.

Decatur, Illinois. Decatur, Illinois is a town with a population of about 90,000 with a fairly large commercial and industrial water demand. It relies on its lake on the Sangamon River in addition to a well field of ten (10) wells. Intense agricultural use within the lake watershed has been cited as one reason for an inordinate amount of sedimentation to the lake.

In 1992 the City spent $3.2 million to remove 1,240 acre feet or 2,000,000 cubic yards of sediment ($1.60 per cubic yard or about $1.90 per cubic yard in 2004 prices). In this project, the sediment was transported to a dewatering site 11,000 feet from the lake. A 620-acre dewatering site was acquired, and a dewatering basin of 400-acres was constructed.

A more ambitious plan was subsequently developed that includes a multi-year program to dredge an additional five million cubic yards of sediment (3,100 acre feet). The estimated cost is $25 million, or $5 per cubic yard. A second 620-acre site was acquired and another dewatering basin of 400-acres was constructed. The plan envisions an 18-inch pipeline with two booster pumps, to move the dredged material 18,000 feet to the dewatering site. The dredging operation is beginning at a portion of the lake where sediment is more consolidated and where tree stumps are located. The City procured its own hydraulic cutter head dredge and will operate the dredge with city forces. Operating expenses are expected to run around $750 thousand to $1 million annually for a ten-year period.

Lake Panorama, Iowa. Lake Panorama is a 1,400-acre lake. The lake residents formed a Tax Incrementing Financing (TIF) district as a rural improvement zone to finance operations. In 1999 the TIF purchased a 14-inch hydraulic cutter head dredge for $11 million. The dredge operates from mid-March to December (or first ice). Two crews are assigned to the dredge and, together, they operate 80 hours per week. The operation has been utilizing a dewatering basin built in 1984 for an earlier dredging operation. Currently a new dewatering basin is being constructed at a cost of $2.9 million, which is planned to provide 20 years storage. Production is 670,000 cubic yards per year. Including annual debt service for the dredge and dewatering basin, the annual costs to operate the dredge equates to from $1 per cubic yard to $1.50 per cubic yard.

Lake Springfield, Illinois. Lake Springfield provides raw water supply for the City of Springfield, Illinois. It is owned and operated by the City's utility. The 59,000 acre-foot lake was constructed in 1935. By 1984 its volume was reduced to 51,500 acre-feet due to sedimentation (a 13 percent loss of storage). The city has undertaken a two-phase dredging project with the first phase completed in 1987. Plans are to remove 2.7 to 2.9 million cubic yards (1,700 acre feet). Acreage has been obtained for dewatering basins. The filled basins used for the first phase of dredging are being used beneficially as farmland. The costs, expressed in 2005 dollars for the dredging, are $3.83 per cubic yard for Phase 1 (1.2 million cubic yards) and $2.90 per cubic yard for Phase II (estimated 1.5 million cubic yards).

The city has embarked on a proactive plan to curtail the amount of sediment that is delivered to the lake each year from upstream erosion. A watershed management plan has been adopted that includes acquisition of easements planted with appropriate vegetation to serve as buffers to filter rainfall runoff. Education programs for upstream landowners have also been established. The management activities have been funded in part by grants and loans from federal and state agencies.

Lake Nasworthy, San Angelo, Texas. The City of San Angelo contracted with L.W. Matheson to dredge city-owned Lake Nasworthy, one of its water supply lakes in the City's water supply system. The contractor constructed a 500-acre dewatering basin on 600 acres of land less than 5,000 feet from the lake. The contractor brought a 20-inch cutter head dredge to the site for its main production and also subcontracted with McAlester Dredging Company for a 10-inch dredge to assist in dredging narrow arms of the lake. The contractor operated 24 hours a day on a six-day per week schedule, with the seventh day used for maintenance. The project resulted in the production of 3.7 million cubic yards of sediment. The contactor was paid $9.96 million, which equates to about $2.70 per cubic yard.

