The Processing and Beneficial Use of Fine-Grained Dredged Material

A Manual for Engineers



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Chapter 1: Introduction

Overview

Sediment is the product of erosion (wind or water) that has disaggregated soil into its components of sand, silt, clay, and organic matter, and carried that material into a waterbody whereupon the particles settle out on the bottom. Sediment is found in every body of water, and can be comprised of one or more of the various particle classes–from fine silts and clays to coarse gravel—in an infinite variety of combinations. The amount of sediment deposited in a waterbody varies depending on local weather conditions, hydrology, and land use. Global estimates of sediment loading to the ocean vary widely, but are on the order of 5 to 15 billion tons per year (Owens, 2008).

Dredging is the act of removing sediments from a waterway, almost always from an authorized navigation channel, berthing area, or marina. Dredged material is the accepted technical term for any and all sediment, water, and debris removed during the process of dredging. Dredging is a necessary component of sound economic management of our maritime infrastructure and can also be an environmental necessity in those locations impacted by highly contaminated sediment. This needed bifurcation often results in confusion regarding the purpose of dredging. For most dredging professionals, and throughout this manual, we refer to navigational dredging projects as either new work dredging (for projects creating new channels or deepening old ones) or maintenance dredging (for projects removing sediment that has deposited into an existing channel). On the other hand, those projects undertaken for environmental purposes will be referred to as remedial dredging. Regardless of the reason for dredging, once sediments have been dredged from a waterway, dredged material must be beneficially used or otherwise properly managed to ensure the sustainability of the marine transportation system and to minimize potential adverse impacts to the environment and public health.

It is the policy of the State of New Jersey that dredged material is considered a natural resource, and that acceptable beneficial uses of dredged material are encouraged and given priority over other dredged material management/disposal alternatives. This policy is the result of more than two decades of experience with research, development, and implementation of new dredged material management techniques brought on by the convergence of both the need to maintain an extensive maritime transportation system and a history of environmental contamination.

Purpose and Intent

To ensure the basis for these policies is remembered, and to provide a ready reference for engineers and planners who contemplate—or are otherwise required—to beneficially use dredged material, the state has undertaken the creation of this beneficial use manual. The manual will have three volumes, the first of which addresses the manufacture and use of processed dredged material (PDM). Because much of the experience with PDM in New Jersey has come from the New York/New Jersey Harbor region, we have focused our discussion on this location. Other volumes regarding beneficial use of material stored in confined disposal facilities (CDFs) and beneficial use for habitat restoration will come later. It is hoped this volume will dissipate some of the mystery about the nature and technical feasibility of beneficially using PDM. This document has been cooperatively developed by the New Jersey Departments of Transportation (NJDOT) and Environmental Protection (NJDEP), academia, and the private dredging industry.

This engineering manual is not a regulatory document; rather, it is intended to be used in conjunction with the latest edition of the NJDEP regulatory technical manual, The Management and Regulation of Dredging Activities and Dredged Material in New Jersey's Tidal Waters (NJDEP, 1997), and its accompanying dredging and dredged material management guidance manual. While the NJDEP regulatory technical manual includes general criteria as the basis for its regulation of dredged material beneficial use projects, it must be emphasized that these regulations are applied on a project-specific basis. The NJDEP Office of Dredging and Sediment Technology should be contacted to discuss a specific project or application.

Historical Perspective on Dredging and Dredged Material Management

The current dredging and dredged material management and regulatory program in New Jersey was largely developed in response to a lack of dredged material disposal/management options following the closure of the infamous "Mud Dump" site off Sandy Hook in the early 1990s. The restrictions to use, and eventual closure of, this open water disposal site put into jeopardy the planned deepening of the entrance channels to the Port of New York and New Jersey to 50 feet. Suddenly without its centuries-old practice of open water disposal, the region found itself at a loss for options to manage millions of cubic yards of contaminated estuarine mud. This resulted in New Jersey Governor Christine Todd Whitman's formation of a task force charged with examining the issues and proposing numerous policy changes that included regulatory overhaul, establishment of policy and planning agencies, and funding of innovative techniques to manage dredged material.

In 1995, the New Jersey Office of Maritime Resources (OMR) was established, providing the state with an agency solely dedicated to the promotion and development of its maritime transportation system. This office was charged with implementing the innovative dredged material management policies needed to respond to the dredging crisis in the New York/New Jersey Harbor, as well as ensuring the proposed harbor deepening plan would not be delayed. OMR was also responsible for implementing the Joint Dredging Plan for the New York/New Jersey Harbor and for administering the projects in the 1996 Dredging and Harbor Revitalization Bond Act. In 2000, OMR was permanently housed in the Department of Transportation. NJDOT/OMR provides the state lead on dredging and dredged material management policy and planning.

In 1997, the NJDEP published its guidance manual, The Management and Regulation of Dredging Activities and Dredged Material in New Jersey's Tidal Waters (NJDEP, 1997), which was subsequently incorporated into the New Jersey Coastal Zone Management Rules (N.J.A.C. 7:7E). At that time, a key management decision was made to consider dredged material a resource, and not a solid waste. This extremely important decision, which specifically excluded dredged material and PDM from its solid waste regulations, enabled the state to develop and adopt a new regulatory program to ensure the safe management of dredged material. This regulatory program, managed by the NJDEP Office of Dredging and Sediment Technology, also takes into account the unique technical and logistical problems presented by dredging and dredged material management activities.

The New Jersey Legislature has also provided legal protections for dredged material placement activities in New Jersey, and mandated that the Departments of Transportation and Environmental Protection provide for and encourage the beneficial use of dredged material. Of particular note, the 1997 Brownfields Law (N.J.A.C. PL1997 Chapter 278) encouraged the use of dredged material in the remediation of contaminated properties by providing incentives to responsible parties that willingly cleaned up their property and agreed to beneficially use dredged material in their project. Typically, sediment is amended with Portland cement, producing a product that can be used as a brownfield or landfill cap.

Beneficial Use Policy

Beneficial use is, quite simply, using dredged material and products made from it for a beneficial purpose. This purpose might be as fill or capping material at a brownfield or landfill, for beach replenishment, or as a raw material for a manufactured soil or product. Since 1996, the State of New Jersey has taken numerous steps to develop and implement a sustainable dredged material management program in New York/New Jersey Harbor and throughout the state. Research was conducted, demonstration projects completed, and dredging projects subsidized, many of which are unique in the nation. This program will hopefully serve as a model to others faced with the dilemma of what to do with dredged material. We have summarized, referenced, or interpreted the results of many of these projects in this manual.

New Jersey considers dredged material to be a resource that should be beneficially used whenever possible. The New York/New Jersey Harbor RDT has established a Dredged Material Management Plan (DMMP) for the harbor (USACE, 2008). While this DMMP contains many specific details, it can be summarized as follows:

1) Reduce the need to dredge
2) Reduce sediment contamination
3) Beneficially use as much dredged material as possible
4) Only dispose of dredged material that cannot be beneficially used

This four-point policy for dredged material management was adopted by New Jersey in the mid 1990s and has been implemented throughout the state. The NJDOT and NJDEP have been working together since 1996 to implement this policy without compromising economic development or environmental protection. Dredging project managers at both state agencies have been charged with finding beneficial use opportunities that encourage the sustainable use of dredged material and/or remediate contaminated properties. In addition, watershed managers in the NJDEP have been working to limit soil erosion by implementing innovative stormwater best-management practices and rigorous coastal zone management regulations. Those NJDEP programs responsible for protecting the state's surface waters are also fully engaged in the fight to clean up contaminated sediments and to keep them clean. The result has been a remarkable reduction in the use of open water and other dredged material disposal techniques. Before 1996, no dredged material was beneficially used in New York/New Jersey Harbor. Today, all of the dredged material from the harbor is beneficially used. The state's goal is to beneficially use 100 percent of the dredged material generated throughout New Jersey.

To date, over 13 million cubic yards of silt/clay dredged material has been used beneficially for the capping and filling of contaminated sites in the greater metropolitan region. Final uses of capped and filled land include golf courses, parking lots, condominium complexes, and highway embankments. PDM has also been beneficially used as fill at abandoned coal mines in Pennsylvania, reducing both environmental and public health impacts in these former mining communities (Voros et. al, 2002).

Regardless of the successes demonstrated to date, New Jersey continues to explore new and innovative beneficial uses of dredged material, perhaps most notably as a feedstock in a manufacturing process that would allow simultaneous removal of contaminants to a safe level. A number of sediment decontamination technologies have been evaluated for this purpose by the NJDOT and the U.S. Environmental Protection Agency (USEPA) over the past decade (http://www.state.nj.us/transportation/airwater/maritime/dresediment.shtm). While considerably more work needs to be done, some technologies, such as thermal destruction or sediment washing, appear to be promising—albeit costly—alternatives, especially for highly contaminated sediments (see Chapter 7 for more information).

A final note is needed regarding the economics of dredging and dredged material management. The federal government continues to stress the importance of utilizing the "least cost, environmentally acceptable" alternative in federally funded projects. This Federal Standard has been used by some to decry upland beneficial use as too costly. However, the reality of disposal options without beneficial use is that they are not sustainable; by definition any disposal site will eventually fill up. If environmental policy or land values make it impossible to designate new disposal sites, it will not be possible to dredge in the affected area. Sustainable management policy that includes beneficial use of dredged material as a resource is certainly more complicated, but far preferable in the long run. The upper limit of this policy, however, is tied to the economic value of the navigation channel itself. If the proposed option costs more than the commercial value of the channel, then it no longer makes sense to dredge. It is imperative that dialogue regarding dredged material management options be tempered by this reality of the "value of a cubic yard." Certainly there will be some options that are not financially sustainable in some regions, regardless of how desirable they may be or even how viable they are in other areas.

Geographical Setting

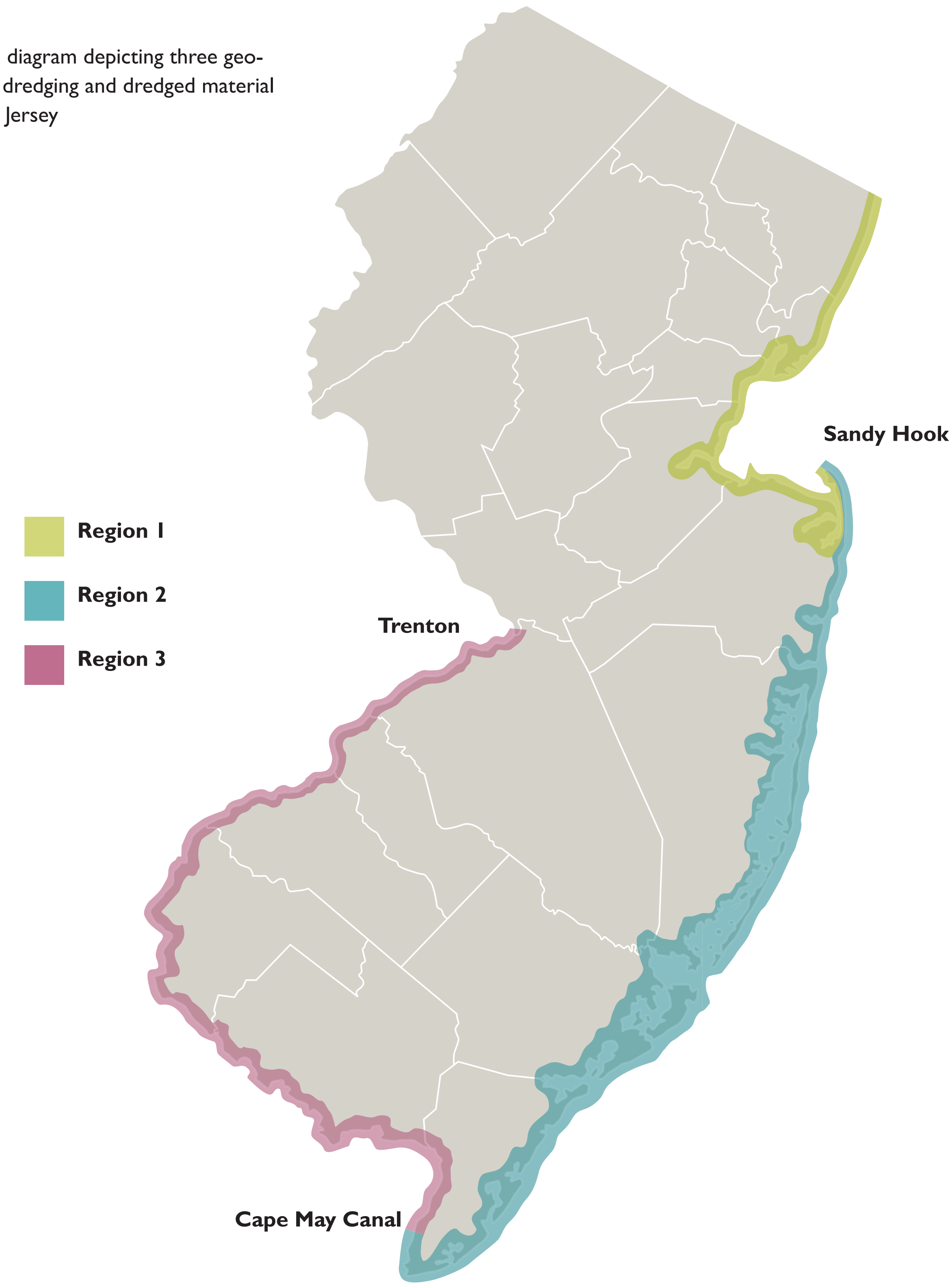
The benthic environment is notoriously heterogeneous everywhere, both in terms of its physical and chemical makeup. New Jersey boasts a great range of benthic environments from riverine to shore to estuarine. Because of the diverse ways in which the waterways of New Jersey are used, the state is divided into three regions for dredging and dredged material management purposes (see Figure 1.1).

- Region 1 is the New York/New Jersey Harbor Estuary complex from the western side of Sandy Hook to the north and west, including the Raritan Bayshore.
- Region 2 is the Atlantic Ocean coastline and bays, from the eastern side of Sandy Hook south to Cape May (including the Shrewsbury and Navesink River system and the western entrance to the Cape May Canal).
- Region 3 is the Delaware River and Estuary from the Cape May Canal north to Trenton, New Jersey.

These regions represent both a logical geographic and geologic separation, and because of this, the sediment found in each region tends to have similar and predictable physical characteristics. That being said, since engineered waterways and waterfront developments tend to create similar hydrologic conditions regardless of where they are built, these tendencies are just that, tendencies, and do not carry the weight of prediction.

The same can be said for historical and current land uses, which often indicate the state of contamination in the sediments. Those sediments from waterways adjacent to industrial land uses are more likely to be contaminated than those found adjacent to agricultural or residential land. But in a long settled and diverse area like New Jersey, no area is free of the potential for contamination. It may be useful to the reader to have a sense of what sediment characteristics are likely to be encountered during a project in a given region of

Figure 1.1: Schematic diagram depicting three geographical regions for dredging and dredged material management in New Jersey



the state. The following sections provide a brief description of the three regions and a summary of chemical and physical characteristics of the sediments found in each.

