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Telescoping Weir (photo couresy of J. Fowler)

IN THIS ISSUE

AIMS & SCOPE OF THE JOURNAL

The *Journal of Dredging* is published by the Western Dredging Association (WEDA) to provide dissemination of technical and project information on dredging engineering topics. The peer-reviewed papers in this practice-oriented journal will present engineering solutions to dredging and placement problems, which are not normally available from traditional journals. Topics of interest includes, but is not limited to, dredging techniques, hydrographic surveys, dredge automation, dredge safety a instrumentation, design aspects of dredging projects, dredged material placement, environment and beneficial uses, contaminated sediments, litigation, economic aspects and case studies.

DEVELOPMENT AND APPLICATION OF THE TELESCOPING WEIR FOR DREDGED MATERIAL CONTAINMENT FACILITIES

Jack Fowler[1], Ronald G. Vann[2] and T.D. Woodward[2]

ABSTRACT

The telescoping weir is an innovative structure that has the ability to closely control the environmental water quality during decantation and drainage of water from the dredged material surface of Confined Dredged Material Containment Facilities (CDF) by mechanically lowering and/or raising the weir crest to the desired elevation. The telescoping weir is designed to meet a range of water and dredged material storage levels common to most CDF sites. The express design life also as a capacity per area i.e. 2.5 MCY per 100 AC of a 15-ft high telescoping weir is ten to fifteen years depending on the filling rate, consolidation and surface area.

The telescoping weir consists of a set of vertically nested cylinders set on end with one cylinder within the other. The telescoping weir is set within and attached to the base of a reaction frame that provides support for it and the machinery that controls the telescoping movements of the weir. The telescoping weir is raised and lowered by a set of mechanical screw jacks that operate simultaneously either manually or by a solar/battery-powered motor. The bottom cylinder is fixed to a foundation that is anchored to the bottom of the CDF and connected to a discharge pipe. The upper cylinders are extended in a telescoping manner to position the rim of the top cylinder to any desired elevation below or above the water surface. As the cylinders are lowered below the water surface, the decant water flows over the weir crest into the interior sections and exits through the discharge pipe in the lower section and returns to the receiving body of water.

Improved safety and ease of operation of the telescoping weir and its ability to extend storage capacity of CDF's by 10 to 20 percent are very attractive aspects. Operational success and increased storage capacity at Craney Island has shown the telescoping weir to be technically, economically and operationally feasibility. Three prototype telescoping weirs have been installed and are operating sucessfully at the Craney Island Dredged Material Containment Island, Norfolk, VA. The Norfolk District is presently assisting the Mobile District with installation of a telescoping weir.

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INTRODUCTION

Proper management of the sedimentation ponding depth, effluent water quality, dewatering, surface water management, surface descication and improved storage capacity of the containment areas are very dependent on the sucessful design, location and operation of these discharge structures. It was recognized in the mid 1970's during the Dredged Material Research Program that an improved weir structure such as the telescoping weir was needed for improved management and dewatering of CDF's. The concept describe in this report is not a totally original idea because similar systems have been used on hopper barges and hopper dredges during filling. The application for improved CDF management is the major contribution.

The U. S. Army, Waterways Experiment Station (WES), proposed to the Nofolk District Corps of Engineers, in 1985 to construct a quarter scale model of the prototype weir to be constructed for the 2500 acre Craney Island Dredged Material Disposal Area, Portsmouth, VA. Construction drawings were prepared by WES in August 1986 and the model was sucessfully constructed and tested at WES. The model weir was able to operate in a bed of sand and a bed of fine-grained maintenance dredged material from Mobile Bay, AL that was allowed to consolidate around the weir for two years. These tests were completed at WES in 1994. In 1995, WES contracted Oceaneering Technologies, Upper Marlboro, MD, a research and development firm to construct the first prototype structure. In 1996, the first prototype telescoping weir was constructed and installed in the middle cell of the Craney Island CDF. A second telescoping weir was installed in the south cell of Craney Island in 1998. Both weirs have received hydraulic fill and have performed successfully without any problems or modifications. The existing weirs were boarded up to allow a settling pond depth and the telescoping weirs have been used for decanting the site. A third telescoping weir has been constructed and installed at Craney Island in April 1999. The telescoping weir was featured in December 1998 issue of "Engineer Update," (USACE 1998) and the proceedings of the WEDA meeting Louisville, KY (May 1999).

PRINCIPLES OF WEIR DESIGN

Weir Parameters

The two most important parameters in weir design are the effective weir length and ponding depth. The next two most important parameters are an acceptable withdrawal depth and approach velocity toward the weir crest. Dredged materials are normally dredged from navigation channels and deposited into upland CDF's at 10 to 20 percent solids. The fine grained maintenance dredged material goes through three phase of dewatering: (a) sedimentation, (b) consolidation, and (c) desiccation drying. The weir plays an important role in maintaining acceptable effluent quality during the sedimentation and decantation phases and periods of excessive rainfall runoff.

Withdrawal Zone

To maintain an acceptable effluent quality, the water near the surface containing low levels of suspended solids should be ponded to depths greater than or equal to the minimum depth of withdrawal zone, (d_w), which will prevent scouring of settled solids from behind the weir crest. The withdrawal depth, (normally equal to the ponding depth), affects the approach flow velocity toward the weir (USACE 1987).

Operating Head

The ratio of the static head to depth of flow over the weir is the best criterion for controlling the weir operation in the field. Weirs used in dredged disposal areas can assume that the weir crest is sharp crested and the thickness, (t_w), is less than two-thirds of the depth of flow over the weir, h. The ratio of depth of flow over the weir to the static head h/H_s equals 0.85 for the rectangular sharp-crested weirs. The relationship between weir crest length, L, static head H_s, and depth of flow over the weir, h, are shown illustrated in Figure 1 where $h = 0.85\ H_s$. If a given flow rate, Q, is maintained, Figure 1 can be used to determine the corresponding head and depth of flow. If the head exceeds this value then the weir crest should be raised or the dredge operated intermittently until the sufficient water has discharged to a lower head. If the effluent is acceptable then the operator need not be concerned with the head over the weir.

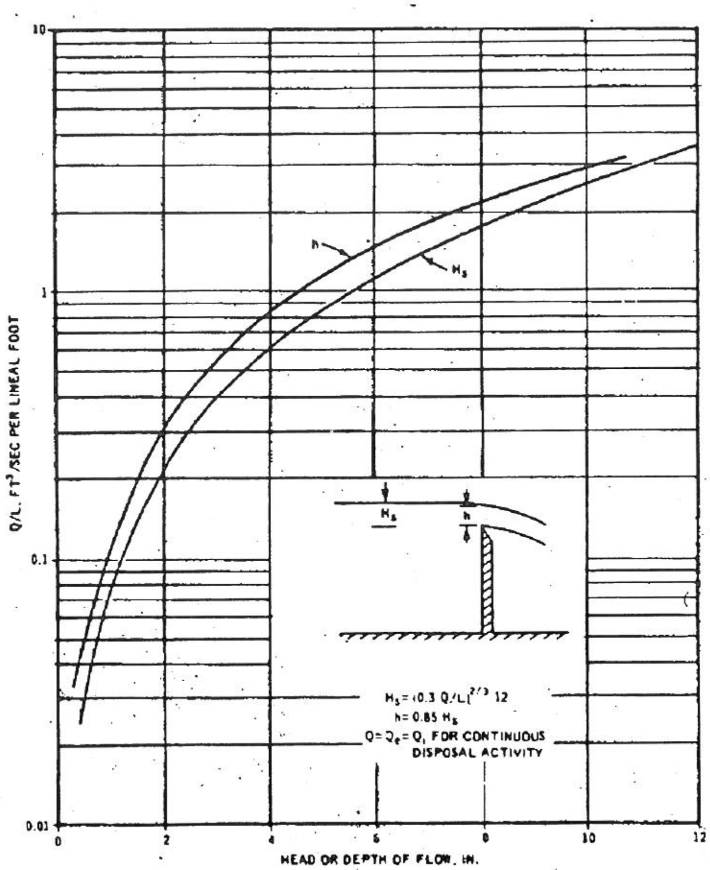

Figure 1. Relationship of flow rate, weir length, and head (USACE 1987)

Weir Shape

The weir shape or configuration also affects the dimensions of the withdrawal zone and consequently the approach velocity and effluent quality. The weir length cannot be infinitely long therefore an optimum length or effective weir length, L_e, is desired to prevent the loss of sediments. The most desirable weir shape is a circular weir because the approach velocity is minimized and withdrawal depth is maximized.

Effective Weir Length

The relationship between effective weir length and ponding depth necessary to discharge a given flow without significantly entraining settled material is illustrated in the nomograph Figure 2. Details for this design procedure are included in USACE 1987.