Lytle Lake, Abilene, Texas. Lytle Lake is a former West Texas Utilities' lake used in its power generating system. The lake was a feature of a residential development whose homeowners' association took over the lake when the utility company discontinued its use of the lake and transferred funds to the homeowners association to dredge the lake. In 2004, the West Central Texas Municipal Water District, Abilene, Texas, acting on behalf of the homeowners association solicited bids to dredge the lake and construct a dewatering basin to remove and store the dredged solids. The bid documents included a provision for removal of 600,000 cubic yards of material with an alternate bid for an additional 200,000 cubic yards. The bid results for the base bid provide interesting ranges for dredging costs. Of particular interest is the spread in mobilization costs. Mobilization costs ranged from eight to 45 percent of total costs. Unit costs (not including the dewatering area) ranged from $2.71 to $6.68 per cubic yard. Unit costs exclusive of mobilization and the dewatering area ranged from $1.78 per cubic yard to $6.15 per cubic yard. Not all bidders submitted a bid for the dewatering area. Of those that did, costs ranged from $338 thousand to $869 thousand. The district owned the land for the dewatering area and the plans were to leave the solids in place, thus avoiding even higher costs of land acquisition and perhaps some further disposition of the material.

TABLE A-3 LYTLE LAKE – TABULATION OF BASE BIDS – 600,000 CUYDS						
Bidder	1	2	3	4	5	6
A. Mobilization ($000)	$724	$798	$1,250	$200	**$555**	$320
B. Base Bid ($000)	$1,146	$1,770	$1,500	$2,430	**$1,071**	$3,690
Total ($000) (A + B)	$1,870	$2,568	$2,750	$2,630	**$1,629**	$4,010
Percent Mobilization of Total Base Bid	39	31	45	8	**34**	8
Unit Cost ($/Cu Yd)	$3.11	$4.28	$4.58	$4.38	**$2.71**	$6.68
Unit Cost Dredging w/o Mobilization ($/Cu Yd)	$1.91	$2.95	$2.50	$4.05	**$1.78**	$6.15
					Low Bid	
Note: Costs do not include dewatering basin construction or real estate						

Lake Jackson, Florida. Lake Jackson, a lake under operational control of the Northwest Florida Management District, Havana, Florida, was dredged by mechanical means using standard excavation practices. Work was accomplished by contract with excavation contractors being paid at unit rates for work. The Florida Fish & Wildlife Conservation Commission also participated and separately contracted for excavation in the first phase of the program.

The purpose of the excavation was to remove built-up sediment of extremely high organic content. The excavation was limited to three feet of sediment from the lake bottom or until a “white sand” stratum was encountered. This latter material was assumed to be the original lake bottom. The lake had a history of large changes in water surface elevation. The strategy was to prepare for the excavation pending the next cycle when the lake volume was reduced sufficiently to expose the sediments. That included arranging for financing the project in advance of the indeterminable time the work could start.

Two phases of construction were involved. Phase 1 involved 400,000 cubic yards, with unit prices ranging from $1.20 to $8.00 per cubic yard. Phase 2 was for 1,600,000 cubic yards and was based on $4.00 per cubic yard. The overall cost for contracting services was $8.7 million with in-kind services bringing the total to $9.2 million or $4.60 per cubic yard.

Contractors used track hoes assisted by tracked dozers. Haul roads were constructed in the lake using lake bottom material to construct the roads. Standard dump trucks were used to transport the material to disposal sites. Road graders were employed to maintain the roads in the lake bottom, and water trucks with sprayers were used for dust suppression.

Contactors were required to locate their own disposal sites. One large plantation near the lake was the predominate source for disposal at $0.25 per cubic yard tipping fee. Disposal sites varied in location from five to fifteen miles from the site. In some cases it was necessary to windrow the excavated material to dry it sufficiently before loading on dump trucks in order to travel public roads to disposal sites. County equipment was used during Phase 1 to remove mud and soil from roads during the transport operation.

The concept was successful because the lake owners were prepared with financing at the time the contractors could begin. Additionally, contracts had already been negotiated with unit price fees with a number of contractors. Turn-key contracts were used including preparing the sites for excavation, excavation, loading, and hauling and land disposal.