New York/New Jersey Harbor and Estuary (Region 1)

Port of New York and New Jersey

The New York/New Jersey Harbor Estuary complex is naturally shallow, with an average depth of only 19 feet at low tide. The Port of New York and New Jersey (the Port) is situated in the metropolitan center of the estuary (Figure 1.2). It is the largest port on the east coast of the United States, the third-largest port in North America, and the largest petroleum distribution point in the United States. Due to the strategic position of the Port in regional and international trade, it boasts some of the most significant maritime infrastructure in the country. The U.S. Army Corps of Engineers (USACE) maintains some 250 miles of engineered navigable waterways in the region, at depths ranging from 20 to 50 feet below mean low water (MLW). This system requires the dredging of 2 to 4 million cubic yards of sediment annually in order to maintain the authorized navigation channel depths. In addition, numerous access channels and ship berths have been constructed in support of freight transportation; these facilities are maintained by the Port Authority of NY and NJ (PANYNJ), the state of New Jersey, the city of New York, and private entities.

The proximity of the port to heavily urbanized and industrial land uses, coupled with historical mismanagement of waste materials and the discharge of pollutants to surface waters, has resulted in a legacy of contaminated sediments. Some waterbodies in the New York/New Jersey Harbor Estuary complex, such as the Passaic River and Newark Bay, have such significant sediment contamination problems that they are listed by the USEPA as Superfund sites. Despite this, historical dredged material management was almost exclusively ocean disposal. Starting in the 1970s, there was increased emphasis on understanding the impacts of contamination in sediments. With this greater understanding came more scrutiny on both dredging and dredged material management alternatives. Today, about half of the material dredged in the harbor each year is considered unsuitable for in-water placement, although each dredging cycle the sediment quality is trending toward more suitable for placement at the former ocean disposal ("Mud Dump") site, now called Historic Area Remediation Site (HARS).

Most of the maintenance dredging in the Port is accomplished with closed clamshell environmental buckets. Traditional upland disposal, using hydraulic dredging into CDFs, is not feasible due to the lack of unused waterfront land. Suitable clean dredged material is beneficially used as capping material at the HARS. However, use of the HARS is subject to the most stringent evaluation criteria for ocean placement of dredged material in the country. Thus, maintenance dredged material from Newark Bay, the Arthur Kill, the Kill van Kull, and the Passaic and Hackensack Rivers, is no longer even tested for HARS placement, the assumption being that it will not meet the current criteria. Dredged material that meets the ocean criteria is considered HARS suitable; material that does not is considered unsuitable for placement at the HARS or "non HARS." All non HARS dredged material from the region is stabilized with pozzolanic additives and is used beneficially to cap landfills or brownfields, or to fill abandoned strip mines. While this has provided numerous environmental benefits, it has also resulted in the highest navigational dredged material management costs in the United States, if not the world.

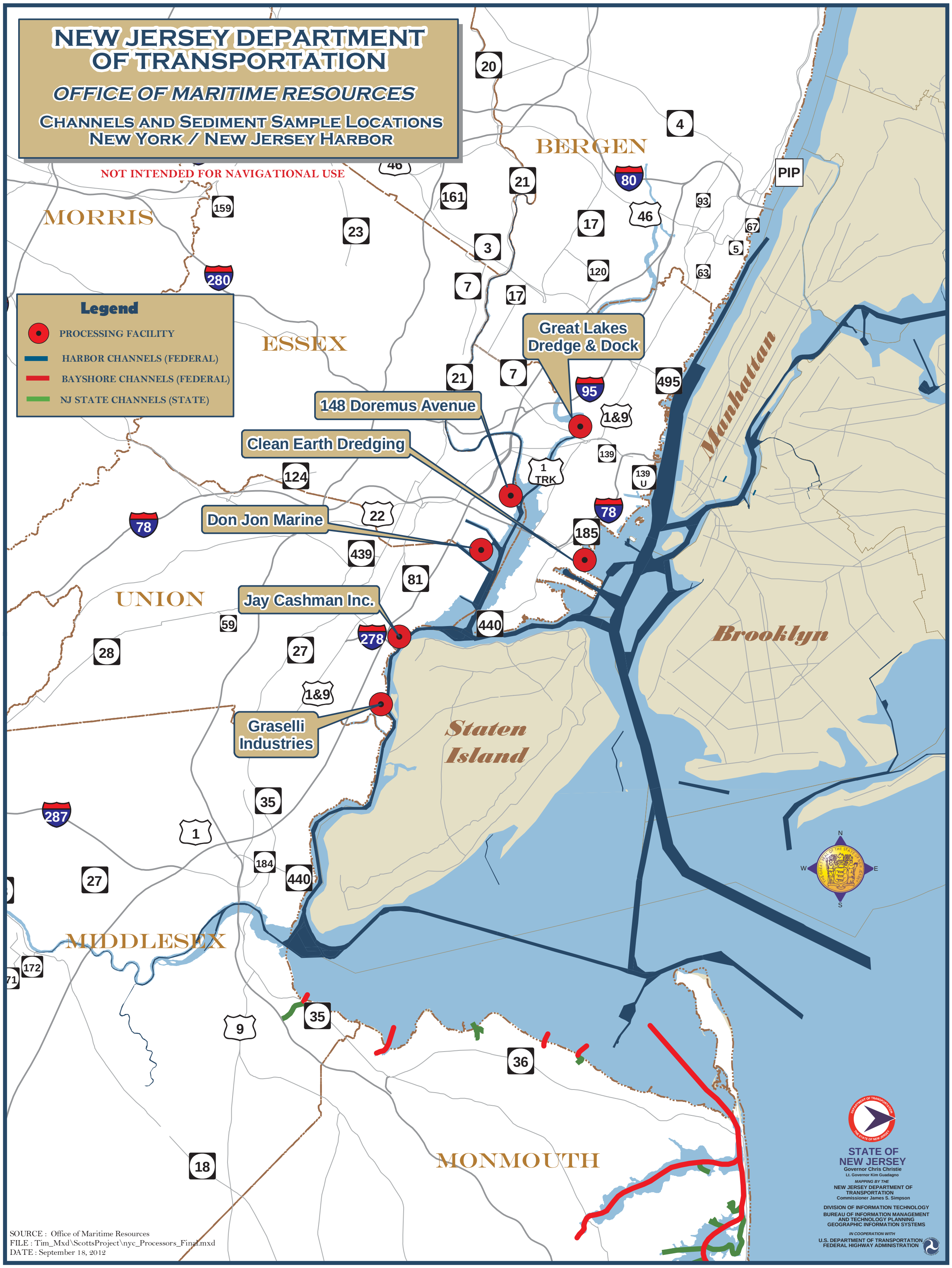


Figure 1.2: Map of New York/New Jersey Harbor Estuary complex and Port of New York and New Jersey facilities.

Complicating this is the fact that maintenance dredged material from the New York/New Jersey Harbor is typically a fluid mud, high in silt, clay, and organic matter (not to mention chlorides, heavy metals, and xenobiotic organic compounds). These characteristics combine to produce sediment that has inherently poor engineering properties in either a wet or dry condition, and is restricted from general use due to contamination. Finding appropriate uses for this material has proven challenging. The optimal solution is to treat the dredged material with a pozzolanic additive that reduces moisture content, improves engineering properties, and helps to bind contaminants by reducing permeability. PDM has proven extremely useful as construction fill and for capping purposes in remediation projects.

There are a number of dredged material processing sites in the Port, each capable of processing 5,000 cubic yards or more of raw sediment daily (see Figure 1.2). To date, almost 15 million cubic yards of dredged material from the New York/New Jersey Harbor Estuary complex have been safely and effectively managed at upland locations (see Table 1.1). Together with the clean dredged material that is placed at the HARS, or clean sand that is used for beach replenishment, all of the sediment dredged from one of the most contaminated harbors in the country is beneficially used.

New York/New Jersey Harbor Regional Dredging Team

The New York/New Jersey Harbor Regional Dredging Team (RDT) is comprised of representatives from the USACE, USEPA, PANYNJ, and the environmental protection and transportation agencies of the states of New Jersey and New York. The RDT is charged with ensuring dredged material management capacity is available for upcoming projects. Information on the current dredging and dredged material needs and sediment conditions in the New York/New Jersey Harbor Estuary complex can be obtained from the RDT.

The New York/New Jersey Harbor Dredged Material Management Plan (DMMP) is a living document that illustrates the needs and opportunities for dredging and dredged material management in the harbor through the year 2060. This comprehensive plan was written in a regional cooperative manner and is updated periodically. Updates can be viewed on the USACE Region 2 website: http://www.nan.usace.army.mil/harbor/dmmp/index.php. The DMMP includes a programmatic environmental impact statement and technical appendix (USACE, 2006).

Raritan Bayshore

Dotted along the southern border of the New York/New Jersey Harbor Estuary complex are the shoreline communities of Raritan Bay (Figure 1.2). While commercial shipping is no longer a major activity in these waters, the U.S. Navy maintains an ammunition depot at Leonardo that requires deep draft access. In addition, commercial maritime traffic exists in the form of fishing vessels (particularly shellfishers) and commuter ferries transporting people between Monmouth County, New Jersey, and New York City. Recreational uses have increased dramatically in recent years resulting in more marinas and residential developments boasting water access. The Raritan Bayshore region has approximately 11 miles of engineered waterways, approximately 2 miles of which is maintained by the State of New Jersey, with the rest federally maintained. Most of the navigation channels are maintained at their authorized depths, but decreasing industrial activity has reduced dredging needs in some areas (for example, the Raritan River).

Dredging practices in the Raritan Bayshore include a combination of those used in the Port and those used along the Atlantic Ocean coastline (Region 2). Contaminated silt is taken upland for processing and subsequent beneficial use, or placed in upland CDFs. Clean sand is usually hydraulically dredged and beneficially used in beach replenishment projects or placed in upland CDFs. Some sand is dredged with clamshell buckets and beneficially used as construction aggregate in upland projects.

While contamination is not as serious a problem in Raritan Bayshore sediment as it is in the Port, the dynamic nature of the New York/New Jersey Harbor Estuary complex has brought sediment-bound contaminants south from the Port into berths and waterways along the Raritan Bayshore. In a few cases, material dredged from the bayshore has been classified as non-HARS and processed as PDM.

Atlantic Ocean Coastline (Region 2)

The Atlantic Ocean coast of New Jersey has a long history of recreational and commercial maritime uses. The natural barrier island system, so famous for its beaches, has also provided a natural harbor system that contains New Jersey's portion of the Intracoastal Waterway (ICW). Navigation channels have been dredged through the system, which runs from the western end of the Cape May Canal north to Manasquan Inlet, to ensure access for fishing vessels and recreational boaters. The Atlantic Ocean coastline region has approximately 150 miles of federally maintained, and 100 miles of state-maintained, navigation channels (see Figure 1.3). The sheer magnitude of the ICW navigation channel system in New Jersey waters (117 miles) has made it a challenge to maintain, since many of the navigation reaches have considerably less than their authorized depth. While the ICW does not consist of deep-draft channels (the average channel depth is less than 7 feet), some areas in this region have authorized channel depths of up to 15 feet.

A large network of state channels provides connections to the ICW, and smaller/shallower channels that lead further inland are almost entirely used for recreational purposes. In addition, there are over 440 marinas along the Atlantic Ocean coastline. Unique to this part of New Jersey are the residential lagoons and channels—individual property owners and homeowner associations are responsible for access to and around their shore-side communities, individual homes, and marinas. However, due to years of neglect and a lack of dredged material disposal sites, many of these waterways are accessible only at high tide or have been abandoned. Dredged material from these channels is a mix of types ranging from clean sand to silt/clay.

Many of the inlets along the barrier islands are established naturally, do not support commercial traffic, and thus do not require maintenance dredging. However, there are several improved inlets along the shoreline (Barnegat, Shark River, Manasquan River, Cape May, and Absecon) where annual maintenance dredging is required. This is the responsibility of the USACE. Much of the sediment dredged from these inlets is greater than 90 percent sand, free of contamination, and therefore suitable for use in nearby beach replenishment projects.

Due to the lack of industry along the Atlantic Ocean coastline, most of the sediment is clean. Dredging in the back bays is usually accomplished with small hydraulic pipeline dredges or conventional clamshell buckets. Non-sand material that is not suitable for beach nourishment is placed in upland CDFs, many of which are located on islands or in near-shore marshes (see Figure 1.3). These facilities are typically owned by the state, but some are in private hands. Many of the upland CDFs in this region are either at or nearing capacity, or have reverted to wildlife habitats, which are protected by a variety of environmental regulations. Inventories have shown that many of the CDFs contain large volumes of useful sandy aggregate, but access to the sites is problematic and expensive (Farrell, *et al.,* 2008, 2009; Barone, et. al., 2012). Despite the difficulties, dredged material has been beneficially used at upland locations in the Atlantic Ocean coastline region (Table 1.2).

While these successes are noteworthy, the reader should be aware that these projects utilized the material without processing or amendment. Unlike the Port, the channels in this part of the state do not generate large amounts of economic activity, nor are they utilized by influential commercial interests. Consequently, it is considered economically unrealistic to suggest that dredged material from these channels could be used to create PDM for upland beneficial use.

Delaware River and Estuary (Region 3)

The Delaware River and Estuary was a commerce corridor long before Europeans came to North America. Today, a full complement of industrial, commercial, recreational, and residential uses is realized along its shores. Currently, federal maintenance dredging is performed on the Delaware River Main Channel in two major projects: Philadelphia to Trenton and Philadelphia to the sea. The 130-mile main shipping channel to the Ports of Wilmington (DE), Philadelphia (PA), and Camden, Salem, Paulsboro, and Trenton (NJ) is maintained by the USACE at depths of 35 to 40 feet (see Figure 1.3).