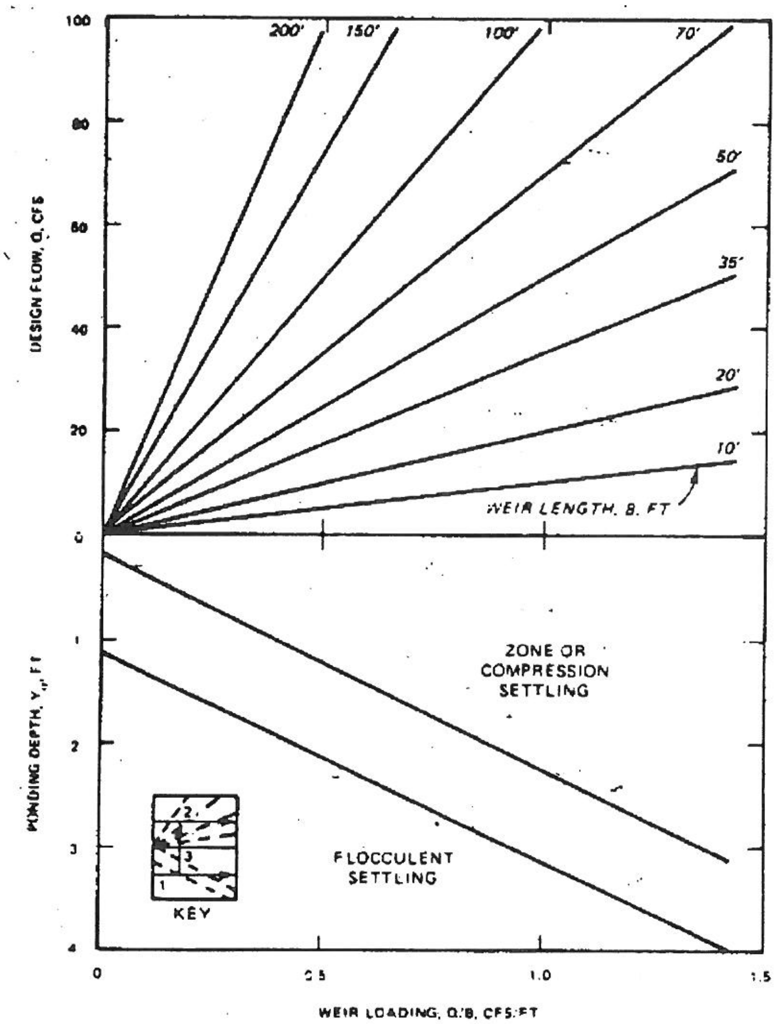

Figure 2. Weir design nomograph (USACE 1987)

Ponding Depths

For a new weir to meet a given effluent suspended solids level the lower part of the nomograph in Figure 2 is used, depending on whether the dredged material slurry exhibit zone (salt water) or flocculent settling (fresh water). The ponding depth may be deeper than average ponding depths for very large containment areas because of the long shallow slopes taken by the dredged material sediment. If the ponding depth is not maintained at the design depth then effluent quality will deminish and surface erosion, channelization, resupension and transport of fines into the water column will occur. One of the more common complaints or reasons for not retaining an adequate settling or ponding depth is the potential for dike damage and erosion caused by excessive wave action.

Weir Location

The most common problem that occurs during weir installation is improper location of the weir to the influence of dike settlement and the dish panning effects of the consolidating dredged material on the dike slopes. The weir needs to be located a sufficient distance out into the CDF to prevent interference with these effects even though it requires additional discharge pipe. The weir should be located beyond the inside toe of the containment dike plus three times the effective weir length. The discharge pipe foundation may have to be stabilized to prevent pipe failure during consolidation of the very soft dredged material beneath the pipe. Many weirs are not effective because they are too close to the dikes and do not drain the surface water from the site. Quite often the site becomes a bathtub and surface water on site never drains because of excessive rainfall and low evaporation rates that prevent surface desiccation cracks to form.

Structural Design

Weirs are designed to resist anticipated soil and water loadings at various ponding depths. Weir design considerations include: buoyancy forces, potential settlement, access for maintenance and operation, excessive corrosion from salt water, and potential piping or erosion around the weir. Outlet pipes must be designed to carry excess water from storm water runoff, the flow of multiple dredges discharging simultaneously and emergency discharge when required.

Weir Installation

The weir should be installed in the dead zones of a CDF in an area that is usually the maximum distance from the dredge discharge pipe or in the corners of a rectangular shaped CDF. Installation of weirs too close to the perimeter dikes will prevent the weirs from performing efficiently. Mounding of material against the weirs to provide access need to be removed. Temporary construction of haul roads into the CDF that are used for weir installation need to be remove immediately after installation because the weight of these soils on the soft dredged materail will cause differential settlement of the weir foundation. Preconsolidation of the weir and discharge pipe foundation (if soft) should be done. Personnel access by lightweight wooden or metal walkways should be installed from the dike to the weir for periodic inspection and maintenance.

OPERATIONAL PROBLEMS OF CONVENTIONAL WEIRS

One of the major problems with conventional weirs is removal and replacement of the weir boards at the proper time for optimum management. Adequate ponding depth to minimize approach velocities is maintained by controlling the weir crest elevation by placement of weir boards or stop logs. The boards ranged from 4 to 10 inches high and 4 to 6 inches thick to prevent excessive bending from the soil and water pressure. The disadvantage of using boards is that they are not installed or removed at the right time to control the ponded depth and approach velocities during decanting. The board thickness do not match the required depth of withdrawal, the boards leak water at the joints, the weirs are good habitat for snakes, spiders, and wasps. The boards also present a safety hazard for someone possibly slipping and falling into the weir during removal and placement of weir boards. The water soaked boards become weak and rotten with time and often fail causing complete loss and failure of the weir structure. Failed weirs and discharge pipes have also been responsible for causing complete dike failure and dike erosion down to the foundation. The lack of interest in proper site management and the lack of manpower to maintain proper weir board elevations during and after dredging has always been a problem.

Some other more common problems experienced in the operation of conventional weir designs are as follows:

- Intermittent dredging is sometimes required because of improper weir designs that cause a loss of heavily laden sediment water to exit the CDF.

- Floating debris at the weir crest causes large withdrawal velocities at greater depths below the weir crest when debris is not prevented from collecting on the weir crest. These problems are averted by simply installing a steel wire mesh 4 to 6 ft high fence with 6x6 inch openings at a distance of 30 to 40 ft from the weir to prevent accumulations of floating debris at the weir crest.

- When several weirs or weirs with multiple sections are used, the crest of all weirs is not at an equal elevation to prevent excessive withdrawal velocities.

- When the suspended solids effluent level exceeds the acceptable limits, the ponding depths are not are always raised by adding more boards and the dredge quantity entering the site is not always reduced.

- Attempts to control the weir elevation in the field by using the head over the weir as an operational parameter is very difficult to control because the volumetric flow over the weir cannot be easily adjusted or measured.

DESCRIPTION AND OPERATION OF THE TELESCOPING WEIR

Background

The purpose of the weir is to regulate the release of environmentally acceptable water from dredged material containment areas or CDF's through the use of telescoping weirs. During dredging, filling and through the sedimentation, consolidation and desiccation phases, it is necessary to continuously decant surface water. Improved weir design and operation, using telescoping weirs, can improve the environmental quality without re-suspension and withdrawal of settled solids.

After review of the literature and a patent search by the U.S. Army Corps of Engineers Office, it was concluded that the telescoping concept was an original and innovative concept for removal of decant water from dredged material containment sites. None of the existing systems provide the in-finite electro-mechanical control over the weir crest elevation and discharge velocities.

Weir Description

The telescoping weir is an innovative structure that has the ability to closely control the environmental water quality during decantation and drainage of water from the dredged material surface in a CDF by mechanically lowering and/or raising the weir crest to the desired elevation. The telescoping weir is designed to meet a range of water and dredged material storage levels common to most CDF sites. The design life of a 15-ft high telescoping weir is estimated to be ten to fifteen years depending on the rate of filling and consolidation.

The telescoping weir consists of a set of vertically nested cylinders set on end with one cylinder within the other. The bottom cylinder is fixed to a foundation that is anchored to the bottom of the CDF and connected to a discharge pipe. The upper cylinders are extended in a telescoping manner to position the weir crest to any desired elevation below or above the water surface. As the cylinders are lowered below the water surface, the water flows over the weir crest into the interior sections and exits through the discharge pipe in the lower section.

The telescoping weir is set within and attached to the base of a reaction frame that provides support for it and the machinery that controls the telescoping movements of the weir. The telescoping weir is raised and lowered by a set of mechanical screw jacks that operate simultaneously either manually or by a 24 volt battery-powered motor system that is charge by a solar panel. Figures 3 and 4 are photographs of the first successful telescoping weir installed in the middle cell of the Craney Island CDF in 1996. A schematic of the weir and how the weir would be typically installed and operate behind a CDF dike is shown in Figure 5.

Figure 3. Photograph showing the telescoping weir, walkway, and wire mesh fence for floating debris