APPENDIX B

DISCUSSION OF DREDGING COST ELEMENTS

SITE SPECIFIC COST CONSIDERATIONS RELATIVE TO HYDRAULIC DREDGING

Operation of dredges requires large capital expenditures for plant (dredge) equipment. Support equipment such as tenders, generators, booster pumps and ancillary equipment also amounts to large investments. Dredging requires a labor force to carry out the daily functions. Additional operation and maintenance costs can be significant. Fuel costs alone can represent a sizable portion of daily operations. However, the same is true of any construction endeavor. The final test is how does the daily cost measure against the daily production rate.

There are some costs associated with the dredge material classification, site conditions, location of dewatering basins, and costs for land and rights-of-way that are variable and specific to the site. Other costs are related to the capital investment in the equipment and the operating factors. The U.S. Army Corps of Engineers has published guidance for this latter category in its engineering publication, EP 110-1-8, Volume 6 Chapter 4 Methodology for Dredging Plant and Marine Equipment, July 31, 2003. The following provides some cost considerations that are included in analyzing dredging operations

Time Available to Dredge

This is defined as the number of months available in any one calendar year. The time excludes downtime for major repairs, bad weather and environmental restrictions. For the Gulf Coast, the USACE experience is ten (10) months per year are available to dredge.

Annual Hours Available

The annual hours available are related to the effective working time versus non-effective working time. "Effective" time is related only to those hours when the dredge is actually in a production mode. All other times are "non-effective." The planned work schedule has a direct effect on this factor. Dredging can be conducted in one, two or three shifts per day, or in some cases one extended shift (e.g. 10-hour day). A factor of 70 percent is provided by way of example for effective hours. Thus, a 24-hour per day operation would involve a potential of 720 hours per month (30 days times 24 hours per day). With a 70 percent factor there would be 500 effective hours (720 hours times 70 percent). The annual hours available would then equate to the 10 months for annual time available times the effective hours per month or 5,000 hours.

Life

The useful life is the economic life of the equipment. The physical life is the life expressed in working hours for the equipment. Examples for various Cutterhead Hydraulic Dredges are shown in the Table B-1.

TABLE B-1
DREDGING PLANT USEFUL LIFE (YRS) AND PHYSICAL LIFE (HRS)

Type Dredge	Useful Life (Yrs)	Physical Life (Hrs)
18-inch thru 20-inch	20	100,000
21-inch thru 22 inch	25	120,000
23 inch thru 24 inch	25	130,000
25 inch thru 29 inch	30	135,000
30 inch and above	30	135,000

Ownership Cost

All plant cost is a one-time cost that is translated to annual cost (or hourly or monthly cost) on the basis of the initial cost less salvage value divided by the useful life of the equipment. A cost of money factor is utilized to adjust the ownership cost for the opportunity cost of funds tied up in the plant equipment. Time value of money procedures would involve annualizing the capital cost of the equipment; calculating the present worth of the salvage value; annualizing the present worth of the salvage value and then subtracting the annualized present worth of the salvage value from the annualized cost of the equipment.

Standby Costs

Standby rates are usually related only to the hourly, daily, or monthly cost of ownership. Depending on circumstances the operational costs of generators can be added to the owner's costs to develop a standby rate.

Mobilization/Demobilization Costs

There can be a great variation in mobilization or demobilization rates. In the first instance contractors often load their mobilization costs in bidding documents since they can bill for that once they have assembled their equipment and are on the water. This has the effect of making production costs appear somewhat lower, since costs have moved to mobilization. Transportation of a large dredge requires an extensive fleet of vehicles. Accordingly the distance that is traveled from the contractor's yard to the job site has a significant influence on mobilization costs. The Cutter Suction Dredge Cost Estimation Program (CSDCEP) developed by the Ocean Engineering Program/Civil Engineering Department, Texas A&M University provides a mechanism to determine mobilization cost based on standard times to assemble dredges and provide the necessary setup of the accessory equipment. On a job that involves large quantities of sediment the mobilization and demobilization costs will become less significant since they are one-time costs, whereas the operational costs (along with depreciation costs for equipment) will generally cover a period of two or more years.