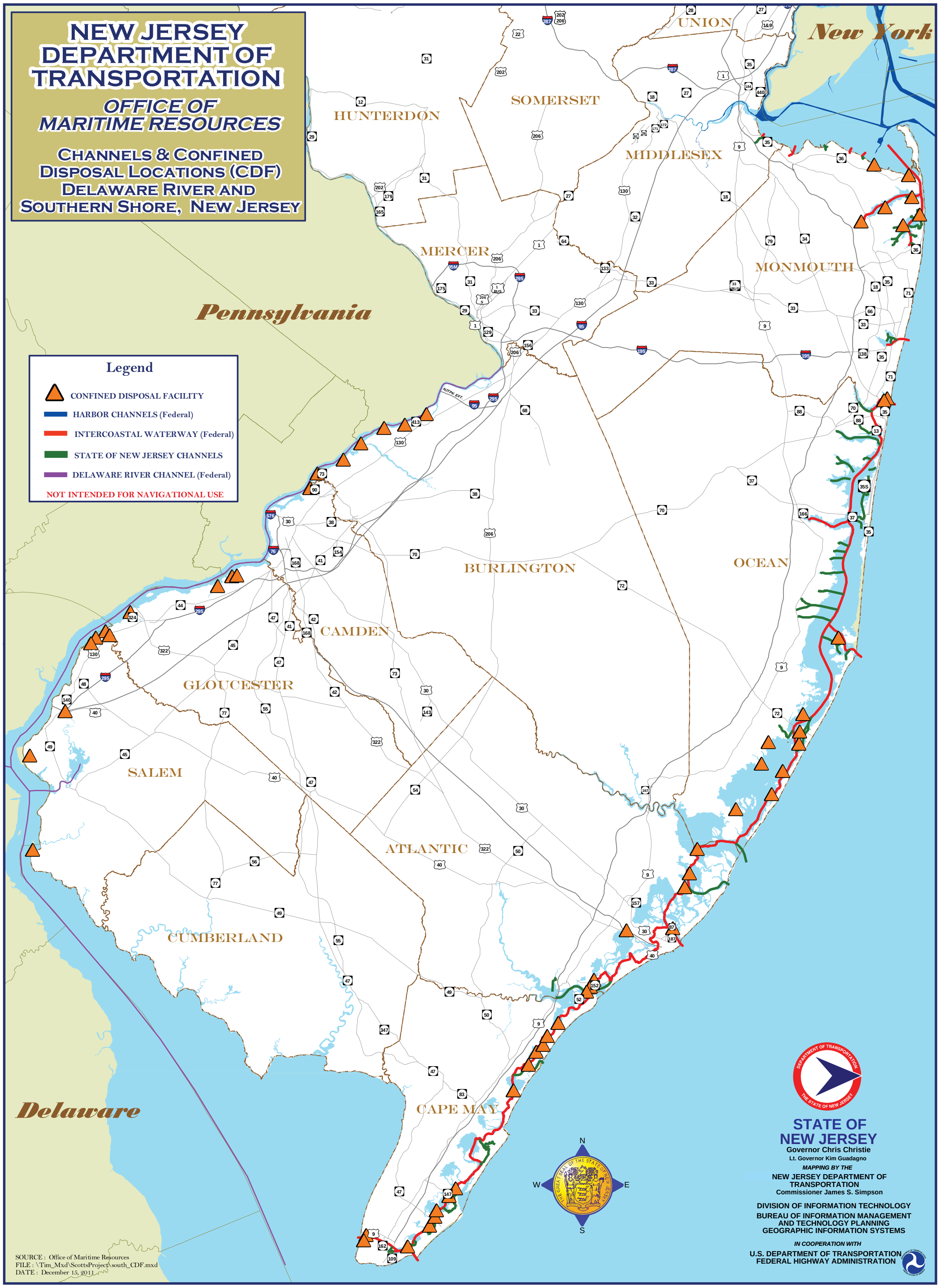
Table 1.2: **Beneficial use projects that have utilized sediment excavated from confined disposal facilities along New Jersey's Atlantic coastline.**

Project Name	Municipality	Volume Placed (cubic yards)
Belford Landfill	Belford, NJ	200,000
Cape May Meadows	Cape May, NJ	15,000
Harbison Walker Site	Cape May, NJ	190,000
Neptune Landfill	Neptune, NJ	100,000
Route 52 ramps	Somers Point, NJ	2,000
St. Peter's Beach	Cape May, NJ	4,000
Terrapin Blocks/Barriers	Atlantic County, NJ	<10

Federal maintenance dredging of approximately 5 to 6 million cubic yards per year is accomplished primarily through trailing hydraulic suction dredging, with disposal of the dredged material at upland CDFs located along the Delaware River. The U.S Congress has authorized deepening the 102.5-mile section of the main channel from Philadelphia to Delaware Bay to a depth of 45 feet. When the Delaware River Main Channel is deepened, not only will maintenance dredging needs increase, but upland CDF capacity will decrease, making it more difficult (and expensive) to dredge. This will necessitate a renewal of upland CDF capacity and/or the development of alternative dredged material management strategies.

Dredging in the Delaware River is accomplished by a combination of hydraulic and conventional bucket dredging. For the larger federal navigation project in the main channel of the Delaware, sediment is pumped via pipeline into large CDFs. Ownership of the CDFs varies depending on the location. Between

Figure 1.3: Navigation channels and confined disposal facilities in New Jersey.



Philadelphia and the bay, the USACE owns several CDFs in New Jersey and Pennsylvania. In the bay proper, much of the material is sand that is clean enough for open water disposal at the buoy 10 site or is used for beach replenishment projects in Delaware. Upstream of Philadelphia, to the falls at Trenton, CDFs are provided by the states. The Pennsylvania site is continually renewed through an agreement with Waste Management, Inc., who uses the material for daily landfill cover. The New Jersey sites are mostly filled to capacity, but efforts are underway to renew their capacity through excavation and beneficial use.

Side and access channels to the main navigation channel are not numerous, but berths and terminals, as well as private marinas and residential communities, do require maintenance dredging. This is usually accomplished through an innovative two-step approach. First, berths and terminals are either hydraulically or conventionally dredged, and the material is hauled to White's Basin in Logan Township, New Jersey, where it is bottom-dumped in an isolated inlet. Secondly, the sediment is hydraulically pumped into an adjacent, privately-owned and operated conventional upland CDF. This operation has worked successfully for many years, but it is currently the only dredged material management facility that is consistently open to many dredgers. Recent development pressure has put the future operation of the White's Basin facility in question.

Dredged material has been beneficially used in the region, mostly through excavation of existing upland CDFs for construction aggregate. Approximately 3.5 million cubic yards has been beneficially used for projects ranging from strip mine reclamation to landfill cover (see Table 1.3). The most significant project was the beneficial use of dredged material from the Fort Mifflin Upland CDF on the Schuylkill River for runway expansion at the Philadelphia Airport and for strip mine reclamation in northeast Pennsylvania. As in Region 2, very little, if any, of this material has been processed into PDM. The reason for this is, again, economics. While the Delaware does have considerably more commercial activity to support more expensive dredged material management options, it is unlikely that it can sustain widespread beneficial use of PDM. However, due to the relatively clean nature of the material, it may be found that other innovative approaches that utilize unprocessed dredged material can be employed rather than the current, equally unsustainable disposal option.

Table 1.3: **Beneficial use projects that have utilized sediment excavated from confined disposal facilities along the Delaware River and Estuary.**

Project	Municipality	Volume Placed (cubic yards)
Burlington County Resource Recovery Center	Bordentown, NJ	15,000
GROWS Landfill daily cover	Morrisville, PA	150,000
Harrison Avenue Landfill	Camden, NJ	180,000
NJ Turnpike, Exit 1	Deepwater, NJ	180,000
Philadelphia Airport	Philadelphia, PA	1,900,000
River Winds Golf Course	West Deptford, NJ	160,000
Route 29 Overpass	Trenton, NJ	2,900
Strip mine reclamation	Tamaqua, PA	550,000
Tweeter Center	Camden, NJ	220,000

Delaware River and Estuary Regional Dredging Team

For quite a few years, the Maritime Exchange of Philadelphia has hosted a semi-annual dredging forum that brings together the state and federal regulatory agencies, dredging and dredged material management contractors, and port and marine facility managers to discuss current and anticipated dredging needs of the private sector. The success of this group, coupled with a need to resolve the controversies associated with the Delaware River main channel deepening, prompted the formation of a regional dredging team.

In 2011, the Philadelphia District of the USACE formed a regional dredging team for the Delaware River and Estuary. This is an interagency committee whose purpose is to ensure that all the public and private dredged material management needs of the region are met. The first task of this group is to develop a regional dredged material management plan (DMMP) that will determine the needs and available management capacity in the region. Also in progress is a regional sediment management plan (RSMP) that is being developed in concert with local environmental groups and will address source control, remediation, and alternative management strategies including habitat restoration/creation.

Chapter 2: Sediment and PDM Sampling, Testing, and Evaluation

Overview

To provide the necessary information to make regulatory or management decisions regarding a dredging project, the sediments to be dredged must be characterized. Likewise, processed dredged material (PDM) must be characterized to evaluate its suitability for a proposed beneficial use. The sampling and testing requirements for sediment (i.e., dredged material) and PDM proposed for beneficial use will vary depending on four basic factors:

1. Volume of the sediment to be dredged or PDM to be beneficially used
2. Physical characteristics of the sediment to be dredged or PDM to be beneficially used
3. Potential for the sediment/PDM to be contaminated (largely dependent on its waterbody of origin and physical characteristics)
4. Type and location of the proposed beneficial use.

The following discussion provides a brief overview of the NJDEP-required procedures used for the sampling, testing, and evaluation of sediment and PDM in New Jersey. A more comprehensive treatment is provided in the most current version of the NJDEP dredging manual (NJDEP, 1997; and subsequent revisions).

A few notes for the project engineer are warranted here. First, the engineer should be aware that some New Jersey placement sites are managed under the Licensed Site Remediation Professional (LSRP) program (a summary of which is provided later in this chapter), and the site's LSRP may have sampling and testing requirements different from those of the NJDEP. Second, although the New York/New Jersey Harbor does not have upland confined disposal facilities (CDFs), if the engineer is intending to beneficially use sediment that has been previously dewatered in a CDF, the NJDEP requires additional sampling and testing for that dredged material. Finally, if the dredged material/PDM is to be beneficially used at an out-of-state location, that state will have its own sampling, testing, and evaluation requirements. Where multiple state jurisdictions could apply, the engineer should not assume that a complete application for one state (or the USACE) will suffice for another state. The engineer should thus coordinate with all applicable state regulatory agencies to ensure that the required data are collected.

NJDEP Sampling Requirements

Sampling and testing is often a lengthy and expensive part of dredging and PDM beneficial use projects; therefore, it is prudent to take care in planning the sampling and testing program. Prior consultation with the appropriate regulatory agencies will help ensure all data necessary for decision-making are collected in one sampling excursion. The sampling and analysis plan (SAP) for a dredging project in New Jersey waters, or for the proposed beneficial use of PDM (or dredged material) in New Jersey, must be approved by the NJDEP prior to its implementation. Thus, permit applicants are encouraged to consult with the NJDEP Office of Dredging and Sediment Technology prior to the development of a sediment/PDM SAP. It is also prudent to consult with the owner/operator of the dredged material processing facility and beneficial use site to determine if there are any facility/site-specific sampling and testing requirements and/or associated performance criteria.

It is often useful to examine available sediment data from the dredging project area to identify likely sediment characteristics, which can aid in identifying suitable beneficial uses for the sediment proposed for dredging. For example, maintenance dredging projects in the New York/New Jersey Harbor are likely to be comprised of sediment that is predominantly silt, whereas deepening projects are likely to be predominantly sand, clay, and/or glacial till. Available information may also provide some insight into the possible extent of chemical contamination likely to be encountered in the sediment, which may limit beneficial use options. This information should be used to determine potential beneficial use sites, confirming the material will, or can be made to, meet processing facility or placement site regulatory and performance criteria.

For a dredging project, the number of samples and the sediment sampling locations are chosen by the NJDEP, with the objective to fully characterize the sediments to be dredged. Sampling locations typically focus on shoaling areas and/or locations near outfalls or other potential sources of contamination, but also include locations systematically distributed across the dredging envelope. In the New York/New Jersey Harbor, one core sample is usually required for every 4,000 cubic yards of sediment to be dredged. While physical testing is usually conducted on every core sample, chemical testing is frequently performed on composite samples of two or three cores. The NJDEP will also determine the core sample compositing scheme.

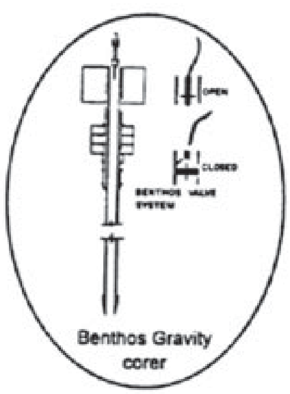


Figure 2.1 Gravity Corer

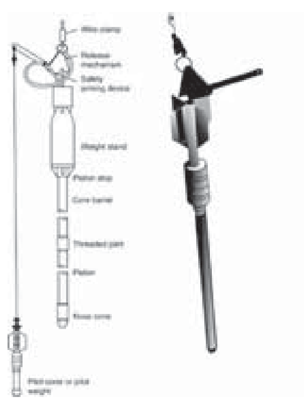


Figure 2.2 Piston Corer

Figure 2.3 Vibracorer

Any distinct sediment strata present along the length of the core samples—identified based on grain size or other noticeable differences—is required to be composited and analyzed separately. In new work and deepening projects, the bottom 6 inches of every sediment core are also composited and analyzed separately to determine the level of contamination that will be exposed at the completion of the dredging project. All of the sampling requirements will be detailed in a SAP developed by the permitee in consultation with, and approved by, the NJDEP.

To evaluate the suitability of PDM for a proposed beneficial use, bench-scale testing of the PDM is also required by the NJDEP. Samples of sediment are processed at a bench scale, first by mixing the sample with additives, then by subjecting that mixture to bulk sediment or leaching procedures. At this time changes to the additive mixture can be made to ensure the PDM meets project-specific criteria. If a placement site has not been selected, the NJDEP requires testing using a generic PDM recipe. Bulk sediment chemistry is conducted using the same methodology as the raw sediment. Leaching potential is assessed using the synthetic precipitation leaching potential (SPLP) procedure. In general, the PDM sampling and testing requirements are determined by the NJDEP on a project-specific basis.

Sediment Sampling Methods

Core Sampling

Currently, NJDEP (and USACE) require that a coring device be used to take representative sediment core samples through the entire depth of the dredging prism. Use of a core sampler is the only reliable way to collect sediment samples suitable for evaluating the geotechnical characteristics of bulk sediment. The collection of sediment core samples also allows the engineer to identify any stratification of the sediment deposits (for example, based on apparent grain size). The presence of different types of sediment in the dredging prism may influence the choice of the dredging equipment to be used and/or limit potential dredged material management/beneficial use alternatives.

Figure 2.4 Split Spoon

All core samplers consist of an open-ended tube that is pushed vertically into the sediment deposit to the desired depth (usually the depth of dredging plus any allowed depth of over-dredging). During retrieval, the sample is retained within the barrel by a flap. The nose and head are separated from the barrel to transfer the sample to a container. Differences among core samplers relate to tube size, tube wall thickness, type of penetrating nose, head design including valve, and type of driving force. Core samplers are provided with a range of driving methods depending on sediment texture and required depth of penetration.

The most common samplers are gravity corer, piston corer, and vibracorer (see Figures 2.1–2.3). Determining the most efficient sampling method depends upon depth of dredging and sediment stiffness. Typically, a gravity corer is used for unconsolidated sediment, but a piston corer or vibracorer can be used for both consolidated and unconsolidated sediments (as wells as deeper sediments). While a gravity corer uses no additional force to move the core into the substrate, the vibracorer and piston corers use vibration or hammer force, respectively.