Figure 4. Photographic view showing water decanting over telescoping weir crest

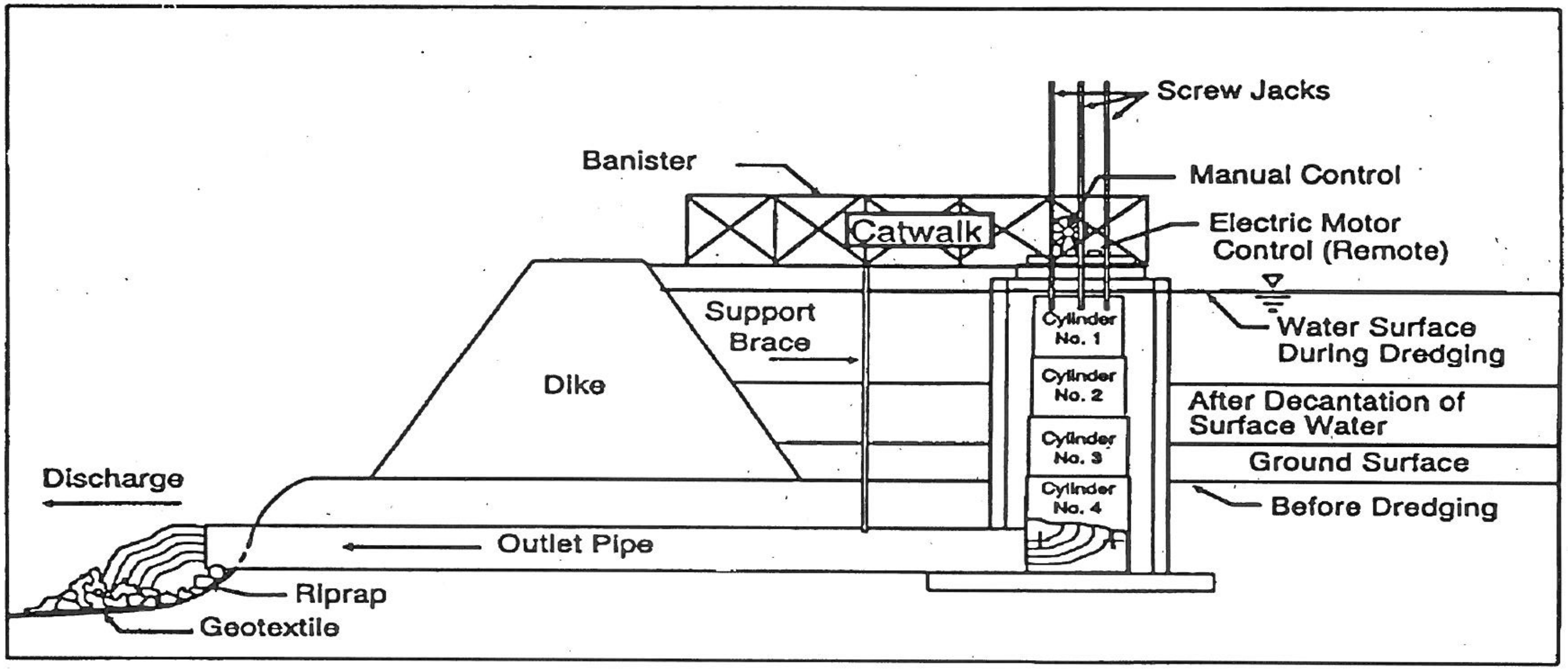

Figure 5. Schematic profile view of the telescoping weir

Present operation of the telescoping weir is basically very simple. Decant water is periodically monitored by Corps of Engineer personnel and dredge contractor personnel in charge of the discharge lines into the CDF during dredging. During inspection if the decant water appears to be dark then the weir crest is raised until the water begins to clear up. As the dredged material sediment settles out and the surface water starts to clear up then the weir crest is lowered.

ADVANTAGES OF TELESCOPING WEIR

The following are some of the new features exhibited by the telescoping weir:

- The telescoping weir can be equipped with optional remote readout and control capability that enable several weirs to be monitored and adjusted from a remote location through a telephone and computer link.

- The telescoping weir can be equiped with a pressure sensor to lower the weir crest when necessary to lower the pond level to prevent overtopping and subsequent dike failure.

- The telescoping weir can also be equipped with a variety of sensors to measure effluent turbidity, temperature, pH, and Biological Oxygen Demand. In the event that the quality of the discharge effluent is unacceptable the weir crest would automatically rise to control or stopped the discharge.

- The telescoping weir provides for efficient sedimentation and consolidation of the dredged materials, which will enhance the desiccation and drying process in the CDFs. The maximum amount of water from the CDF can be removed by lowering the weir crest to the bottom of the desiccation cracks in the dredged material.

- Removal of water from the deep desiccation cracks also provides some measure of mosquito control. It also eliminates periodic excavation with backhoe or dragline around the weir to lower the surface elevation at the weir.

- More efficient, frequent and friendly use of the telescoping weir will increase the storage capacity and longevity of CDF's thus extending the life of a very valuable and expensive storage facility for dredged material containment.

- The telescoping weir provides an infinite elevation adjustment of the weir crest and discharge velocities thereby providing precise control of the effluent turbidity.

- The telescoping weir reduces labor and cost requirements through the elimination of weir board handling, weir board cost, weir maintenance, and possible weir failure and replacement.

- The telescoping weir is easily adaptable for use in other dewatering applications and water control structures including reservoirs, ponds, water treatment, waste water, mining waste, paper mill lagoons, animal waste lagoons and chemical waste lagoons, and irrigation control.

- The improved safety of the telescoping weir through avoidance of lifting and handling heavy water soaked wooden boards or logs, and exposure to snakes, spiders and wasps that habitat these structures could possibly eliminate conventional weir structures.

- The telescoping weir meets and exceeds the safety requirement normally required of the US Department of Labor Occupational Safety and Health Administration (OSHA).

CRANEY ISLAND CDF

Present experiences operating the telescoping weir by personnel at the Craney Island CDF and the Norfolk District are as follows:

- Three telescoping weirs have been installed at the Craney Island CDF. The first was installed in April 1996, the second was installed in June 1998 and the third was installed in April of 1999 and they are all operating satisfactorily.

- In the past three years the telescoping weirs have been fully operational and have not required any maintenance.

- The first telescoping weir installation and the two existing conventional weir boxes in the middle cell at Craney Island CDF were able to accommodate a record annual placement of six million cubic yards of dredged material. Successful performance of the telescoping weir prevented temporary shutdowns of two large dredging projects.

- The telescoping weir has operated at all elevation levels through out the dredging cycle. Because of the ease of operation the weir has been 100 percent efficient in decanting clear water from the CDF.

- Managers at the Craney Island CDF are very supportive of the installation and operation of the telescoping weirs. Their only complaint is that they could manage the CDF surface water a lot more effectively if they had more telescoping weirs.

- Once the weir foundation is in place the pre-constructed telescoping weir is installed on the foundation in one day. The discharge pipe leading from the weir through the perimeter dike requires additional time.

- The telescoping weir has met all design and performance expectations for decanting surface water from the Craney Island CDF. The debris fence has work well without maintenance.

- The ease of operation and the novelty of the telescoping weir has promoted more interest in management of decant surface water from the Craney Island CDF which is not normally the case when operating the traditional box weirs which require a tremendous amount of manual labor and effort to repositioning the stop logs.

- This new and innovative technology will eventually eliminate conventional weir boxes because they are difficult to operate and are not safe to operate.

- The Norfolk District plans to construct and install additional weirs at the Craney Island CDF and other location in the District and are presently assisting the Mobile District Corps of Engineers installing a telescoping weir.

The telescoping weir patent is a government owned patent and the inventors have no rights as to disposition of licenses to promote and build the weir. The decision to license the patent to potential contractors will be made by the US Army Corps of Engineers Executive Office, Washington, DC in the near future. When this decision is made, it should open the door to industrial uses other than dredging applications.

FUTURE RESEARCH AREAS

The Dredging Operaitons and Environmental Research (DOER) Program supports the U.S.Army Corps of Engineers Operation and Maintenance Navigation Program. Research under this program is designed to balance operational and environmental initiatives to meet complex economic, engineering, and environmental challenges in dredging and disposal activites. Results from these activities will provide technology for cost effective operation, evaluation of risks associated with management alternatives, and environmental compliance.

Continued evaluation and validation of the performance and improvement of the telescoping weir technology will be conducted under the DOER's program. Mr. Norman Francingues and Mr. Steve Pranger, Environmental Laboratory at WES are presently working with the Norfolk District on this innovative technology with the telescoping weirs and other opportunities at the Craney Island CDF. This work is one of six-research focus areas idenitfied by the field office personnel. This focus area will identify and demonstrate emerging dredging and disposal technology used worldwide.

ACKNOWLEDGEMENTS

The telescoping weir was invented and designed by Jack Fowler, Ronald G. Vann and T.D. Woodward. Vann and Woodward were responsible for coordination of WES and Oceaneering contracts, assisting in preparation of plans and specifications, modifications and installation of the prototype telescoping weirs at the Craney Island CDF.

Acknowledgements are made to the Geotechnical Laboratory (GL), Environmental Laboratory (EL) Coastal and Hydraulic Laboratory (C&HL) and The Dredging Operations and Environmental Research Program, Waterways Experiment Station (WES), US Army Engineers and the US Army Engineers, Norfolk District. Acknowledgements are also made to Dr. Mike Palermo, EL, WES, Mr. Braxton Kyser, US Army Engineers, Charleston District, Mr. Pat Langan, US Army Engineers, Mobile District and the late Dr. T.A. Haliburton, Haliburton Associates for their assistance and encouragement in supporting the original concept and need to develop a more effective weir. This concept was originally discussed during informal discussions in the late 70's during the Dredge Material Research Program but nothing was accomplished until the GL,WES and the Norfolk District implemented this technology.

Special acknowledgements go to Mr. Rufus McClodden, Engineering and Construction Services Division, WES, Mr. Bill Hanks, GL, WES and to Mr. Glynn Banks, C&HL, WES for their efforts in preparation and review of the plans and specifications, construction and testing of the quarter scale model of the telescoping weir. Special acknowledgement also go Mr. Bill Rawls, Craney Island CDF manager, Norfolk District, who was responsible for planning, installation and operation of the prototype telescoping weirs at the Craney Island CDF. Special thanks go to Mr. Jim Thomasson and Mr. Tom Friberg, Norfolk District for their support in development of this innovative concept.

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USING A MATERIALS ASSESSMENT PROCESS FOR MANAGING PLACEMENT OF CONTAMINATED DREDGED MATERIALS

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ABSTRACT

The presence of toxic contaminants in many harbors and waterways is changing past disposal practices. The industrial ecology approach of turning wastes into useful products is well suited to dredged material. Clean dredged materials have been used successfully in the past for a wide variety of beneficial uses. The future may well include the use of most contaminated material in some positive fashion as well. The Port of New York and New Jersey has a significant volume of contaminated dredged material to handle since criteria changes and government decisions that eliminated the Port's historic disposal site. Closure of the Mud Dump Site left the Port looking for new disposal alternatives for approximately 75 percent of its material -- material that had previously gone to the ocean. However, instead of seeing the contaminated sediments as a waste to be disposed, a policy decision by Port stakeholders was made to seek a sustainable approach for handling the dredged materials. The Corps of Engineers New York District and the states of New York and New Jersey favor this approach of managing the dredged material. However, public and regulatory concerns about the beneficial use of the sediment. Development of a systematic, accredited engineering approach for assessing contaminated dredged material suitability for specific beneficial uses is the first step in gaining greater acceptance. If the sediment is appropriately characterized, treated, and placed, it can be recycled in a beneficial fashion. An understanding of the relationships of material type, treatment approaches and beneficial use opportunities is essential to achievement of a successful final project.