USACE Operating Factors

Planning factors for operating costs for dredges based on effective hours have been developed by the USACE for planning purposes.

Prime Engine Factors

The prime engine operates the pump that develops the suction at the cutter head and provides the head to pump the slurry to the dewatering basin or to a booster pump along the pipeline. A prime power favor of 0.045 is used to develop hourly costs. The factor is multiplied times the horsepower rating of the pump and by the price for diesel fuel per gallon. The result is the operating cost of the prime engine.

Secondary Engine Factors

Secondary engines include generators, hydraulic system, cutter head drive and water jets. The total horsepower of these separate systems represents the secondary engine horsepower. A fuel factor of 0.039 for diesel fuel is used to develop the hourly cost (again, the factor is multiplied times the horsepower and the cost per gallon for diesel).

Repairs (See Table B-2)

Repairs costs are estimated based on the size of dredge and determined by multiplying a percent factor times capital cost divided by the physical life (hours).

TABLE B-2
DREDGING PLANT REPAIR COST FACTORS

Type Plant	Factor (Pct)	Physical Life (Hrs)
18-inch thru 20-inch	120	100,000
21-inch thru 22 inch	130	120,000
23 inch thru 24 inch	130	130,000
25 inch thru 29 inch	130	135,000
30 inch and above	130	135,000

For example, if a 24-inch Hydraulic Cutter Head Dredge cost $3,700,000, its repair cost would be $37 per hour ($3,700,000 x 130 percent/130,000 hours (physical life)). These repair costs can be adjusted based on the acquisition year of the dredge. In other words the original capital cost can be brought forward or adjusted to current costs. This assumes that repair costs have increased over the same period of time, thus using current capital costs adjusts the repair costs to "current."

Water, Lubricants, And Supplies (WLS)

The USACE has developed a factor for the combination of WLS. For hydraulic pipeline dredges it is 22 percent of capital costs divided by the number of hours in the dredge's physical life. As in the case of repair costs the WLS can be converted to current costs by adjusting the original capital to current cost.

Other Equipment Costs

One or more tenders must accompany a pipeline dredge. Total operating costs are associated with these special purpose pieces of equipment the same as for dredges. Pipelines have a useful life and physical life. The only operating costs associated with pipelines are repairs. Most pipelines in dredging operations have a useful life of about three years. Thus for long-term projects the pipelines will have to be replaced one or more times.

Labor Costs

Annual Labor costs equate to some forty percent of total annual costs. A large dredging operation involves a large and diverse crew.

The labor costs include support personnel such as tender operators, as well as the personnel that operate and maintain the dredge. Some form of salaried supervision is typically involved in the operation. Labor costs are significantly affected by workman's compensation rates. Rates on the order of 55 percent of salaries are typical for marine workers, or persons working above water. For estimation purposes it is prudent to apply a factor to equipment and operating costs to determine labor costs (1.67 times equipment and operational costs). The CSDCEP system develops its overall costs based on crew positions required to operate various sized dredges. The wage information from that program is depicted in Table B-3. The wage rates for the more common positions, such as engineer, oiler and mate were compared with the U.S. Department of Labor Bureau of Labor Statistics, State Occupational Employment and Wage Estimates for Texas and were found to be in general agreement with the CSDCEP wage rates.

TABLE B-3
TYPICAL WAGES FOR DREDGING OPERATIONS

Position	Monthly Rate
Captain	$5,000
Officer	$4,500
Chief engineer	$4,000
Office staff	$2,000
	Hourly Rate
Leverman	$18
Dredge mate	$15
Booster engineer	$15
Tug crew	$15
Equipment operator	$20
Deckhand	$15
Dump foreman	$17
Oiler	$15
Shore crew member	$15

Monthly Operating Costs

Hourly costs as developed above are utilized to develop the monthly cost by multiplying the hourly costs times the effective hours per month.

Total Cost for Dredge Operation

The monthly cost for the dredge operation is a combination of the monthly owners cost (depreciation plus opportunity costs) and to sum of the operating costs.