For harder, more consolidated sediments it may be necessary to use a fourth technique, the split barrel sample spoon (also known as a split-spoon sampler, see Figure 2.4). These devices are capable of penetrating most sediment, regardless of how tightly compacted. A split-spoon sampler is typically smaller in diameter than either the gravity corer or vibracorer, resulting in a smaller sample, which makes it less desirable if large volumes of sediment are needed for biological testing.

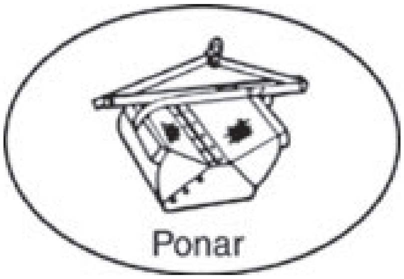


Figure 2.5 Ponar

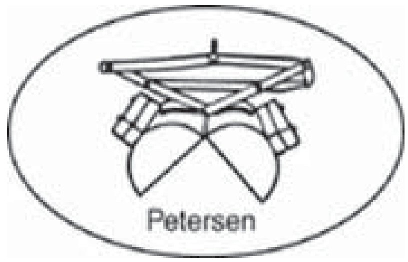


Figure 2.6 Petersen

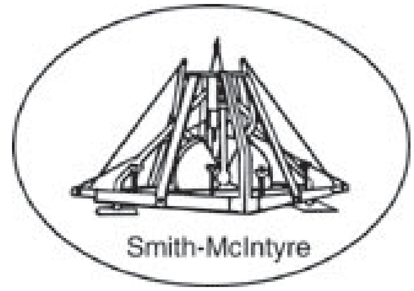


Figure 2.7 Smith-McIntyre

Grab Sampling

A grab sampler consists of a scoop or bucket container that bites into the soft sediment deposit and encloses the sample. Grab samplers are used primarily to sample surface materials, as the depth of penetration into the sediment is usually 12 inches or less. Grab samplers are easy to use and inexpensive to obtain, and may be sufficient to characterize sediment for routine maintenance dredging, provided the depths are not too great (USACE, 1983). Typical grab samplers used in New Jersey waters are the Ponar, Petersen, and Smith-McIntyre samplers (see Figures 2.5–2.7). All are capable of efficiently sampling marine sediments. In some cases, the depth of dredging is too shallow or the sediments too loose to sample with a coring device, making the grab sampler the only option. Grab samplers are also useful to collect biological samples when only the top few inches of the sediment are aerobic enough to support benthic life. They can also be valuable if a large volume of surficial sediment is required for biological testing.

PDM "Quality Control" Sampling

Once blended with pozzolanic additives or otherwise processed, the resulting PDM may need to be further sampled to confirm that the processing operation actually achieves the required geotechnical and chemical criteria for its approved beneficial use. These "quality control" tests are often random grab samples of PDM from the facility's process stream, or samples collected directly from a stockpile, truck, or barge. While there are no formal procedures for this "quality control" sampling, it is necessary to determine the required rate of sampling for the particular characteristic being observed. In some cases the sampling rate will be dictated by the NJDEP permit or acceptable use determination (AUD) for the PDM, while in other cases (or in addition) the LSRP or owner/operator of the PDM beneficial use site will specify the sampling rate.

Sample Storage and Custody

To preserve sample integrity, collect and store samples in properly cleaned glass jars capped with air-tight lids lined with an inert material. Since this can be impractical for transporting or storing large volumes, sediment for biological testing can be temporarily held in 5- to 6-gallon plastic buckets lined with polyethylene sleeves. All samples to be analyzed for chemical parameters must be held consistent with the requirements of the specific analytical procedures to be used (typically in the dark at 4°C or less). Samples to be analyzed for geochemical parameters should be held in the dark at 20°C or less. Proper chain of custody procedures must be followed, consistent with the requirements in the NJDEP Field Sampling Procedures Manual (NJDEP, 2005).

Sediment Testing Methods

The NJDEP will specify the chemistry target analyte list (TAL) for the sediment/PDM; the required TAL for most projects is usually that identified in the NJDEP dredging manual (NJDEP, 1997; and subsequent revisions). The NJDEP (or LSRP at some sites) will also specify the chemical criteria that the sediment/PDM must achieve to be acceptable for the proposed beneficial use. While the NJDEP dredging manual (NJDEP, 1997) identifies various analytical procedures that can be used for each contaminant class, any procedure can be used as long as the achieved detection limits are lower than the chemical criteria specified by the NJDEP (or LSRP). Testing for New Jersey permits should be performed by a NJDEP-certified laboratory.

Geotechnical Testing

Testing for the basic geotechnical parameters of grain-size distribution, organic matter content, and percent moisture are required in the SAP approved by the NJDEP. Ultimately, project-specific geotechnical testing may be required, as determined by the LSRP or owner/operator of the proposed beneficial use site, to establish the engineering properties of the sediment and/or PDM. A geotechnical testing plan should be developed based on the intended beneficial use of the sediment to be dredged, including, at a minimum, Atterberg limits, specific gravity, and in-situ density. Bench-scale tests of strength and compressibility may also provide insight into the performance of PDM. Since the types of tests and criteria against which they will be compared are highly dependent on the site and the intended application, it is strongly recommended that the project engineer consult early in the project development process with the beneficial use site manager, as well as the owner/operator of the dredged material processing facility, to identify the geotechnical testing requirements.

Potential beneficial uses of sediment and/or PDM are separated into two basic categories—non-structural and structural applications. Non-structural applications have little-to-no load placed upon the fill material, such as golf courses, recreational fill, or some landfill applications. Structural applications, on the other hand, may consist of roadway subbase, embankments, or as protective mediums. Table 2.1 and Table 2.2 list recommended geotechnical tests based on the proposed end use of the dredged material/PDM. Many projects utilize, but are not limited to, the tests found in these tables.

Geotechnical tests for non-structural fill beneficial uses include evaluations of general index properties, basic gradation, and compressive strength. While the proposed beneficial use may not require a compressive strength component, it is often important to know the capabilities of the dredged material/PDM should it need to support future loads. These tests characterize some of the basic engineering values that a soil can have and should be considered when developing a testing strategy using dredged material/PDM as non-structural fill.

Table 2.1: Geotechnical testing for non-structural applications

Non-Structural Applications		
Compressive Strength	Unconfined Compressive Strength of Cohesive Soils	ASTM D2166
	Unconfined Compressive Strength Index of Chemical-Grouted Soils	ASTM D4219
Unit Weight	Unit Weight Voids in Aggregate	ASTM D29
	Standard Test Methods for Specific Gravity of Soil Solids by Water Pynometer	ASTM D854
	Standard Test Method for Density of Soil in Place by the Sand Cone Method	ASTM D1556
	Standard Test Method for Density of Soil and Soil Aggregate in Place by Nuclear Methods	ASTM D2922
Gradation	Particle Size Analysis of Soils	ASTM D422
	Sieve Analysis of Fine and Coarse Aggregate	ASTM D136
Moisture Density Characteristics	Standard Proctor Compaction for Optimum Moisture Content	ASTM D698
	Modified Proctor Compaction for Optimum Moisture Content	ASTM D1557
	Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils	ASTM D4318

Table 2.2 presents some typical tests for identifying and determining the structural properties of dredged material/PDM. Project managers will need to choose the tests that are applicable to engineering the proposed beneficial use of the material. In structural applications, not only are index properties useful, but they also indicate the compressibility, strength, and durability of the material.

Table 2.2: **Geotechnical testing for structural applications**

Structural Applications		
Unit Weight	Unit Weight Voids in Aggregate	ASTM D29
	Standard Test Methods for Specific Gravity of Soil Solids by Water Pynometer	ASTM D854
	Standard Test Method for Density of Soil in Place by the Sand Cone Method	ASTM D1556
	Standard Test Method for Density of Soil and Soil Aggregate in Place by Nuclear Methods	ASTM D2922
Compressive Strength	Unconfined Compressive Strength of Cohesive Soils	ASTM D2166
	Unconfined Compressive Strength Index of Chemical-Grouted Soils	ASTM D4219
Shear Strength	Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils	ASTM D2850
	Direct Shear Test of Soils Under Consolidated Drained Conditions	ASTM D3080
	Standard Test Method for Consolidated Undrained Triaxial Shear Test	ASTM D4767
Gradation	Particle Size Analysis of Soils	ASTM D422
	Sieve Analysis of Fine and Coarse Aggregate	ASTM D136
Moisture Density Characteristics	Standard Proctor Compaction for Optimum Moisture Content	ASTM D698
	Modified Proctor Compaction for Optimum Moisture Content	ASTM D1557
	Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils	ASTM D4318
Bearing Capacity	California Bearing Ratio (CBR) of Laboratory Compacted Soils	ASTM D1883
Permeability	Permeability of Hydraulic Conductivity of Saturated Porous Materials using Flexible Wall Permeater	ASTM D5084
	Permeability of Granular Soils by Constant Head	ASTM D2434
Durability	Standard Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures	ASTM D560
Consolidation	Standard Test Method for One-Dimensional Consolidation Properties of Soils	ASTM D2435

Table 2.3 lists a sample of tests selected based on the type of sediment and its proposed beneficial use. Sandy sediments are considered to be those with particle diameters of 0.5 to 2.0 millimeters. Silty/clay sediments are considered to be those with particle diameters below 0.5 millimeters, as per NJDOT specifications (NJDOT, 2007). A more complete analysis of the geotechnical properties of PDM and the requirements of various potential PDM beneficial uses are presented in Chapter 6.

Table 2.3: **Geotechnical testing recommendations by beneficial use and soil type**

	Silts and Clays	Sands
Flowable Fill (CLSM)		ASTM D421, 422, 4318, 698
Embankment Fill		ASTM D560
Roadway Subbase		ASTM D1883
Topsoil	ASTM D4318, 422, 4972, pH, Chloride Content, Organic Content	
Landfill Daily Cover	ASTM D4318, 422, 4972, 2434	ASTM D2434
Landfill Final Cover	ASTM D4318, 422, 4972, 2434	

Chemical Testing

Dredged material and PDM proposed for upland beneficial use requires extensive chemical and geotechnical testing, but usually no biological testing (with some exceptions—for example, manufactured topsoil). Bulk sediment chemistry analysis is required, usually following the NJDEP-specified target analyte list (TAL) (NJDEP, 1997; or as revised). In some cases the TAL may vary depending on site-specific criteria. To beneficially use PDM, the analytical laboratory must prepare a bench-scale sample of the PDM, following the same recipe (as close as practical) as will be used at the dredged material processing facility. In many cases, this will be a mix of dredged material and 8 percent Portland cement by weight. However, the engineer is advised to consider testing any alternate recipes that might be used. The resulting bench-scale PDM sample is then analyzed for the same TAL as was the bulk sediment.

In addition to bulk sediment chemistry analyses, samples of the bench-scale PDM must be tested for leaching potential. For New Jersey applications, the sample is evaluated using the synthetic precipitation leaching procedure (SPLP, EPA Method 1312). Other states may require the multiple extraction procedure (MEP, EPA Method 1320) or the toxicity characteristic leaching procedure (TCLP, EPA Method 1311), all of which evaluate the potential for contaminants to be leached off of dredged material/PDM and transported to surface or groundwater. The artificial leachate is usually analyzed for the same TAL as was the bulk sediment.

It is important to confirm with the laboratory the required method detection limit (MDL) for the chemical analysis. In some cases, the target analytes have regulatory limits that are extremely low. If less costly analytical methods are used that cannot detect concentrations at or below the regulatory limit, then the resulting data will not be adequate to make a permit decision. In these cases it may be necessary to resample and retest. Consequently, what may appear at first to be an economical analytical package may turn out to be a costly mistake.

Evaluation of the Testing Data for the Proposed Beneficial Use

Once the sediment/PDM sampling and testing program is complete, the data is compared to the relevant criteria for the proposed beneficial use by the NJDEP and/or LSRP. A potential first cut for New Jersey applications is to compare the sediment/PDM bulk chemistry results to the New Jersey Residential or Non-Residential Soil Remediation Standards (see Appendix), depending on the proposed beneficial use. However many potential beneficial sites have site-specific criteria, particularly those managed by a Licensed Site

Remediation Professional (LSRP). Acceptability limits are also frequently set for processing facilities, either on a project or annual basis, or both. These limits are part of the facility's operating permit. Leachate data are usually compared to the New Jersey Groundwater Quality Standards applicable at the proposed beneficial use site (see Appendix), with potential mitigating factors such as leachate collection facilities and slurry walls considered in the evaluation.

With a few notable exceptions, arsenic and benzo(a)pyrene being two, most PDM made from New York/New Jersey Harbor navigational dredged material will be able to meet the New Jersey Non-Residential Soil Remediation Standards. However, because many potential New York/New Jersey Harbor PDM beneficial use sites are already contaminated with one or more of the contaminants usually present in the PDM, site-specific acceptability standards are developed for most of these sites. In addition, the determination of what constitutes acceptable "alternative fill" at a site may be determined by the NJDEP or by an LSRP (see the following section for details on the LSRP program). Because site-specific standards for some contaminants are usually less stringent than the generic New Jersey Soil Remediation Standards, PDM produced using dredged material from almost all navigation dredging projects will be acceptable for use at most sites in New York/New Jersey Harbor. For sites that are in less industrial locations, or near residential areas, PDM may have to meet the New Jersey Residential Soil Remediation Standards. Dredged material from New York/New Jersey Harbor that cannot meet the criteria for any available beneficial use must be placed in a secure landfill or decontaminated to an acceptable level.

As for water quality, most New York/New Jersey Harbor projects do not violate the surface water quality standards because of the industrial nature of the system. However, if dredging in other parts of the state, particularly if the waterway is used as a source of drinking water, elutriate chemistry may be a factor that needs to be controlled through dredging BMPs (best management practices). Leachate chemistry is not usually a concern for harbor placement sites either, since PDM is usually placed on properties where the groundwater is already contaminated, or where engineering controls are in place. In cleaner areas, strict monitoring and mitigation for leachate may limit beneficial use.

Licensed Site Remediation Professional Program

In 2012, the NJDEP implemented the Licensed Site Remediation Professional (LSRP) program in New Jersey. This program allows private sector professionals to become licensed to oversee the implementation of Remedial Action Workplans (RAW) at contaminated sites on behalf of the state. An LSRP is responsible for determining the acceptability of any and all fill materials used at a site he/she manages, and therefore has the right to reject any and all materials proposed for placement at the site. This has obvious ramifications for the placement and beneficial use of PDM (and dredged material) at LSRP-managed contaminated sites, since it is possible for an LSRP to request additional sampling and testing (beyond that required by NJDEP) to provide assurance that the PDM meets the general or site-specific geotechnical and chemistry criteria. Therefore, it is highly recommended that dredging project proponents discuss with the NJDEP and the proposed dredged material processing facility whether or not remedial activities at the proposed PDM beneficial use sites are managed by the NJDEP or an LSRP. In either case, the dredging project engineer should discuss the PDM sampling and testing requirements, and the terms and conditions of PDM beneficial use at the site(s), with the NJDEP or LSRP during the initial phases of the permitting process for the dredging project.