WATERBORNE TRANSPORTATION

Ports and Waterways

Throughout the ages, waterborne transportation has been a significant contributor to the expansion of civilization. The United States' ports and waterway system, operating since the early 1800s, has played a major role in the growth of the Nation's economy. Today, foreign and domestic waterborne commerce handled by this transportation industry exceeds 2 billion metric tons, generates 13 million jobs and contributes $743 billion to the Nation's GDP or Gross Domestic Product (Maritime Administration, 1998). Waterborne transportation's contribution to economic growth will continue well into next century as predictions for annual world GDP

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growth surpass 3 percent (Behravesh, 1998).

One of the primary requirements for an efficient waterborne transportation system is to preserve safe and secure movement of people and cargo. Without safe and secure mobility, the Nation's transportation system would breakdown, competitiveness would be lost, and economic benefits would be reduced. Ports and waterways must be maintained and periodically improved to keep traffic operating efficiently. This requirement includes removal of silt and sediments to enable unimpeded passage. The U.S. Army Corps of Engineers (USACE) is the Federal agency responsible for accomplishing these activities, as authorized by the U.S. Congress (Palermo and Wilson, 1997). The United States has more than 40,000 kilometers of navigation channels that must be routinely dredged to remove naturally recurring shoals of deposited sediment. Together with the sediments removed to improve ports and navigation channels, approximately 300 million cubic meters are dredged from the Nation's water transportation infrastructure annually (Palermo and Wilson, 1997). If the sediment is allowed to build up in channels and berths, then navigational access for deep-draft vessels is restricted. These undredged shoals compel shipping companies to lighten their loads by transferring cargo at a less efficient port or to lighten cargo onto a barge in mid-harbor to reduce the required draft. Either approach increases the cost of commerce. Currently, these companies are merging operations and building bigger and bigger ships, particularly in the container trade (Rubin et al., 1997). Ports that cannot provide adequate water depth face closure as cargo is diverted.

Dredging and Disposal Activities

The act of dredging involves the excavation and removal of flooded soils or sediments. Dredging to enable navigation to reach ports along coastal margins or in shallow waterways has been conducted for many centuries (Herbich, 1992). The excavated materials are transported away from the project site and disposed. Dredging and disposal activities are typically conducted in a similar fashion worldwide, using conventional mechanical and hydraulic machines and standard open water or confined upland disposal practices. Of the approximately 300 million cubic meters dredged annually in the U.S., about 45 million cubic meters are discharged into the oceans and most of the remainder is discharged into estuarine and freshwater water sites and on land (Palermo and Wilson, 1997).

The presence of toxic contaminants in many harbors and waterways is changing past dredging and disposal practices. As environmental concerns over contaminated sediments grow, the costs associated with new dredging and, more importantly, disposal options are rising precipitously (Fairweather, 1995). Contaminated sediments are a problem because, first, there is potential release of contaminants during the dredging process when sediments are suspended. Mobilized contaminants can be biologically available for uptake, accumulation in edible aquatic species, and impact human health (Demars et al., 1995). Second, after these dredged materials are excavated, they must be placed in an acceptable location that will isolate the sediments and their associated contaminants from causing future human health or ecosystem impairment. Typically this requires the construction and operation of a confined disposal facility, either aquatic or on land. These facilities are expensive to use (Curran et al., 1998). Their cost is frequently many times more than traditional open water options, which average only several to twenty dollars per cubic meter (AAPA, 1998).

The estimates of the size of the contaminated sediment problem for the nation vary depending on the source of the estimate. The Corps of Engineers have estimated approximately 5 to 10 percent of the country's dredged sediments are contaminated (Palermo and Wilson, 1997). The US Environmental Protection Agency (1997a) has completed a national sediment assessment that concludes that the problem is larger with adverse effects from contaminated sediments being "highly probable" at 26% of 21,000 sites inventoried nationwide. Another estimate from the National Research Council's Marine Board (1989) has stated that sediment contamination is widespread throughout the country with potentially far reaching environmental and public health significance. Of dredged sediments, the Marine Board (1985) considers maintenance materials to be potentially the most environmentally threatening because they typically are composed almost exclusively of fine-grained sediments. It is this size fraction that contains the greatest percentage of contaminants (Demars et al., 1995; Stamatios et al., 1996). Further, this size fraction accounts for the largest percentage of sediments found deposited at berths and between finger piers in river ports.

Port of New York and New Jersey

The Port of New York and New Jersey is the third largest port in the United States in cargo value. It is the largest port on the East Coast and has been described as the economic engine of the New York/New Jersey metropolitan area. New York City's passenger ship terminal, the Brooklyn and Staten Island marine terminals, and the container and liquid product terminals in New Jersey provide a gateway for manufactured and raw materials for use and consumption by 17 million citizens within the region. Additionally, within two days of the Port, more than 90 million people in the mid-Atlantic and Midwest sections of the United States as well as eastern provinces of Canada benefit from this intersection of ships, train and truck delivery networks.

The New York harbor (Figure 1) is situated in a shallow estuary, typically less than 6 meters deep. The annual sediment inflow is quite heavy from the Hudson, Hackensack, Passaic and Raritan Rivers. Because of its naturally shallow depth and high sediment load, the harbor has been artificially deepened to allow for navigation. As shown on the following map depicting the Federal channels, there are 45 federally authorized channels in the Port of New York and New Jersey that provide 386 kilometers of access to the harbor's terminals and berths (USACE, 1998). The suspended silt deposits in these deepened channels and berthing areas of the harbor. In order to sustain commercial shipping, the federal and local governments and terminal operators must dredge to maintain adequate channels and berth depths. Maintenance of these navigation channels is the responsibility of the federal government. The Corps of Engineers dredges approximately 3.2 million cubic meters each year to clear its channels. Dredging at terminals to

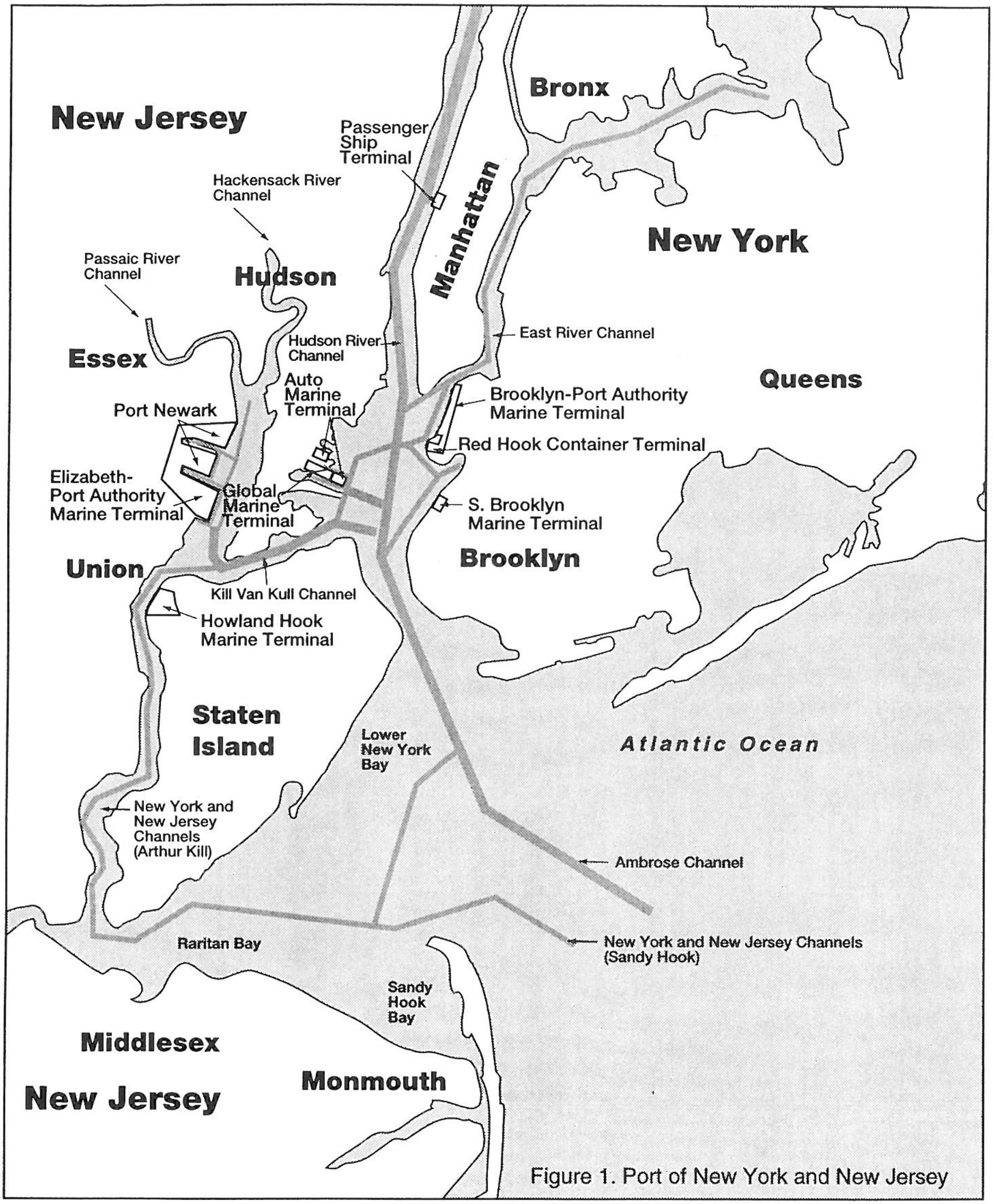

Figure 1. Port of New York and New Jersey

maintain adequate water depth in berths is the responsibility of the owner or tenant. These maintenance activities generate another 1.9 million cubic meters. The requirement for routine dredging is complicated by trends in the maritime industry, most notably the increasing size of ships. Changing ship designs to mega carriers demand that ports provide deeper water to stay competitive (USDOT, 1998). Currently, the Port's interior channel depths are about 12.2 m., but future container ships will require underkeel clearances of approximately 15.5 meters. This new deepening is estimated to create an additional disposal requirement of more than 10 million cubic meters (USACE, 1998).