APPENDIX C

COPY OF EXECUTIVE ADMINISTRATOR'S COMMENTS

Comments were received from the Executive Administrator and staff members of the Texas Water Development Board, which are attached in this appendix.

All comments were incorporated into changes within the report with the exception of comment Chapter 1, page 1-2 *"although it's addressed later in the report, Table 1-1 could be significantly supplemented with data from the TWDB"*. The table that was included at that point in the chapter was developed from information on five U.S. Army Corps of Engineer (USACE) lakes. The representatives from the USACE were confident of the survey accuracy for the purposes intended for this report. The TWDB has surveyed significantly more lakes; however, it was understood that only recently has the survey equipment and boat size (shallow draft) been suitable to get reliable information that could be used for comparative purposes. Thus current survey data is more in the nature of base line information. When successive surveys are made the value of the comparative information will be of great significance.

ATTACHMENT I

TEXAS WATER DEVELOPMENT BOARD
Contract No. 2004-483-530 Comments on the Draft Final Report entitled "Dredging vs. New Reservoirs"

Executive Summary

ES-1. change "farther to the future" to read "farther into the future"

ES-2. delete "using" from the sentence "Mechanical dredging may involve using draglines or clamshells that are mounted on barges.

ES-4. delete 2nd period at end of sentence "Lake Ralph Hall...constructing new lakes.."

ES-5. add a period at the end of the sentence "Cost alone... viable alternative"

Chapter 1

1-2. although it's addressed later in the report, Table 1-1 could be significantly supplemented with data from the TWOB

1-2. delete "of' from"... because subdividing of large tracts..."

1-4. Houston, San Antonio and EI Paso all either currently have surface water, or plan to use it in the near future

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1-4. add comma after "em ail" in the sentence "Opposition to reservoir..."

1-5. change "than" to "that" in the last sentence of the 1 st full paragraph..., "particularly those that would require interbasin..."

1-6. bottom - this calculation could benefit from the additional data at the TWOB

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1-8. mid-page - instead of Region C, Senate Bill 1 , characterize it as the Region C 2001 Regional Water Plan

1-9. change "For example, it one" to "For example, if one" in the 5th sentence

1-10. add a comma after PCB's

Chapter 2

2-1. add period after "feet" in the yth line

2-1. move parentheses from after "lakes" to after "family" in the 11 th line of the 1 st paragraph

2-1. insert a comma after "kilometer" and change "that represents" to "representing" in the last sentence of the 1 st paragraph

2-9. paragraph after Table 2-6, needs a reference and an indication that this is Texas. Is the 9% quoted, as is the 8.87% later in the paragraph? TWDS has surveyed more than 78 reservoirs. Need to explain why a gain in storage might be seen.

2-10. end of first paragraph - 0.5 percent *per year?*

2-10, change "though" to "thought" in the fourth line from the bottom of the page

2-12. delete "for" from 3rd sentence from the bottom of the page

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2-18. delete "could" and "to" from 1 st sentence under Programs by Water Supply Owners

Chapter 3

3-1. add comma after "dipper", 1st sentence under Mechanical Dredges

3-3. add "in" between "feet" and "length", last sentence of 1 st paragraph

3-6. Figure 3-2 - Can you find a better quality photo?

3-11. add a period in 4th line from the bottom after "feet"

3-14. add a comma between "conditions" and "among" in the last bulleted item

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3-18. Section 3.4.5, add a comma after "capacity" and add "way" after "navigable water"

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Chapter 4

4-5. add a period at end of last sentence under "Dredge Manufacturers"

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add "the" before "dredging" in the 3rd line from the top

4-26. Suggest removal of the columns entitled "Gut Rank" and "Delta" and associated text. This is useful for the contractor, but not for the reader.

Chapter 6

6-1. change "and" to "as" in the 5th line of the 2nd paragraph and change "he" to "the" before "amortization"

Appendix A

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A-3. change sentence "Decatur, Illinois is a town of about 90,000 population with a ... to "Decatur, Illinois is a town with a population of about 90,000, with a ..."

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B-2. change "the" to "then" after "salvage value and..." in the 2nd to last line of the page

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