Alternative Fill Protocol

In August 2011, the NJDEP issued an Alternative Fill Protocol that provides guidance for sampling and testing materials proposed for placement on contaminated sites managed by the NJDEP site remediation program or an LSRP. Since PDM is an alternative fill specifically mentioned in the guidance, a good understanding of this protocol will help develop the sampling and testing program needed to determine the suitability of PDM for placement at a contaminated site. Because this protocol requires the use of site-specific data, it will be necessary to consult with the NJDEP staff or LSRP (as appropriate) to develop the SAP for PDM to be used at the site. In many cases, site-specific placement criteria will already have been developed for a site where PDM is beneficially used, so the project engineer will only need to compare the bench-scale PDM data to the criteria to determine if the PDM is acceptable for use.

There are two major objectives of the Alternative Fill Protocol, quoted here directly from the 2011 guidance (NJDEP, 2011).

- No new contaminants may be placed in an area of concern (AOC) other than those already determined to be present. This concept is referred to as the **like on like requirement.**
- Contaminant concentrations in the alternative fill shall be lower than those on the receiving site AOC. This objective is referred to as the **75th percentile compliance requirement.**

First and foremost, alternative fills can only be used on sites where engineering controls are in place, and only placed in such as way as to ensure the given engineering control is acting to control the loss of contaminants from the alternative fill. Second, and importantly, the alternative fill must be placed in the AOC that is used to determine compliance with the two objectives—the aerial extent of the AOC cannot be increased.

Calculation of the 75th percentile compliance contaminant concentrations requires data from the contaminated site and from the bench-scale testing of PDM. In most cases, the NJDEP-approved SAP implemented for the dredging permit will suffice, but the project engineer is encouraged to verify that this is the case with the proposed placement site LSRP before implementing the SAP. If the maximum concentrations in the PDM bench-scale data are greater than the 75th percentile for a given contaminant, then it may not be possible to use the PDM at the site.

Conclusion

Sampling and testing of sediment proposed for dredging can be an expensive and time-consuming part of any dredging program and therefore should be carefully planned and conducted. Sampling plans must be developed in concert with and approved by the NJDEP prior to sample collection. Sampling methods and equipment are specified by both federal and state permitting authorities and are not at the discretion of the applicant. Samples of raw and processed dredged material are subjected to bulk sediment testing of target analytes using approaches with appropriate method detection limits that take the complicated matrix of harbor sediments into account. In order to determine compliance, data are compared to processing facility limits, placement site, and, occasionally, groundwater criteria. In some cases, Licensed Site Remediation Professionals may be involved in the placement site and require additional tests and/or target analytes.

Chapter 3: Geochemical Properties of New York/New Jersey Harbor Dredged Material

Overview

There is probably no aspect of dredging that raises more concern than sediment quality. Fortunately, considerable effort has gone into evaluating the extent and nature of sediment contamination over the past several decades. The engineer should take advantage of this information to develop an understanding of whether or not contamination poses a risk to a given project, and then determine the appropriate course or courses of action. This basic understanding of sediment origins and properties can be used to better understand the nature of the material typically dredged and how dredged material is best managed. Finally, the engineer needs to collect information specific to the sediment to be dredged. A historical context is often useful when predicting and even interpreting sedimentquality data.

Sediment is comprised of soil particles that have been eroded into and fallen through a body of water. Since soil is a mixture of mineral and organic particles that have predictable and measurable properties, it is possible to predict the way that the particles will interact with dissolved contaminants in the water column. Consequently, sediments with similar physical properties—such as grain size and organic matter—are equally likely to bind contaminants. In general, clay particles are more highly charged than sand particles, making them more likely to bind contaminants. Organic particles, while a relatively small proportion of sediment, are even more highly charged. Thus the engineer can use relatively inexpensive physical data combined with a general understanding of land use in the parent watershed to make a reasonably good prediction of sediment quality. Fine-grained silt from an industrial watershed is much more likely to be contaminated than coarse sand from a protected coastal inlet. In older industrial areas, the age of the sediment is also important. As pollution engineering has improved, so has water quality, making more recent deposits likely to be less contaminated than sediments deposited during less enlightened times. Exceptions abound, but it is often useful to think of sediment as a record of the water quality in the watershed from which it is generated and at the time it was deposited.

Finally, physiochemical characteristics such as pH, redox, and sulfides can affect the ability of sediment particles to bind and hold chemical contaminants.

Sediment that is removed during dredging projects is referred to as dredged material. Sediment dredged during new work (or deepening) projects will likely be consolidated glacial tills, clays, and/or rock. In contrast, sediment dredged during maintenance of existing channels is often finer grained silts and clays, although sand will predominate in higher energy areas such as coastal inlets. Consequently, maintenance dredged material is often—but not always—more contaminated than sediment dredged in deepening projects. In some areas, digging deeper can result in uncovering older, more contaminated sediments. This phenomenon is typical of historically industrial areas in and around ports, where water quality conditions were more degraded in years past. It is also of particular concern where main shipping channels are deepened and widened, opening up the entire historical depositional record and associated contaminants to the aquatic ecosystem. Because of this, regulators typically require that samples of the bottom of the dredging envelope be obtained to demonstrate the quality of the newly exposed sediments.

Perhaps the most vexing problem for the dredging engineer is the loss of particles through re-suspension. Fine-grained particles are most easily re-suspended and, since these are the most likely to be contaminated, raise the greatest regulatory concern. However, all particles can cause problems in sensitive marine ecosystems. Fortunately, a good understanding of the nature of the dredged material and the hydrodynamics of the dredging area allow the engineer to choose equipment and management practices that minimize loss of sediment. The propensity for sediment to hold contaminants is at least as important as their ability to bind them in the first place. A complex array of physiochemical properties including pH, redox potential, metal and sulfide complexes, as well as consolidation and the chemistry of the surrounding water, will impact whether or not the contaminants remain bound to sediments once disturbed during dredging. This is true for the dredging activity itself as well as the management of the sediment, whether on land or in water. Consequently, it is important to subject the dredged material (either in raw or processed form) to bench-scale tests that measure the strengthof the bonds that hold the contaminants, namely elutriate and/or leachate tests. Again, historical context can help to predict and interpret the data from these tests. What follows is historical data from testing of New York/New Jersey Harbor dredged material, in raw and processed form, to provide context.

Characteristics of New York/New Jersey Harbor Dredged Material

Sediment from the New York/New Jersey Harbor spans the gamut from clean Pleistocene clay to fluid mud contaminated by industrial discharge. Because of the extent of engineered waterways in the harbor, dredged material also varies similarly. Contamination of sediment usually occurs while the sediment is in the water column or in surficial deposits; therefore, the nature and extent of contamination tends to be correlated with the age of the sediment. Sediment in the estuarine mudflats, or deposited in previously dredged navigation channels and berths, is often fine grained, organically enriched, and contaminated. Those sediments that were deposited during pre-industrial times, such as the ubiquitous red-brown clay or glacial tills, are typically free of industrial contamination. Since water quality has steadily improved in the harbor over the past several decades, so has the quality of newly deposited sediment.

The following data summarizes the results from several recent sets of chemical and physical tests of New York/New JerseyHarbor (Region 1) dredged material. These data are intended to give the planner or engineer an idea of the quality of dredged material that can be expected in this part of the New Jersey. While experience dictates that these data are representative, it should not come as a surprise if a given project presents sediment quality completely at odds with the sediment data summarized here—either more or less contaminated. As such, the information provided here is not intended to take the place of project-specific investigations required for regulatory purposes, and does not supersede the requirements of the NJDEP for specific projects (see Chapter 2).

Physical Characteristics of Bulk Sediment

From a physical standpoint, dredged material from the harbor is mostly fine grained (approximately 35 percent clay and approximately 45 percent silt). Total organic carbon content of maintenance material from the data set ranged from 0.5 to 5.3 percent with an average of 2.8 percent (dry weight basis); however, historical records indicate that organic matter content in harbor sediments can range as high as 15 percent (Parsons

Brinkerhoff Quade Douglas, 1999). Since both fine-grained particles and organic carbon have a high affinity for organic contaminants, this combination of characteristics by itself should raise concern regardless of where the sediment is found. Combined with the historical industrial land use and heavy urbanization of the watersheds of the harbor, it is obvious that much of the sediment is contaminated with a variety of metals and manufactured organic chemicals.

Chemical Characteristics of Bulk Sediment

The chemical character of harbor sediment varies considerably, even for fine-grained silty material (see Figures 3.1–3.6). Since this manual is intended to meet the needs of engineers seeking to bring dredged material upland, it is appropriate to consider these geochemical characteristics in relation to upland criteria; the applicable 2008 New Jersey Soil Remediation Standards are provided in each figure. These criteria are listed in full in the appendix. Note that there are two sets of remediation standards: the RSRS is for residential applications, and the NRSRS is for non-residential (industrial/commercial) applications. These criteria are based on a human-health risk assessment.

Figure 3.1: **Average metals concentration in New York/New Jersey Harbor dredged material (mg/kg dry wt. basis). Error bars represent one standard deviation of the mean. Criteria are from NJDEP, 2008. RSRS = New Jersey Residential Soil Remediation Standard; NRSRS = New Jersey Non-Residential Soil Remediation Standard**

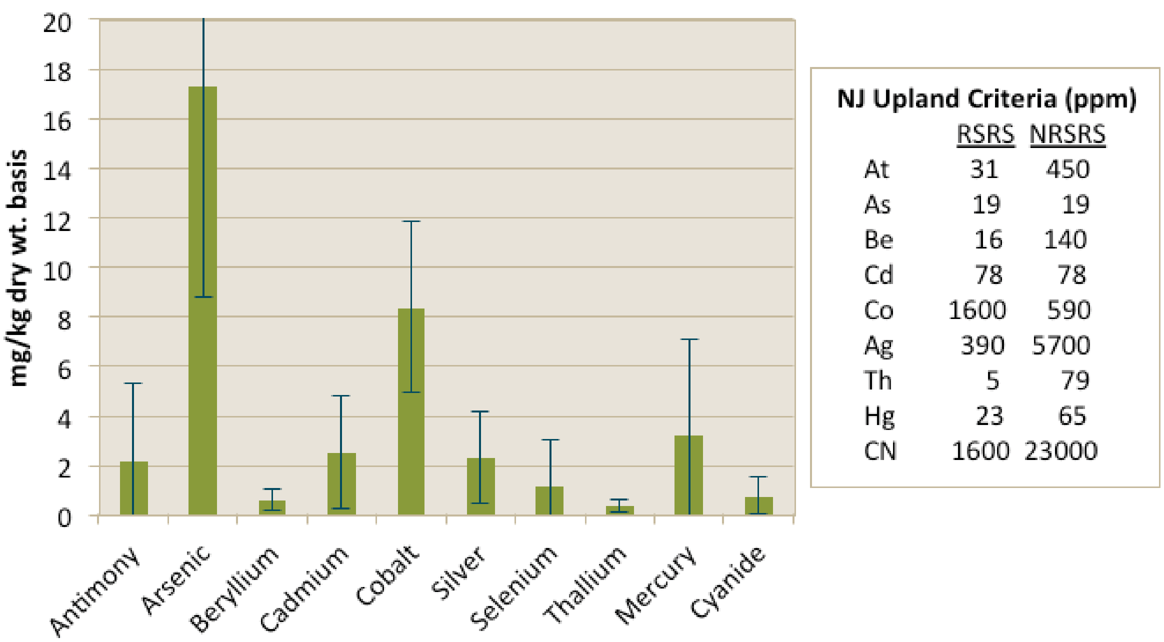
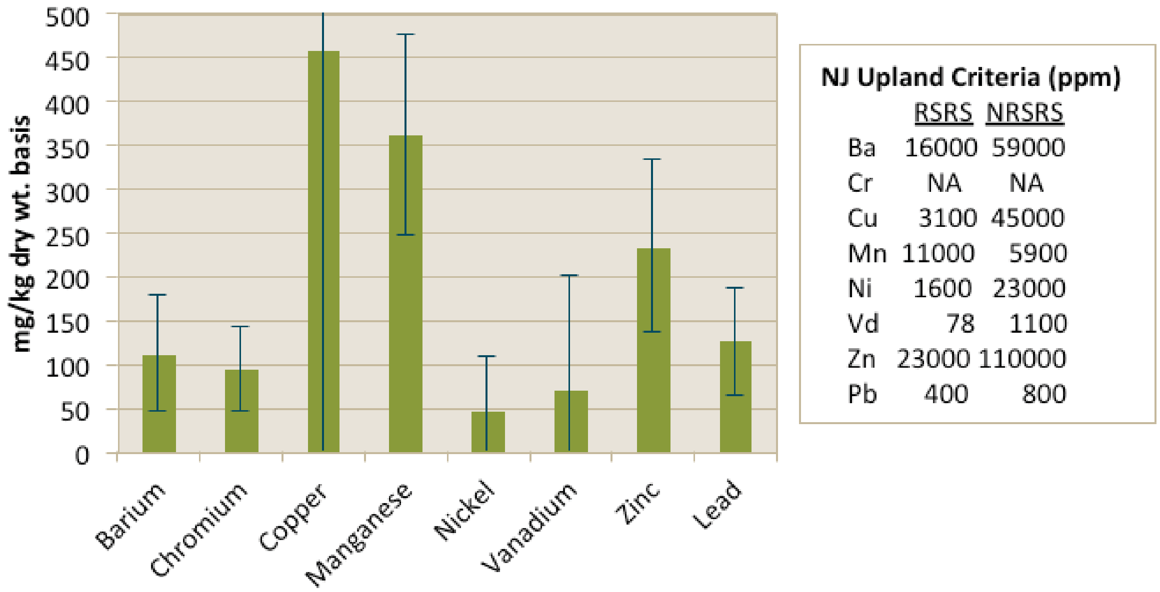


Figure 3.2: **Average metals concentration in New York/New Jersey Harbor dredged material (mg/kg dry wt. basis). Error bars represent one standard deviation of the mean. Criteria are from NJDEP, 2008. RSRS = New Jersey Residential Soil Remediation Standard; NRSRS = New Jersey Non-Residential Soil Remediation Standard; NA = Not Applicable**



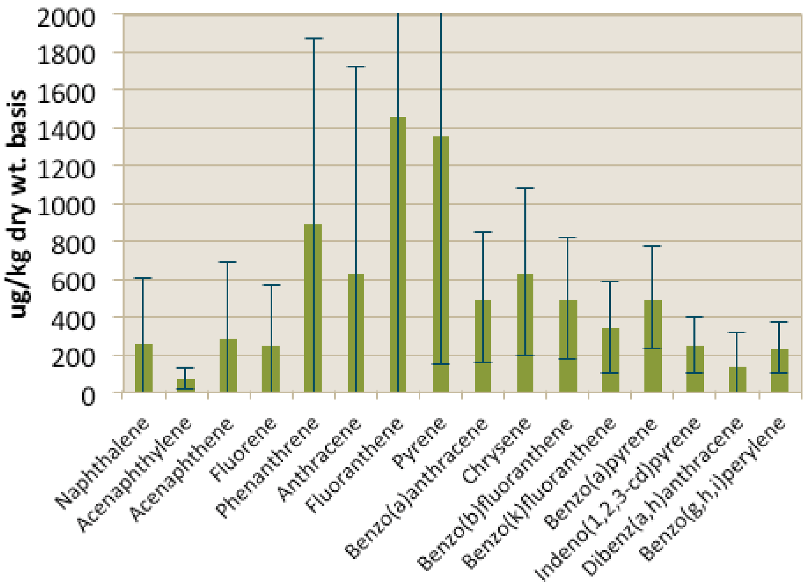
Metals in Bulk Sediment

From these data it is apparent that most maintenance material from the New York/New Jersey Harbor is likely to meet upland placement criteria in New Jersey for metals. The only notable exception to this general characterization is for arsenic. Since the soil remediation standards for arsenic are based on natural background levels, and the standard is the same for residential and non-residential uses (19 milligrams/kilograms), elevated arsenic concentrations may be a limiting factor for the beneficial use of harbor dredged material. While the presence of arsenic above the standard does not necessarily preclude beneficial use, since concentrations on the target use site may already exceed background, it does limit options significantly.