Since 1914, the Port of New York and New Jersey has depended almost exclusively on a single disposal site for placement of its dredged material (USACE, 1988). This site, the Mud Dump Site, is situated approximately 10 kilometers off of the New Jersey Coast. Since the late 1970s, sediment testing has been utilized to determine the acceptability of dredged material for ocean disposal. In 1992, the US Environmental Protection Agency and the Corps of Engineers implemented new testing procedures. The 1992 sediment testing protocols were more restrictive than the earlier protocols. Consequently, the percent of dredged material deemed unsuitable for ocean placement has increased significantly from minor amounts to about 75 percent (USACE, 1998).

The Mud Dump disposal site was closed in September 1997, and a new kind of site was opened -- the Historic Area Remediation Site (HARS). The action, taken by the Federal government, was prompted by the site's increasingly limited capacity and public concerns that the dredged sediments discharged there may be causing contamination of fish (USEPA, 1997b). Approximately 41 square kilometers of contaminated sediments from earlier disposal operations are exposed at the HARS. These sediments were examined, using the 1992 protocols, and were found unacceptable for ocean disposal because of their toxicity and/or bioaccumulation characteristics. When the HARS was opened, it was agreed that the contaminated sediments at the historic site would be remediated by capping. Future discharges will be limited to the placement of clean material determined to be suitable for remediating the site.

Disposal Options

Because of the closure of the Mud Dump Site, the Port must find new disposal alternatives for the 75 percent of material deemed unsuitable for HARS remediation cover each year. This annual volume is approximately 3 million cubic meters of fine-grained materials (USACE, 1998). There are a several alternatives that could potentially meet the Port's disposal requirements, including disposal alternatives, beneficial use applications and decontamination technologies (Wakeman et al., 1997). With respect to traditional disposal alternatives, they generally utilize a containment strategy, either in the water or on land. Possible options for material containment include:

- **Subaqueous Pit.** Dredged material can be contained in underwater depressions that remain after sand and gravel are mined or are specifically constructed to hold contaminated sediment. The dredged sediments would be placed in the pits and covered with a layer of clean sand, thus isolating the contaminated dredged material from the surrounding marine environment. The Port Authority and the State of New Jersey have constructed a subaqueous pit in Newark Bay (Wakeman, et al., 1996). The pit is designed to contain and isolate about 1.5 million cubic meters of contaminated dredged material.

- **Confined Disposal Facilities** (CDF). Dredged material can be deposited within a large diked area constructed adjacent to land, in protected waters or harbors, or even in open waters (Richardson et al., 1995). One important aspect of CDF planning and design is the determination of the site's ultimate end use, such as open-space, habitat, recreational area or for development. One type of CDF used along the East Coast is the containment island. There is a containment island near Norfolk (Craney Island) and two others near Baltimore (Hart-Miller Island and Poplar Island). There are numerous nearshore CDFs along the shores of the Great Lakes.

- **Upland Disposal.** Dredged material also can be deposited within a confined area constructed on the surface of the land. Historically upland sites have been built along rivers, where the dredged material was pumped behind levees. This option can be particularly expensive option due to the cost of land, transportation, construction of the containment area, dewatering and ongoing site maintenance. There is very little open land in the metropolitan region any longer for upland disposal activities because there are more profitable commercial or residential uses for property.

SUSTAINABLE DISPOSAL

Industrial Ecology Approach

The 1990s brought forth the call for "sustainability" in economic development. This initiative was most clearly voiced at the United Nation's Conference on Environment and Development held in Rio de Janeiro in 1992, which examined mankind's interaction with the environment. Since that time there have been numerous activities to assist planners and engineers to reconcile future economic development with its environmental influences. One of these approaches is the discipline of Industrial Ecology.

The conceptual basis of industrial ecology focuses on a systems approach to measuring interactions between the economic world and the physical environment (Allenby and Richards, 1994). When properly balanced, an economic system is tuned to act in harmony with the surrounding ecological system. Manufacturing operations, product consumption and waste utilization are configured to optimize their total material and energy cycles (Raymond, 1997). Materials and energy are tracked quantitatively in time and space in order to measure changes.

In essence, industrial operations are designed to mirror natural ecosystems with every output becoming input for some other use (Graedel and Allenby, 1995).

In industrial ecology, there are no wastes. Allen and Behmanesh (1994) advocate that post-consumer waste, industrial scrap, unwanted by-products from manufacturing operations and construction residues should not be considered as wastes to be disposed but as resources to be recycled and utilized. In a closed system, such as planet Earth, this approach is not only reasonable but also is essential if humans desire not to ultimately poison themselves. Unfortunately, many areas in the world have already been contaminated. For example, population and economic expansion have impacted the Hudson-Raritan watershed for three centuries (Tarr and Ayres, 1993). This activity caused significant degradation of the estuarine environment with massive discharges of heavy metals, pesticides, PCBs and chemicals of concern. Although the water in the harbor complex is cleaner than it has been in six decades (O'Shea and Brosnan, 1997), the sediments act as a reservoir of toxic chemicals that contaminate fishery resources and negatively affect benthic community structure (Adams et al., 1998). The sediment contaminant levels are declining as the largest generators of wastes appear to be regulated (Ayres and Rod, 1986), but contamination of new sediments entering the Hudson-Raritan estuary continues to present problems to the ecosystem and to maritime interests. In fact, the problem of handling of contaminated dredged sediments from navigation channels has threatened to close the harbor (Rubin et al., 1997) because the public's concern with the material's disposal.

Beyond descriptions of material cycles, industrial ecology subscribes to the tenant that there is a positive alternative use for every "waste" if the proper niche is identified. The contaminated sediments in the harbor flowed initially from the land as weathered soil and rock. Earlier they were treated as waste materials that were best handled by being dumped into the Atlantic ocean. However, if this sediment is appropriately characterized, treated, and placed, it can be recycled back to the land for use in a beneficial fashion (Wakeman, 1998a). This approach of managing the dredged material to turn it into a resource and to use it beneficially is favored by the Corps of Engineers and the states of New York and New Jersey (USACE, 1999).

Beneficial Use Approaches

Beneficial use of dredged material has been carried out in the United States and Europe for many years (USACE, 1986; PIANC, 1992). There are more than 1300 projects identified in the US Army Corps of Engineers manual on the subject (USACE, 1986). Broadly, these projects can be categorized into six classifications: habitat, recreational, beach nourishment, residential/ commercial, industrial, landfill cover and reclamation projects. The first four categories generally require clean materials because of the potential for toxic or bioaccumulative impacts from contaminants. Construction uses at industrial sites, landfills and reclamation sites can allow higher levels of contamination because there is a lower likelihood of environmental or human exposure.

- **Habitat Development**. Habitat development refers to the establishment and management of relatively permanent and biologically productive plant and animal habitats (Landin et al., 1998). In general, there are four types of habitat that can be developed with dredged material: submerged habitat for seagrasses and fisheries; wetland, or marsh habitats for any community of plants that tolerate periodic or permanent inundation; upland habitat, which includes a very broad variety of terrestrial communities; and island habitat is upland and/or wetland habitats distinguished by their isolation and particular use including nesting sites. A special category of plant and animal habitat is agriculture. Fresh water sediments can have many applications on a farm. If the dredged material has a salt content, then it either must be washed or used with a salt tolerant crop.

- **Recreational**. The nature of recreation and park sites, with requirements of substantial open space and light-weight structures, is especially suited to the weak foundation conditions associated with fine-grained dredged material. If organic fiber is added, the material can be used as topsoil. Recreational use and wildlife and fish habitat can be developed simultaneously on the same site when properly designed to provide wildlife isolation from disruption.

- **Beach Nourishment.** Placement of dredged sand on a beach provides a desirable, cost effective, shore protection and beach restoration opportunity (USACE, 1986). To the greatest extent, the selected dredged material should closely match the sediment composition of the eroding beach to achieve the greatest degree of retention.

- **Residential/Commercial.** Land creation and land fills for homes and business using dredged material have been constructed worldwide (PIANC, 1992). LaGuardia, Washington D.C.'s Ronald Regan, Portland International, San Francisco International, San Diego, Hong Kong, and numerous other airports have dredged material bases (Landin et al., 1998). In the cities of Oakland (and across the San Francisco Bay in San Mateo), Galveston, and Portland, hundreds of homes have foundations poured in sediments pumped from their harbors.

- **Industrial and Construction Use**. Fill for heavy industry, including most major harbor and port facilities, have been employed in many regions of the world for decades. Dredged material can be used to build or repair dikes and levees for erosion control and flood protection. Coarse and fine dredged material can be used in the construction of coastal structures or create offshore berms (PIANC, 1992). Dewatered dredged material from confined disposal facilities or following processing can be used as fill material for building, road and parking lot foundations (Wakeman, 1998b). Eroded land can be replaced, or low-lying can be improved to prevent flooding (PIANC, 1992).

- **Solid Waste Landfill Cover**. Another use for dewatered dredged material is in sanitary landfilling operations. Material from the Ports of Oakland and San Francisco has been used at the Redwood Sanitary Landfill for daily cover. Dredged material has been used for grading, liners, gas vents, leachate drains, and gas barriers at other locations. The primary constraint on use of dredged material for landfill cover or grade in the New York-New Jersey region is the lack of adequate space for the necessary dewatering and drying (USACE, 1989). Consolidated clay from New York Bay could be used for capping Fresh Kills, Penn and Fountain Landfills, which have a requirement of approximately 2 million cubic meters (Rosenfarb and Goldberg, 1998).

- **Reclamation.** It is estimated that there are up to 450,000 abandoned brownfields in the United States (Hanley, 1995). These sites are major obstacles to the redevelopment of the nation's urban areas. Brownfield reclamation using dredged material has been proposed for the area of the Great Lakes (Petrovski et al., 1998) and the New York-New Jersey region (Morgan, 1995). Several reclamation projects are underway in New Jersey (Wakeman, 1998b). Dredged material also has been used to reclaim abandoned strip mines in Pennsylvania (Scheetz and Schantz, 1998).

Decontamination

The removal of contaminants from sediments is not strictly a disposal option; but in some cases, regulatory agencies may require treatment to decontaminate materials before disposal or beneficial use occurs (Armitage and Farris, 1998). Most decontamination methods are still in the developmental stage -- limited to "pilot-scale" operations -- and facilities are not available to economically treat even a small portion of the annual disposal requirement. When production facilities are operational, there will still be a need to identify locations to dispose or place the decontaminated materials as well as a disposal site for any generated residues or by-products.

Traditional approaches of disposal or decontamination for contaminated sediments do not meet the industrial ecology goal of materials recycling. In fact, spending money to clean-up sediments without systematically determining a productive end use for processed material is itself wasteful. The Europeans have known for years that dredged material can have significant value if properly applied in a beneficial manner (PIANC, 1992). Developing the right engineering, economic, environmental and political conditions is needed for even a greater percentage of contaminated dredged material to be used beneficially in the future.

CONTAMINATED SEDIMENT RECYCLING

Materials Assessment Process

Development of a systematic, accredited engineering approach for assessing contaminated dredged material suitability for specific beneficial uses is the first step in gaining greater acceptance. ASTM (1997) has been developing a standard guide for planning, design, restoration, creation and enhancement of wetland systems. A similar ASTM protocol could be developed for using clean and contaminated dredged material for this and other beneficial uses. Having an accredited methodology for decision making would not only create uniformity in engineering practice but also could significantly reduce public apprehension.

The level of sediment contamination would be a critical consideration in any assessment process. To implement sediment recycling for beneficial uses, the contaminated sediment typically must be characterized and treated in some manner in order to render it suitable for a specific end use. Not all treatment technologies decontaminate the sediments; some result in a product where the contaminants are immobilized but not removed or destroyed. Heavily contaminated dredged material will probably have to be fully decontaminated to remove the harmful constituents prior to most uses (Marine Board, 1997). In these cases, securing an appropriate disposal alternative may be the only cost effective approach.

In the past, beneficial use applications have been generally limited to opportunities where the material was clean and the cost differential between the beneficial use option and the traditional disposal alternative was negligible (Landin et al., 1998). When this cost was restricted to several dollars per cubic meter, consideration of more exotic methods to use sediments, whether contaminated or not, were not discussed. Today's concerns over contamination and the growing volume of contaminated material that must be dredged have changed that thinking. The challenge is to turn this situation into an opportunity to develop an array of resources (products) for industrial or other beneficial applications.

A material assessment decision making process could be broken into three assessment categories: characterization of properties; selection of end use options; and evaluation of treatment methodologies (Figure 2). This assessment process can be initiated either from the dredger's perspective or from the landholder's perspective. In the first case, the raw dredged material must be characterized to determine its properties and potential uses. In the second case, the desired end use for the placement site must be specified by the landholder, which will drive the design (engineering and regulatory) requirements for the type of dredged material needed. When the dredged material source is known and the end use has been determined, the potential treatment methodologies can be explored. Each potential treatment methodology must be evaluated with respect to its ability to meet the design requirements, cost feasibility and public acceptance (Jones et al., 1998). The final use whether habitat, recreational, residential, commercial, or industrial, may have engineering and environmental requirements that are design-driven by the selected end use. Public acceptance depends on credible demonstrations that the resultant product is environmentally acceptable and presents no unacceptable human health or ecosystem risk.

Classification of Properties

Raw sediment should first be characterized to determine the optimum processing scheme or

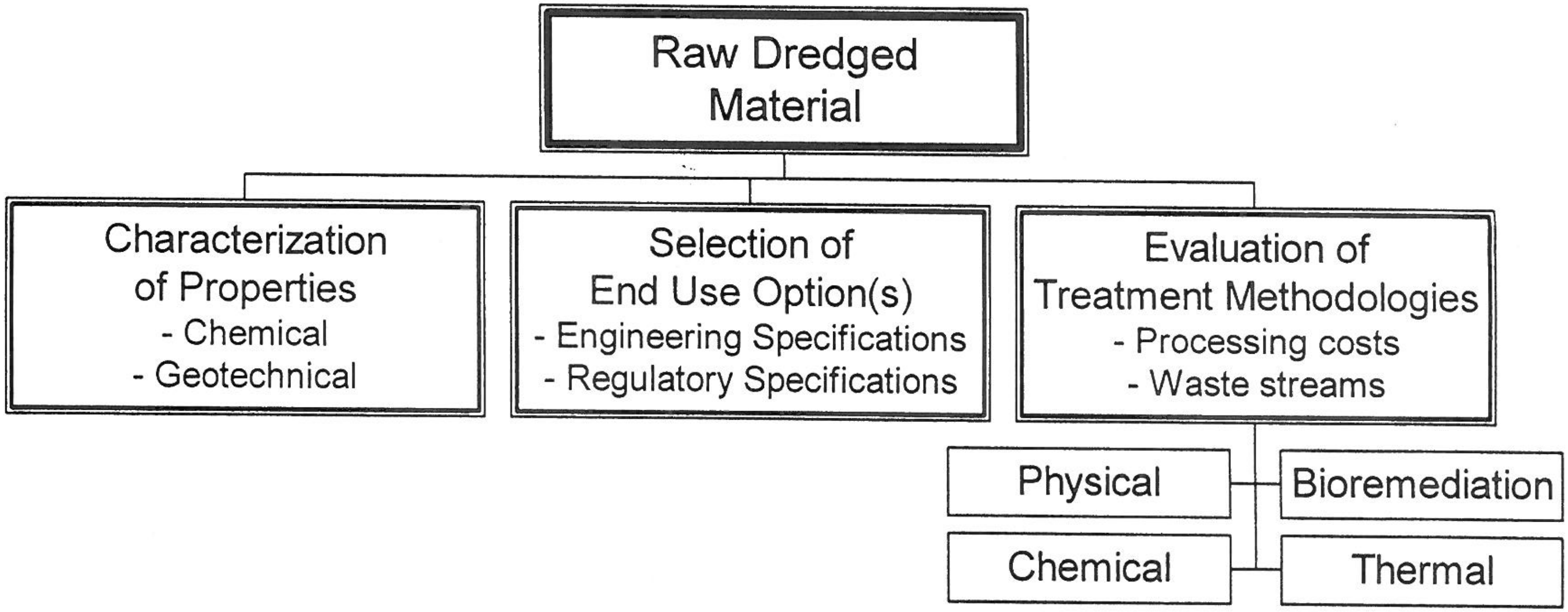

Figure 2. Sediment Assessment Categories for Potential Beneficial Use Applications

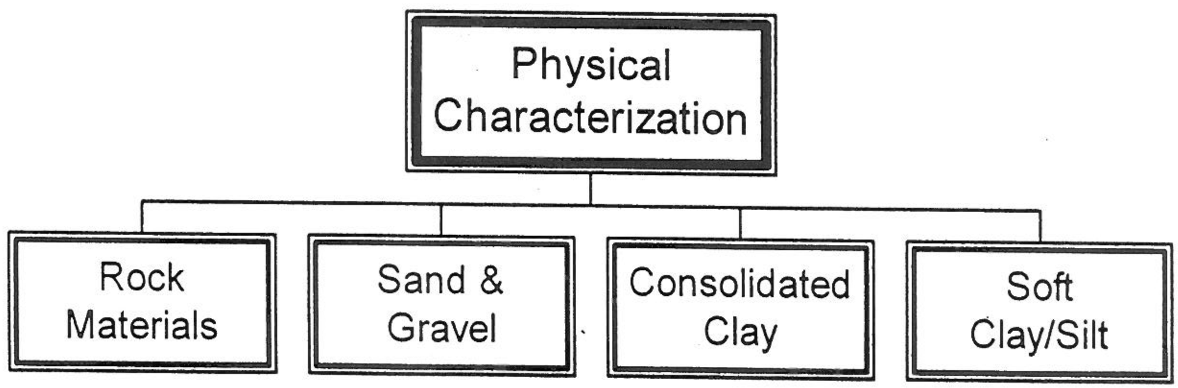

Figure 3. Characterization of Sediment Properties & Categorization (After PIANC, 1984)

treatment alternative to achieve the design requirements for the selected end use. The dredged material should be physically and chemically characterized using an overall screening strategy (Amdur and Boudreau, 1998; Winfield and Lee, 1999). Jones et al. (1997) suggest measurements be made to define major element composition, mineral content, salt content, moisture content, plasticity indices, and grain size distribution. Jones et al. (1997) also state that it is imperative to know the concentrations of organic carbon, sulfides, ammonia, hydrocarbons, organic compounds, and metals prior to choosing a processing technology. Winfield and Lee (1999) have compiled an extensive list of sources for various physical and engineering properties and characterization test methodologies to use in evaluating sediments.