Organics in Bulk Sediment

The average concentrations of the pollutants polycyclic aromatic hydrocarbons (PAH) are very high in dredged material from Region 1 (see Figure 3.3). Although most PAHs are below the soil remediation standard for residential use, the substituted benzene compounds, like benzo(a)pyrene and benzo(a)anthracene, may be problematic. Like arsenic, the standards for these compounds are the same for residential and non-residential uses, so beneficial uses of dredged material are limited because of contamination by these PAHs. Benzo(a)pyrene is of particular concern in the New York/New Jersey Harbor area, as the average concentration is over twice the non-residential standard. However, there are a number of New Jersey sites currently permitted to take sediment with elevated PAH levels.

Figure 3.3: **Average PAH concentration in New York/New Jersey Harbor dredged material (µg/kg dry wt. basis). Error bars represent one standard deviation of the mean. Criteria are from NJDEP, 2008. RSRS = New Jersey Residential Soil Remediation Standard; NRSRS = New Jersey Non-Residential Soil Remediation Standard; NA = Not Applicable**



NJ Upland Criteria (ppb)

	RSRS	NRSRS
Napth.	600	1700
Aceny.	NA	NA
Acen.	3.4×10^6	37×10^6
Fluo.	2.3×10^6	24×10^6
Anth.	17×10^6	30×10^6
Flonth.	2.3×10^6	24×10^6
Pyre.	1.7×10^6	18×10^6
B(a)a	600	2000
Chry.	62000	230000
B(b)f	600	2000
B(k)f	6000	23000
B(a)p	200	200
I(123-cd)	600	2000
D(a,h)a	600	2000
B(ghi)p	38×10^7	30×10^7

The New York/New Jersey Harbor region has had appreciable inputs of PCBs over the years from both local businesses and the upper Hudson River (see Figure 3.4). Average concentrations are close to the standard for some Aroclors, making the total PCB standard of 200 parts per billion (ppb) for residential use difficult to meet. However, the non-residential standard is 1,000 ppb, so most sediment proposed for dredging in New York/New Jersey Harbor should be able to achieve this standard.

While the harbor dredged material typically contains many of the targeted pesticides, most are far below applicable upland standards (see Figure 3.5). The exception for this rule is dieldrin, which is frequently found at concentrations slightly above the residential standard, but still far below the non-residential standard. Despite this, it is rare for dieldrin to be the sole compound that dictates a placement decision. Though not included in our dredged material database, toxaphene is another pesticide found at relatively high concentrations in some localized areas. Current NJDEP criteria for toxaphene are 600 ppb (residential) and 1,000 ppb (non-residential). As with dieldrin, it is unlikely that toxaphene, if present in amounts that exceed applicable criteria, would be the sole compound dictating a placement decision.

Dioxins and furans may generate the most concern for dredged material management. These compounds are byproducts of chemical processes or from the burning of organic materials; consequently, dioxins and furans are frequently found in New York/New Jersey Harbor dredged material. While their presence, particularly in Newark Bay and the Kills, can result in unacceptable bioaccumulation results when testing sediment for the HARS, it does not usually influence management decisions regarding upland placement because of the large difference in sensitivity of the aquatic verses terrestrial receptors. Upland criteria are typically orders of magnitude higher than the bulk sediment chemistry observed. This may not be true if the material is from channels close to the 2,3,7,8-TCDD source in the Passaic River (upper Newark Bay) and if the material is targeted to go to upland locations with more stringent dioxin criteria, such as Pennsylvania. Pennsylvania limits the concentration of 2,3,7,8-TCDD in PDM to 120 parts per trillion (residential) or 530 parts per trillion (non-residential).

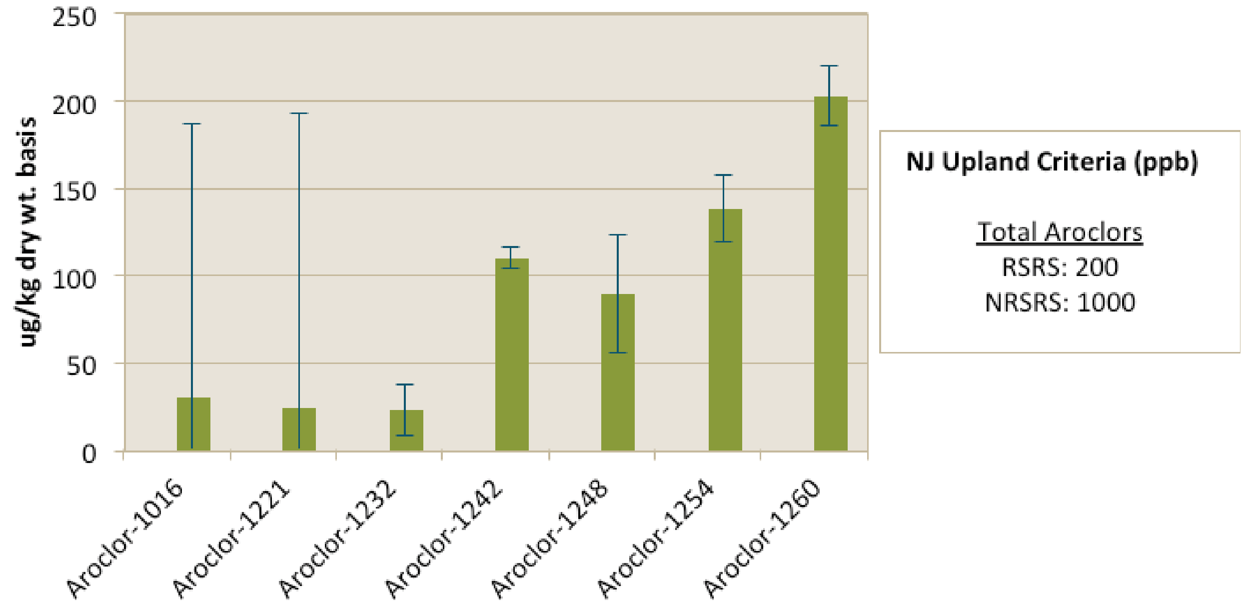


Figure 3.4: **Average PCB concentration in New York/New Jersey Harbor dredged material (μg/kg dry wt. basis). Error bars represent one standard deviation of the mean. Criteria are from NJDEP, 2008. RSRS = New Jersey Residential Soil Remediation Standard; NRSRS = New Jersey Non-Residential Soil Remediation Standard**

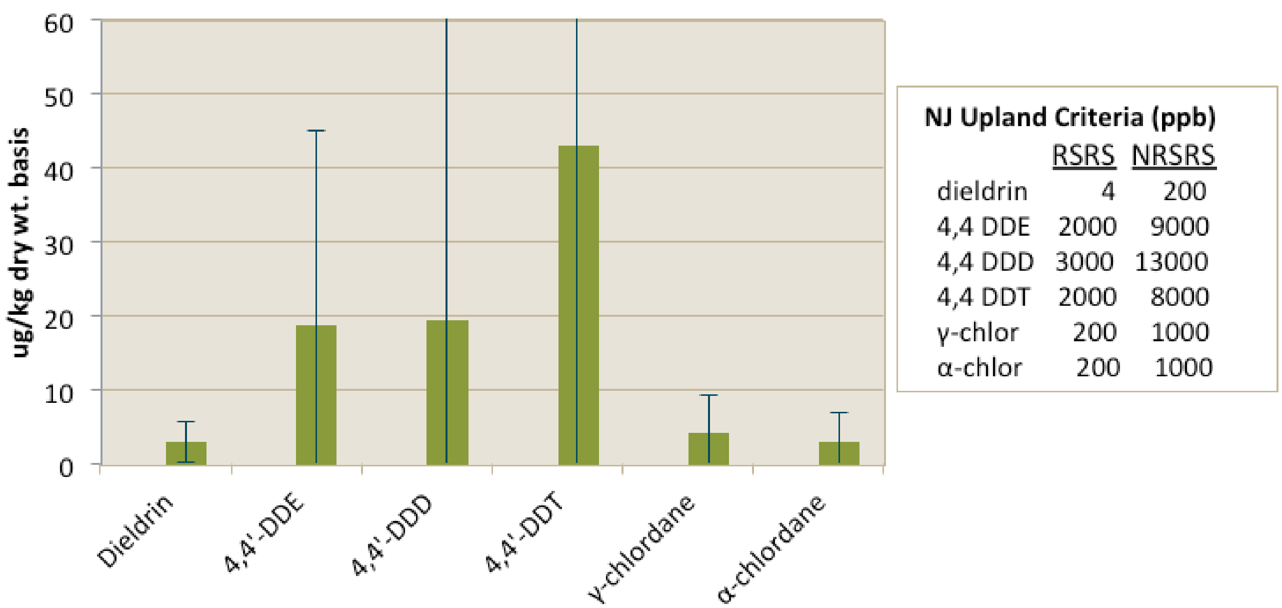


Figure 3.5: **Average pesticide concentration in New York/New Jersey Harbor dredged material (μg/kg dry wt. basis). Error bars represent one standard deviation of the mean. Criteria are from NJDEP, 2008. RSRS = New Jersey Residential Soil Remediation Standard; NRSRS = New Jersey Non-Residential Soil Remediation Standard**

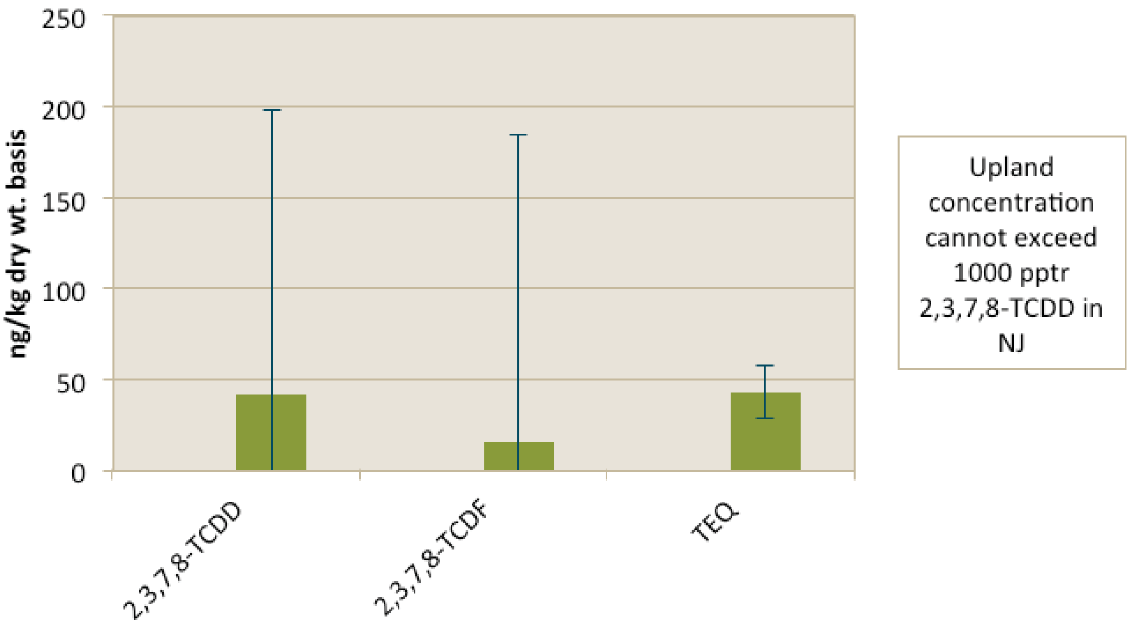


Figure 3.6: **Average concentration of selected dioxin/furan compounds and TEQ in New York/New Jersey Harbor dredged material (ng/kg dry wt. basis). Error bars represent one standard deviation of the mean. Criteria are from NJDEP, 2008. TEQ = Total Equivalency Quotient, calculated by WHO equivalents**

Characteristics of Processed Dredged Material

While the regulatory oversight of dredging relies on a good understanding of bulk sediment chemistry, the oversight of processing and upland placement requires an understanding of the unique chemistry of PDM. This includes bulk characteristics as well as leaching potential of the manufactured material. We compared the data on a number of key constituents across test type to show the relationship between raw and processed sediment and the leaching potential of the PDM.