Physical characterization should first be used to classify the dredged material with respect to gradation. PIANC (1984) developed a classification scheme for various types of dredged materials including rocks, boulders/cobbles, gravel, sands, silts, consolidated and soft clays and organic peat material. For the types of dredged materials from New York harbor, this list (Figure 3) can be shortened to rock, sands/gravel, consolidated clays, and soft clay/silts. For most berth areas and interior channels, the majority of dredged materials have a range spread around a particle size distribution reflecting a D50 of 0.03mm (Dunlop, 1996). About 90 percent of the solids by weight will be fine-grained with the remaining consisting of particles larger than 0.2 mm. Approximately 1 percent of the solid particles is considered to be larger than 2 mm.

Beneficial Use Opportunities

Contaminated dredged material can be used as it is (following drying), as a blended mixture, or as a manufactured product in an advantageous fashion. Examples include landfill daily cover, grading materials, processed engineered fill, and aggregate or other construction materials. This approach is an expense alternative to open water dumping at aquatic disposal sites, but the environmental consequences can be managed and even avoided. A key reason to select beneficial uses is that, when dredged material is used beneficially, there is a positive outcome that may include revenue from sale of the product or future fees for land use. (In addition, the dredged material is typically removed from the harbor such that there is no chance of having to redredge the same material, which is possible with some aquatic disposal options.) Using a process flow chart for the project is helpful in assessing the merits and deficiencies of each strategy.

The types of potential beneficial uses are primarily determined by the materials' characteristics. PIANC (1992) broke potential uses into three categories: engineered uses, agricultural uses, and environmental enhancements. Cross-correlating the four material classifications presented earlier with the PIANC beneficial use categories gives a method for assigning different materials to several appropriate end uses. Rock characteristics (Figure 4) such as hardness, influence its size and shape when dredged. Depending on the intended use, the material may need sorting and larger pieces may need to be crushed into smaller ones. Larger pieces, on the other hand, make excellent fishing reefs and good for shore protection structures. Gravels and sand (Figure 5) are

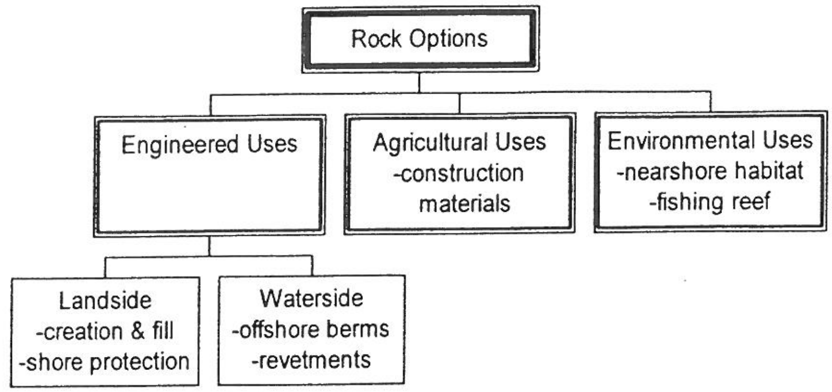

Figure 4. Beneficial Use Options: Rock Material Potential Applications (After PIANC, 1984)

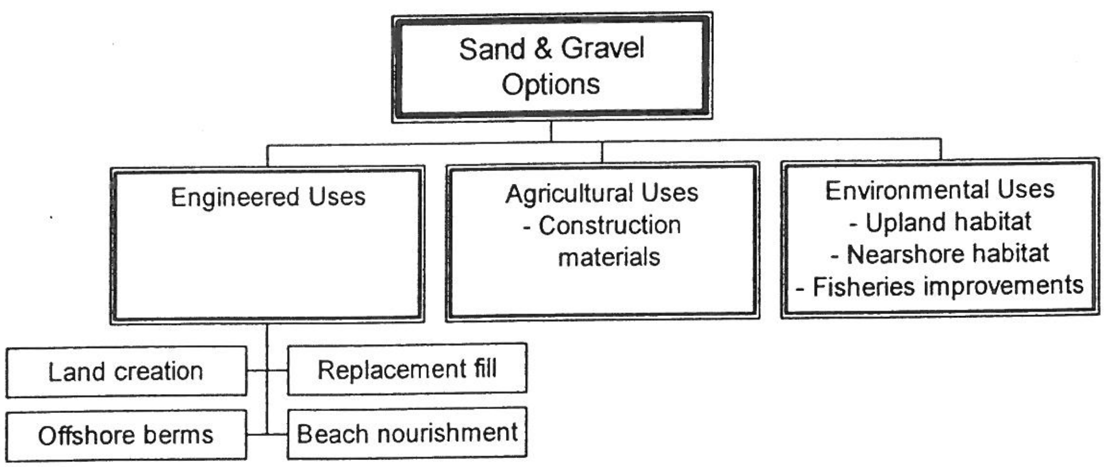

Figure 5. Beneficial Use Options: Sand & Gravel Potential Applications (After PIANC, 1984)

extremely valuable for construction in the metropolitan region. Sand is mined in the Bight for commercial sale. Gravel and sand are excellent for beach nourishment and replacement fills without processing. Gravels are particularly useful as nearshore habitat for fisheries. Consolidated clay (Figure 6) is typically excavated during navigation improvement or deepening projects and is generally free from pollution. The material may emerge from excavation as homogeneous mixture clay and water if a suction dredge is used or as lumps if a mechanical dredge clamshells the material. In either case, the material will require some processing and handling in order to meet construction requirements. Nevertheless, consolidated clay can be excellent material for the core of dikes, landfill closure, used in land improvements or for habitat creation.

Soft clay/silt (Figure 7) are typically the most difficult dredged materials to use beneficially. But even these sediments are being applied to multiple beneficial uses. For example, a project is underway in Elizabeth, New Jersey, to construct a shopping mall on a former municipal landfill or "brownfield" by using soft clay/silt material to create an engineered fill (Morgan, 1994; Wakeman, 1998b). The dredged material was stabilized with cement kiln dust prior to compaction. There was approximately 0.76 million cubic meters of capacity available for contaminated material at the site at a placement cost of $73 per cubic meter ($56 per cubic yard). New Jersey has permitted another brownfield application in South Kearney and the closure of a landfill in Bayonne. Price for material placement at these new locations is about 20 percent less than the first site at Elizabeth. Upon completion of processed dredged material placement, the South Kearney site will be used for warehousing, and the Bayonne site will be a golf course. Soft clays have also been successfully used in wetlands creation projects at numerous sites (Landin, 1998).

One of the most intriguing projects for beneficial use of soft clays/silt material is the creation of a grout for abandoned mine reclamation (Scheetz and Schantz, 1998). Coal mining began in Pennsylvania in the mid-1700s in support of the colonial iron industry (Dolence and Giovannitti, 1998) and continues through today supplying fuel for electric power generation. The mining has left numerous scars on the Pennsylvania landscape. The two major problems associated with abandoned coal mines are: fall hazards created by the exposed highwalls from strip mines and the formation of acid mine drainage caused by the reaction of iron pyrite with water. Dolence and Giovannitti (1998) estimate that there are over 100,000 hectares of abandoned surface mines with dangerous highwalls and water filled pits, and about 3,800 kilometers of streams that do not meet water quality standards because of drainage from abandoned mines. The estimated cost to reclaim these sites is over $15 billion.

Pennsylvania is investigating whether dredged material from east coast harbors and rivers can provide needed fill material for reclaiming abandoned surface and underground mines. It can be used in surface mines to help restore the land to original contour (Scheetz and Schantz, 1998). Dredged material is mixed with a cement-like material or fly ash and placed into underground mines to stabilize the surface and prevent subsidence. Pennsylvania's Department of

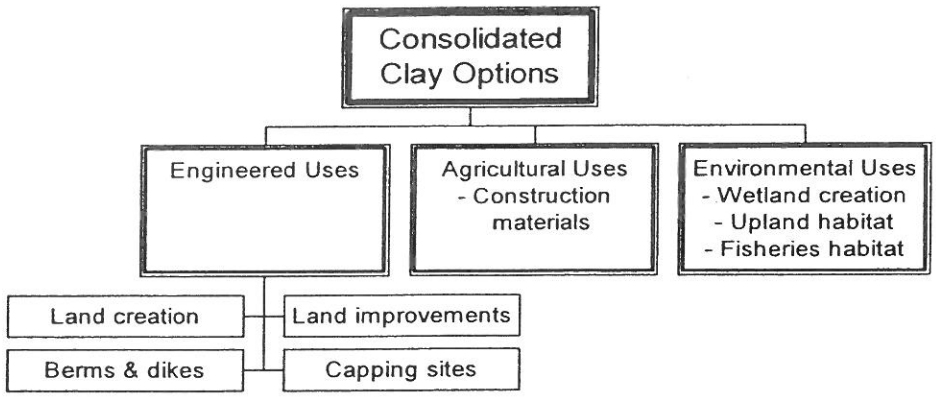

Figure 6. Beneficial Use Options: Consolidated Clay Potential Applications (After PIANC, 1984)

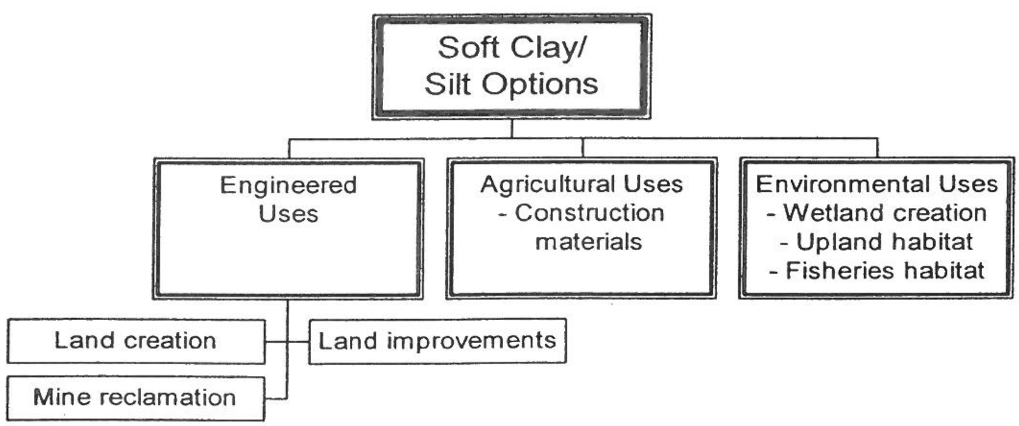

Figure 7. Beneficial Use Options: Soft Clay/Silt Potential Applications (After PIANC, 1984)

Environmental Protection (DEP) is conducting a pilot project at its Bark Camp Mine Reclamation Laboratory to determine the feasibility of using dredged material. The site is permitted for a demonstration project with approximately 400,000 cubic meters. The first dredged material placement project, with about 15,000 cubic meters of mud, was completed in August of this year. DEP is currently conducting its investigations, and the results look promising (Consolidated Technologies Inc., 1998). The recycling of dredged material out of the harbor back into the mountains of Pennsylvania is an outstanding application of industrial ecology principles.

Treatment Methodologies

The final step in the materials assessment process is the selection of a treatment methodology. Contaminated sediments can be treated and remediated in several ways depending on the beneficial use application desired. Treatment approaches include physical processing, bioremediation, chemical treatments, and thermal treatments. All approaches share various initial characterization measurements to aid in selecting the best treatment alternative for the final end use. There may be several pretreatment steps required before the sediment can be amended (Mahannah et al., 1998). For example, raking or screening must remove debris (including piling, tires, cable, buckets, etc.). These materials are typically placed in landfills. Other pretreatments that may be needed before the material can be processed including dewatering or washing. Dewatering is particularly important in the cases of chemical and thermal options.

- **Physical Processing.** The primary materials handling technology applied to dredged material is physical sorting. This process can be used with washing to extract size fractions that have commercial value for construction. Sorting methods separate the gravel and sands from the fine-grained materials, which general also removes most of the contaminants as mentioned earlier. The fines are then handled as a waste stream to be placed in a landfill or treated in a subsequent process for other beneficial use. This approach suggests the utilization of a treatment train including pre and post-processing of the material to use all size fractions (Mahannah et al., 1998).

- **Bioremediation.** This methodology uses microorganisms to metabolize or breakdown the organic chemicals of concern. If the sediment is highly contaminated with heavy metals, its toxicity may be too great for this approach. The organisms may be natural or engineered and may be introduced *in situ* or inoculated into a reactor. Both aerobic and anaerobic degradation pathways are possible. The simplest form of bioremediation is land farming. In this approach, the sediment is spread on land and seeded with the microbes. Typically fertilizer is added to increase the available carbon and mixture must be "worked" to achieve a satisfactory level of digestion. Although the technique is inexpensive compared to other treatment approaches, it has the disadvantage of being a batch process that is limited by the area of land available for processing. The end product is a manufactured soil, which is used as top or potting soil (Stern et al., 1998).

- **Chemical Techniques.** This methodology involves chemically modifying the sediment to extract or isolate the contaminants. Solvent extraction treatment targets certain contaminants for removal (DiGasbarro et al., 1998). It has the advantage of being a continuous process and reuse of the solvent is possible. However, it creates a secondary waste stream. The use of soluble silicates can result in isolation of contamination in a granular silicate matrix. This technique results in a change in sediment grain size and is particularly appropriate for isolating metals. The process has certain advantages including the fact that it is continuous and can treat large volumes of material. In addition, the process has been studied for years at land based hazardous waste sites. Because of the mixing requirements and the additional cost of reagents and admixtures, this approach is fairly expensive.

- **Solidification/Stabilization.** These techniques are a special case of chemical treatment (USEPA, 1989). It is not a decontamination technique, but it generates a product that has multiple uses and is environmentally acceptable. Typically the dredged material is dewatered and is mixed with a reagent. The reagent can be Portland cement, fly ash, bottom ash, or cement kiln dust depending on the dredged material's characteristics and the intended end use for the product. A total additive concentration of 5 to 25 percent by weight is typical, although approximately 5 to 10 percent are preferred because of costs. The processing and curing process take approximately 48 hours. The pozzolanic reaction completes the dewatering process and immobilizes the metal and organic contaminants in the sediment. One disadvantage of this option is that the resulting volume of product is increased, which will generally add to the handling and transportation costs.

- **Thermal Treatments.** This option is perhaps the most effective means to deal with persistent sediment associated contaminants such as organic compounds, PCBs and volatile metals (Hall et al., 1998). The technology offers substantial reductions in volume. The sediments can be vitrified to create glass products. However, the approach is energy intensive, hence expensive, and creates a hazardous residue with non-volatile contaminants in a more mobile form.

Metrics

The quantification of mass flows and measurement of process shifts -- desirably improvements -- in energy use and material handling processes is another important aspect of industrial ecology (Allenby and Richards, 1994). Measurements can be instructive in ascertaining the utility of different strategies or activities to prevent pollution, reduce waste, and encourage efficient resource use (Wernick and Ausubel, 1995). Comparisons of measurements over time can provide engineers guidance as to whether process shifts are constructive or damaging to the overall operation.

The application and quantification of a materials assessment approach to beneficial uses of dredged material should apply standardized metrics to aid in its development. The maximum benefit would be gained if the entire dredging process and sediment treatment process were analyzed as a system. Proposed categories for the dredging and placement process include three metrics: dredging efficiency, material processing, and product placement. These factors and the sub-categories should be repeatedly measured and reported to allow data comparisons as methodologies are developed for using contaminated dredged material. Quantification is necessary to maximize performance, minimize costs, and secure project benefits.

A proposed framework for analyzing the performance of the entire process is presented at Table 1. The specific metrics utilized on a dredging project may require modification from the proposed measurements. New processes for contaminated are sure to be developed, and new parameters may be useful to gain the optimum process characterization.

CONCLUSION

The industrial ecology approach of turning wastes into useful products is well suited to dredged material. Clean dredged materials have been used successfully in the past for a wide variety of beneficial uses. The future may well include the use of most contaminated material in some positive fashion as well. The proposed sediment assessment process can assist in determining potential beneficial use applications of dredged material. The assessment depends on characterization of the dredged materials properties and identification of a desired end use for the placement site. The process is flexible to allow modifications and enhancements as new technologies and methodologies evolve. In addition, it offers development of multiple uses at diversified costs depending on the design parameters and regulatory requirements.

The Port of New York and New Jersey cannot depend on any one dredged material handling option as was done in the past. In the future, an array of short and long term options, including traditional disposal activities, material recycling for beneficial uses and decontamination strategies, must be available to Port users. This multifaceted approach is crucial -- not only for the Port to avoid a similar situation in the future (i.e., where the only disposal site is lost) but also to seek market forces as a means to drive the cost of dredged material disposal and recycling projects down. Beyond developing an array of environmentally acceptable and economically sound options, the New York-New Jersey region must simultaneously work to eliminate further pollution of sediments from discharges and land sources. It must work with others outside the traditional port community to advance clean-up activities of harbor sediment. Using this multiple objective strategy will enable the Port of New York and New Jersey to overcome its current navigation and dredging challenges and successfully move into the 21st century.

Table 1. Metrics for Processed Dredged Material Placement

Metric	Dimensions	Formula	Envir. Significance
Dredging Efficiency			
Overdredging	Percentage	Excess volume removed/ Total volume excavated	Benthic organism loss & water column impacts
Excess water content	Percentage	Scow water content/ in situ water content	Excavation efficiency
Dredged material loss	Percentage	Weight suspended solid/ Weight ambient solids	Turbidity, water column impacts & burial
Nutrients, organic conc. & heavy metals loadings	Percentage	Concentration desorbed/ Conc. In ambient waters	Media contamination & Stimulate eutrophication
Material Processing			
Debris generation	Dimensionless	Weight of solid wastes/ Total weight of material	Solid waste generation & materials accounting
Reagent virginity	Dimensionless	Weight virgin materials/ Total materials added	Materials efficiency & recycling of ash wastes
Mixing efficiency	Percentage	Volume reagent added/ Total vol. processed	Materials monitoring & accounting
Product Placement			
Site recovery rate	Percentage	Spread on brown sites/ Total placement area	Recovery of sites with recycled materials & sediments
Dissipation index	Percentage	Volume lost to envir./ Total material produced	Dissipation of sediment into air & water media
Process efficiency	Dimensionless	Volume product output/Total sediment removed	Materials efficiency & beneficial sediment use

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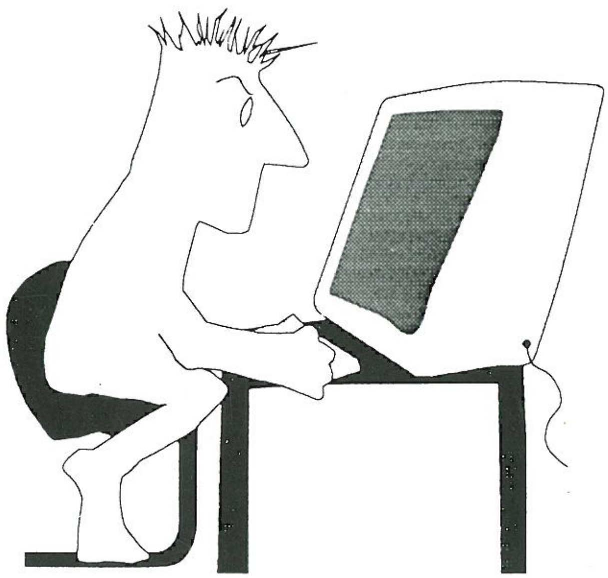

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