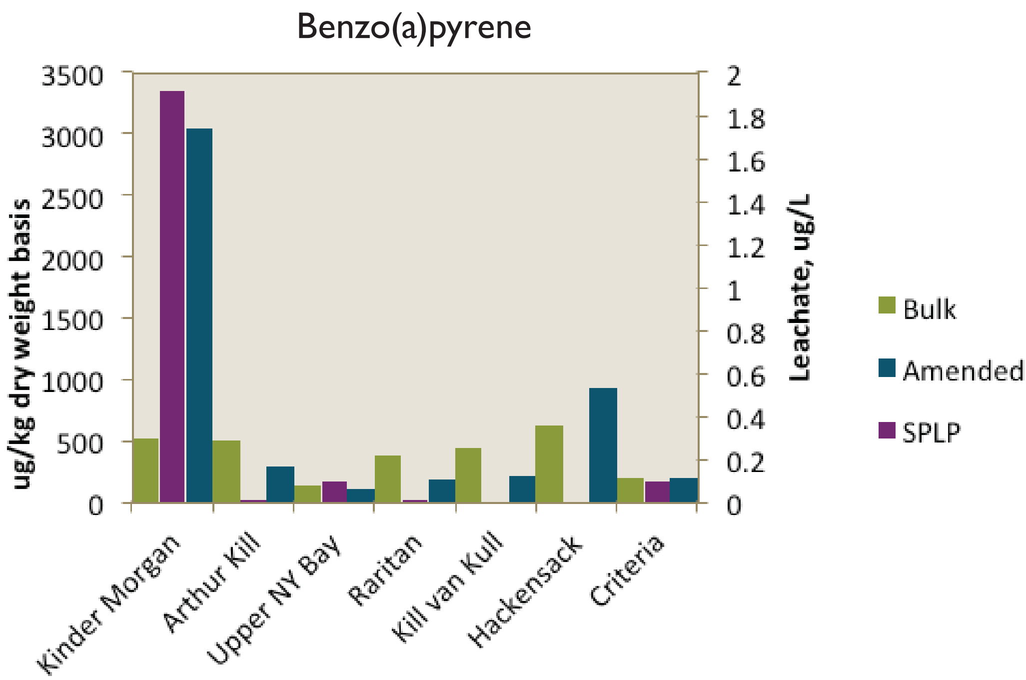
Bulk Chemistry of PDM

Amendment with stabilizing pozzolans such as Portland cement will, in most cases, result in a measurable reduction in concentration for many target analytes, simply by dilution (see Figures 3.7–3.10). In some cases, heterogeneity in the sediment (or laboratory testing procedure) might make it appear that concentrations are elevated by the additives (see Figure 3.7 and 3.8 for Kinder Morgan), but this is unlikely for conventional additives. However, additive contamination is a concern for waste products such as municipal solid waste incinerator ash or other fly ashes. Before considering use of waste amendments, it is prudent to thoroughly evaluate their chemistry and to check the stream periodically to guard against contamination that might result in permit violations.

Leachability of PDM

Leaching potential is determined through an artificial leachate test such as the Synthetic Precipitation Leaching Potential test (SPLP). These data can then be compared to standards for groundwater or surface water contamination. The leachability of contaminants from harbor sediments can be significantly higher than the groundwater standards (see Figures 3.7–3.10), but this has rarely resulted in denial of a placement permit in the harbor since many of the sites are either not in groundwater sensitive areas or have secondary containment systems—or both.

Figure 3.7: **Average concentration of benzo(a)pyrene in raw bulk sediment, PDM, and artificial leachate from a selection of recent harbor projects. No leachate data are available for KVK or Hackensack River.Criteria are from NJDEP, 2008**



Note that for some contaminants, the SPLP concentrations appear to be dramatically higher than the criteria for leachate (see Figures 3.7–3.8). However, closer examination of the data reveals that these are not detected concentrations; rather, the method detection limit of the analysis was greater than the standard. For these particular projects, this oversight was insignificant due to the high site-specific criteria for placement. Nevertheless, the prudent engineer will verify with the laboratory prior to sample collection that the analytical method can provide detection limits below the relevant criteria.

Figure 3.8: **Average concentration of the benzo(a)anthracene in raw bulk sediment, PDM, and artificial leachate from a selection of recent harbor projects. No leachate data are available for KVK or Hackensack River. Criteria are from NJDEP, 2008**

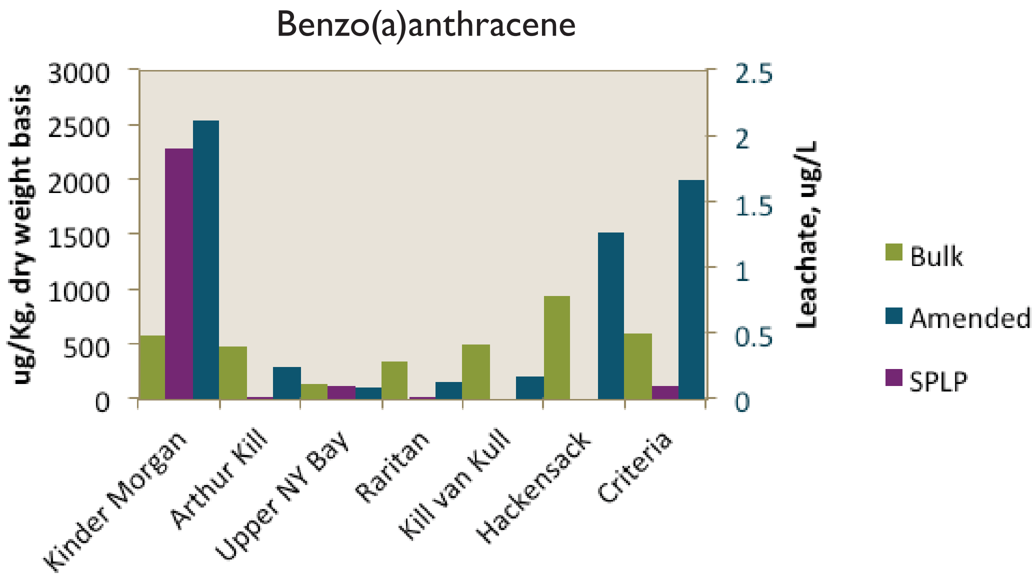


Figure 3.9: **Average concentration of the PCB Aroclor 1260 in raw bulk sediment, PDM, and artificial leachate from a selection of recent harbor projects. No leachate data are available for KVK or Hackensack River. Criteria are from NJDEP, 2008**

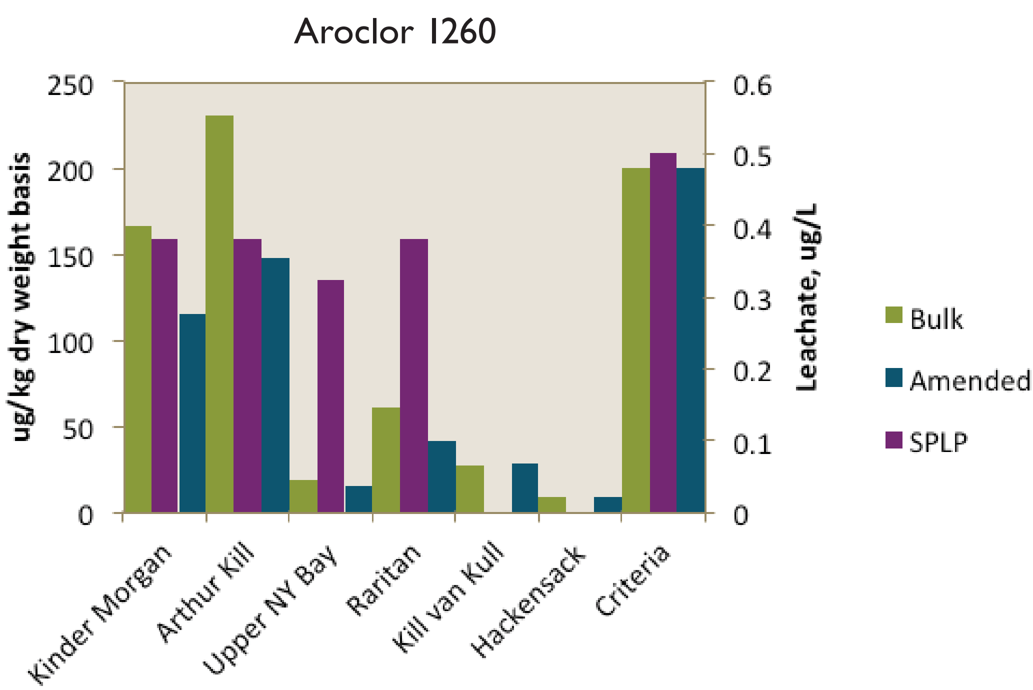
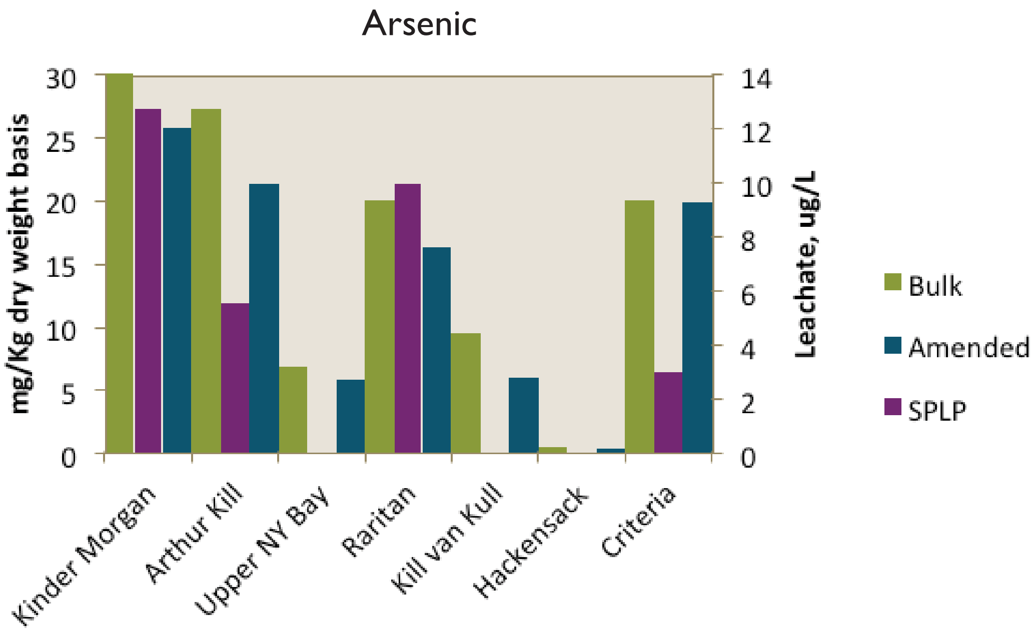


Figure 3.10: **Average concentration of arsenic in raw bulk sediment, PDM, and artificial leachate from a selection of recent Harbor projects. No leachate data are available for KVK or Hackensack River. Criteria are from NJDEP, 2008**



Conclusion

Much of the sediment in the harbor region is fine-grained silty material that contains varying concentrations of contaminants of concern. However, since many sites have engineering controls and on-site contamination that is considerably higher than that found in harbor sediments, almost all dredged material can be processed and safely placed upland. The engineer needs to evaluate historical data and surrounding land use, as well as site-specific chemical and physical data, in order to interpret sediment quality and make recommendations for dredged material management.

Chapter 4: Geotechnical Properties of New York/ New Jersey Harbor Dredged Material

Overview

This section provides a framework for geotechnical testing and evaluation. It also provides the engineer with a good background in the available geotechnical data on raw and processed dredged material (PDM).

Background

In New Jersey, the three management regions of harbor (Region 1), shore (Region 2), and Delaware River (Region 3) neatly divide the general physical properties of the sediment into estuarine, coastal, and riverine sediments, respectively. In general, estuarine sediments are typically comprised of fine-grained silts and clays; coastal sediments are primarily sand; and riverine sediments are a combination of all grain sizes, sorted by hydrologic condition (see Figure 4.1). Note that in the case of New Jersey, Region 2 contains both estuarine and coastal sediments, due to the extensive barrier island system which separates the coastal and estuarine backbay areas. Because the coastal region's silty sediments tend to be relatively clean due to lack of industrial land use, we will focus the remainder of this chapter on the silty sediment of NY/NJ Harbor, which tends to be too contaminated for ocean placement and requires processing prior to upland placement.

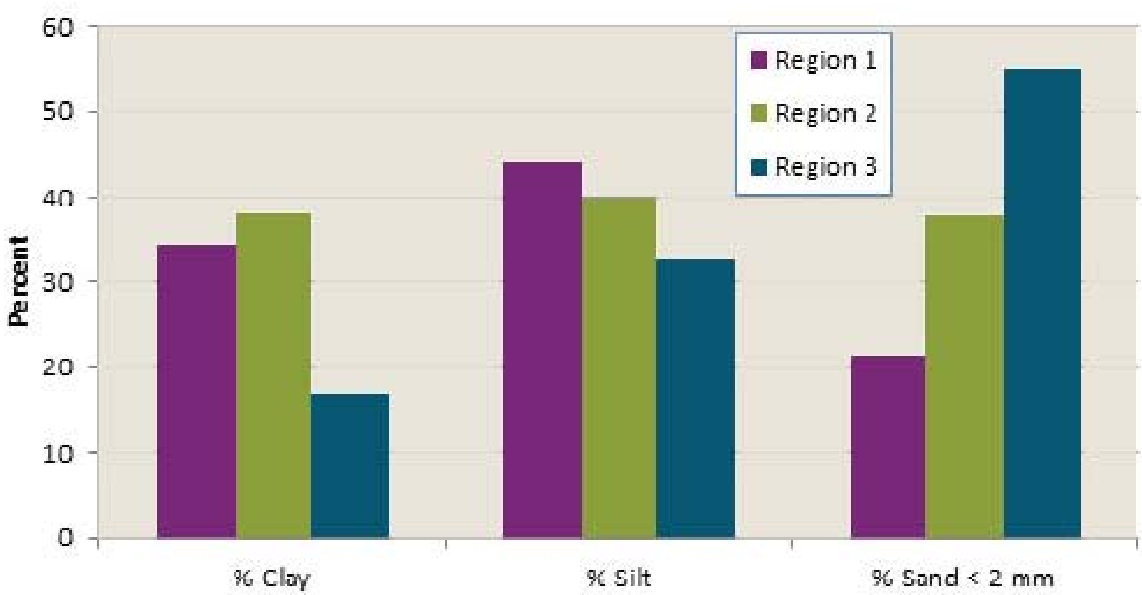


Figure 4.1: Average grain size of New Jersey dredged material by region

The Geotechnical Evaluation Process

Understanding the geotechnical behavior of sediment is essential for determining its suitability for beneficial use. In most cases, key geotechnical indices, such as index properties, unconfined compressive strength, and permeability, are the basis for selection and evaluation of material performance and meeting geotechnical design criteria. However, depending on the type of application and project performance specifications, a project-specific geotechnical experimental plan is normally devised to aid with design and performance evaluation. The focus of this section is to provide a framework for geotechnical testing and evaluation. The process for assessing the potential for beneficial use from geotechnical standpoint is summarized in Figure 4.2.

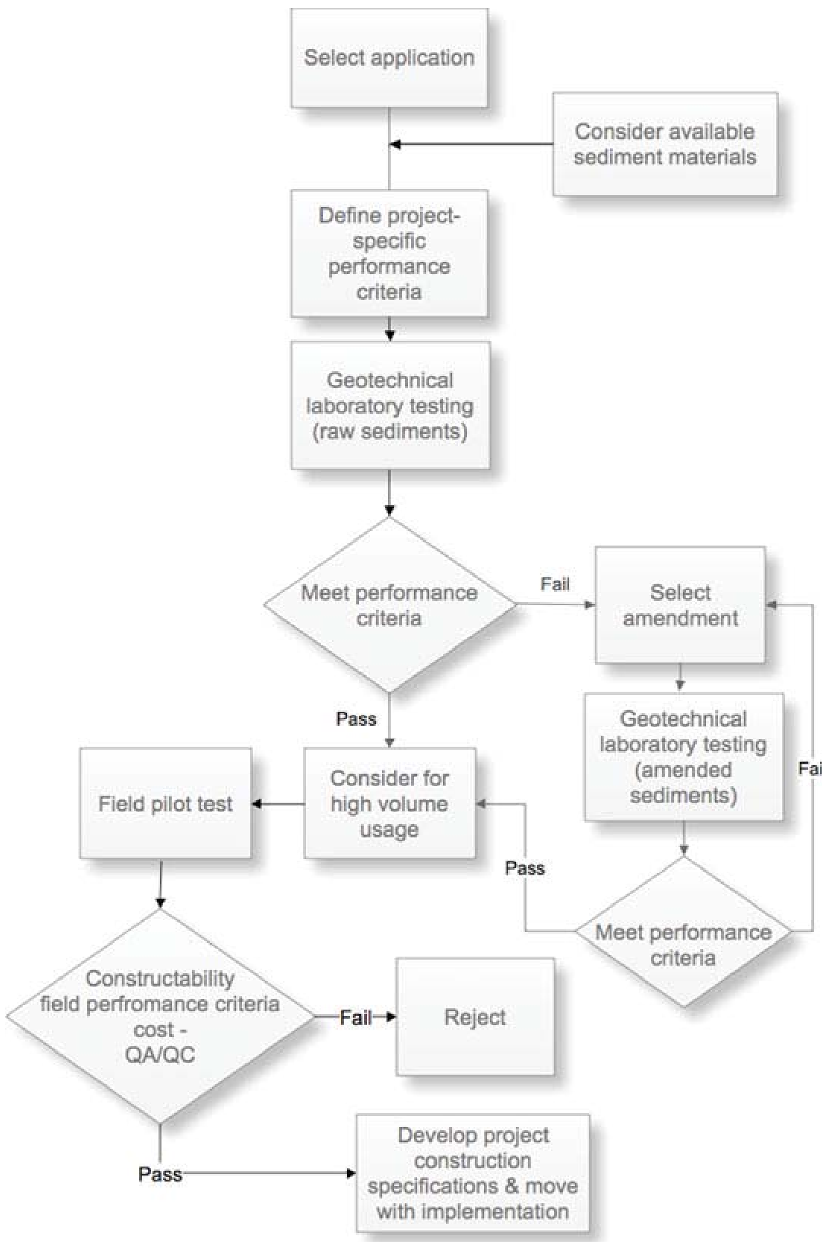


Figure 4.2: The process for beneficial use assessment

Dredged Material Source Characteristics

A wide variety of sediment types are dredged from the New York/New Jersey Harbor during capital construction or maintenance of navigation channels. These include fine-grained silt, pre-industrial red clay, glacial till, rock, and sand. With the exception of silt, most of this dredged material is not only clean, but able to be used beneficially in much the same way as any other quarried aggregate. Accepted beneficial uses include transportation-related construction materials, reef construction, habitat remediation, and beach replenishment. Over the past several decades, millions of cubic yards of these materials have been beneficially used for these purposes. However, it is the fine-grained material typical of mudflats, and fluidized mud typically found filling previously dredged channels, that has proven difficult to beneficially use and is the management concern addressed by the techniques presented in this manual. This section discusses the geotechnical properties of maintenance dredged material typical of New York/New Jersey Harbor.

Maintenance dredged material from the New York/New Jersey Harbor tends to be a highly organic fluid mud. It has high moisture and high organic matter content, making it very difficult to handle and use beneficially. An effective way to improve the geotechnical properties and handling characteristics of this type of dredged material, as well as make it suitable for a variety of beneficial uses, is to process (i.e., stabilize) the material using lime or cement-based additives. Stabilization and subsequent solidification of sediment results in a product with a lower moisture content, a stronger internal matrix, and in some cases, lower potential to leach contaminants. Throughout this manual, we refer to this stabilized sediment product as processed dredged material (PDM).

There has been considerable research into the methods, types, and ratios of additives required to produce useful PDM. Although most processors utilize Portland cement or lime, due in part to their predictable characteristics and ready availability, other additives have been used as well. Byproducts of lime or cement production, such as lime kiln dust or cement kiln dust, are cheaper than their parent products and are readily available. However, due to the lower amounts of available calcium oxide (CaO) in these products, lime kiln dust and cement kiln dust are less effective than lime or Portland cement.Fly ash has also been used as an additive, mostly in conjunction with cement or lime, to lower the overall cost of the additives in the PDM mix design. However, lowering costs in this way results in an increase in the overall volume, requiring transportation and placement. Therefore, the choice of additive and method of processing becomes a balancing act that necessitates a good understanding of the desired outcomes and the methods to achieve them. This chapter provides the engineer with a good background in the available geotechnical data on raw and processed dredged material.

Potential Beneficial-Use Applications

Increasing the potential to utilize high volumes of sediment from dredging operations in beneficial use applications is a priority for maritime transportation planners because it ensures adequate placement capacity for the management of dredged material. High-volume usages include the following:

- Landfill caps and fills
- Brownfield caps and fill
- Roadway embankments
- Controlled low-strength flowable fills

Each of these applications has separate and distinct aggregate and fill needs. In order to determine if the dredged material from a specific project is suitable for a specific beneficial use, geotechnical data must be obtained and analyzed. See Table 4.1 for a summary of applications and corresponding geotechnical criteria and testing methodologies.

Application	Index Properties & pH	Shear Strength	Compaction Characteristics	Permeability	Durability (freeze-thaw)& Corrosivity	Compressibility
	ASTM D421, D422 D4318, D4972, AASHTO T267	ASTM D2166, D5102, D1883, C109	ASTM D698	ASTM D2434	ASTM D560 ASTM G51	ASTM D4168-06
Landfill Caps & Fills	For final cover <20% passing No. 200 At least 40% Pass No. 10	Function of design specification	90–95% of Standard Proctor*	$\leq 1x10^{-7}$ cm/sec for liners, and $\leq 1x10^{-5}$ for final cover		
Brownfield Caps & Fills	For final cover: <20% passing No. 200 At least 40% Pass No. 10	Function of design specification	90% of Standard Proctor*	$\leq 1x10^{-7}$ cm/sec for liners, and $\leq 1x10^{-5}$ for final cover		
Roadway Embankments	Acceptable Materials for Embankments include I-7, I-8, I-10, I-11, I-13, I-14 and I-15*	Slope Stability = f (design) but could reach up to 1:1, CBR=10 for sub-base of roadways over embankment	90–95% of Standard Proctor*		Corrosivity Criteria Chloride <0.5% Sulfate<0.3% Must protect PDM against frost to minimize volume change	Thresholds are project specific
Controlled Low-Strength Flowable Fills		Shear strength range from 300 to 1000 psi, to allow for future excavation				
Top Soil	NJDOT Manual* Table 917.01-1					

* State of New Jersey Department of Transportation (NJDOT) (2007). *Standard Specifications for Road and Bridge Construction,* Trenton, New Jersey

Table 4.1 Required geotechnical properties and evaluation procedures

A summary description of the key testing procedures indicated in Table 4.1 above is as follows:

o ASTM C109: Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-inch [50-mm] Cube Specimens)

This test method provides a means of determining the compressive strength of hydraulic cement and other mortars. Typically, a 2-inch (50-mm) cubed specimen is compressed in a hydraulic apparatus. The amount of force being applied at failure is recorded as the compressive strength. This result may be used to determine compliance with specifications or to obtain a general understanding of the specimen's strength. Caution must be exercised in using the results of this test method to predict the strength of concretes, especially those containing large amounts of aggregate.

o ASTM D421: Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants

This practice covers the dry preparation of soil samples as received from the field for particle-size analysis and the determination of the soil constants. Typically, the sample is air-dried until all moisture has been removed. The dried sample can then be used in other test, such as particle-size and plasticity analysis. When it is known that air drying may have an effect on the prepared sample, other wet preparation practices can be sought out and utilized.

o ASTM D422: Standard Test Method for Particle-Size Analysis of Soils

This test method covers the quantitative determination of the distribution of particle sizes in soils. Typically, the sample is first dried using ASTM D421. Then, for those particles with sizes larger than 75 micrometers (µm) (those particles retained on the No. 200 sieve), the distribution is determined by sieving. For those particles with sizes smaller than 75 µm, the distribution is determined by a sedimentation process using a hydrometer.

o ASTM D560: Standard Test Method for Freezing and Thawing Compacted Soil-Cement Mixtures

These test methods are used to determine the resistance of compacted soil-cement specimens to repeated freezing and thawing. Typically, the sample is wetted using the test methods detailed in ASTM D559. The sample is then subjected to repeated freeze-thaw cycles and compared with criteria given in the Soil-Cement Laboratory Handbook to determine the minimum amount of cement required in the soil-cement to achieve a degree of hardness adequate to resist field weathering.

o ASTM D698: Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12400 ft-lbf/ft3 (600 kN-m/m3))

These test methods cover laboratory compaction methods used to determine the relationship between molding water content and dry unit weight of soils (compaction curve). Typically, the soil is compacted in a 4-inch or 6-inch (101.6-mm or 152.4-mm) diameter mold with a 5.50 pound-force (24.5 N) rammer dropped from a height of 12.0 inches (305 mm), producing a compactive effort of 12400 ft-lbf/ft3 (600 kN-m/m3). Compaction, the densification of soil by mechanical means, can increase the shear strength, decrease the compressibility and decrease the permeability of the soil.

o ASTM D1883: California Bearing Ratio (CBR) of Laboratory-Compacted Soils

This test method is used to evaluate the potential strength of subgrade, subbase, and base-course material, including recycled materials for use in road and airfield pavements. The test is performed by measuring the pressure required to penetrate a soil with a plunger of known area. This pressure is then compared to standardized crushed rock material. In general, materials with a higher CBR are capable of higher load bearing capacities.

o ASTM D2434: Standard Test Method for Permeability of Granular Soils (Constant Head)

This test method covers the determination of the coefficient of permeability by a constant-head method. The test describes multiple devices for this purpose, but a typical set up involves the soil being placed in a cylinder while allowing water, at a constant head and undergoing laminar flow, to pass through. Regardless of the device chosen, the procedures are used to establish representative values of the coefficient of permeability of granular soils that may occur in natural deposits as placed in embankments, or when used as base courses under pavements.

o ASTM D4318: Standard Test for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

These test methods are used to determine the liquid limit, plastic limit, and plasticity index of soils. The plastic limit measures the amount of water present in the soil when it just begins to exhibit plastic behavior. The test is performed by recording the amount of water present at the time the soil just begins to crumble when rolled up into a thread approximately 1/8-inch in diameter. The liquid limit test is used to determine the amount of water present in the soil when it changes from plastic to liquid. This test is performed by recording the amount of water present when a pat of soil, cut by a standard groove, flows together and meets after being impacted 25 times in a round bowl. The plasticity index is the difference between the liquid limit and the plastic limit. These tests are used extensively, either individually or together, with other soil properties to correlate engineering behavior such as compressibility, hydraulic conductivity (permeability), compactibility, shrink-swell, and shear strength.

o ASTM D4972:Determination of Soil pH

The pH of the soil is a useful variable in determining the solubility of soil minerals and the mobility of ions in the soil, and assessing the viability of the soil-plant environment. Measurements of pH values are made in both water and a calcium-chloride solution because the calcium displaces some of the exchangeable aluminum. The low ionic strength counters the dilution effect on the exchange equilibrium by setting the salt concentration of the solution closer to that expected in the soil solution. The pH values obtained in the solution of calcium chloride are slightly lower than those measured in water due to the release of more aluminum ions that then hydrolyses. Therefore, both measurements are required to fully define the character of the soil's pH.

o AASHTO T267:Determination of Organic Content in Soils by Loss on Ignition

TRB's National Cooperative Highway Research Program (NCHRP) web-only document 163,"Precision Estimates of AASHTO T267: Determination of Organic Content in Soils by Loss on Ignition," includes the results of an interlaboratory study to prepare precision estimates for the American Association of State Highway and Transportation Officials' T267 test method used for the determination of organic content in soils by loss on ignition.

Geotechnical Properties of Unprocessed Dredged Material

The geotechnical engineering properties of raw silt sediments are typically very poor. Compressibility, plasticity, and moisture content are high, resulting in low shear strength. Such poor physical properties make silt sediments difficult to handle and compact. A number of shear strength and compressibility tests were conducted by the Port Authority of New York/New Jersey in 1996 to quantify the shear strength and consolidation properties of silt sediments in New York/New Jersey Harbor. The results are presented in Table 4.2.

Source Location	Moisture (%) Content	Specific Gravity	Shear Strength (psf) [1]	Consolidation Parameters Cc/1+eo	Cr	eo
Port Authority Brooklyn Piers, New York	173.8	2.53	28-132	0.22	0.2	4.34
Howland Hook, New York	174.2	2.53	--	0.2	0.15	4.34
Raritan River, New Jersey	88.6	2.64	--	0.21	0.08	2.34
Passenger Ship Terminal, New York	130.7	2.54	--	0.22	0.12	2.69

Table 4.2: Engineering properties of New York/New Jersey Harbor silt sediments [2]

(1) Laboratory Tore Vane Shear Device was used for strength determination

(2) From Dunlop, 1996

Although it is not typically used beneficially in upland situations, it is important to understand the geotechnical properties of unprocessed fine-grained silty dredged material in order to understand how to handle and treat it.We have described the physical properties of sediments following the same conventions as soils: using the index propertiesto describe the characteristics of compressibility, permeability, and strength.

Grain Size Distribution

Surficial sediment in the New York/New JerseyHarbor istypicallyclassified as high plasticity silt (MH) or organic silt (OH) based on index properties and organic content.Most samples are high in silt (50 to 85 percent), with smaller amounts of clay (2 to 24 percent) and little or no sand (see Table 4.3). Organic matter content can run as high as 5 percent or more. In the outer reaches of the harbor, sands are more prevalent, some of which are suitable as high-quality beach sand. In the deeper deposits, consolidated clays and glacial tills are found, as are outcroppings of basalt, gneiss, and sandstone. Grain size and organic matter content are required testing parameters for all dredging permits; however, the engineer will need to infer the soil classification from these data.

Moisture Content

Moisture content is defined as the ratio of the mass of water to the mass of dry solid in a sample. Due in part to the high energy of the system, most of the surficial sediments in the harbor are high in moisture, with some actually containing more water than solids. Note that in situ water content is lower than the water content in the actual dredged material, since additional water is mixed with the sediments during the dredging process. This fluid mud character is the reason that maintenance dredged material is often referred to as "black mayonnaise."

Since the amount of water that a soil will hold varies considerably depending on the grain size distribution and the type of parent material that the soil arises from, engineers prefer to gauge moisture content against the behavior of the particles using the liquid limit and plastic limit index properties. The liquid limit represents the amount of water needed to allow a soil to flow, whereas the plastic limit is the amount of water that is necessary to hold the particles into a single shape, such as a cylinder. The range of these two moisture contents is the plasticity index and is an indication of the potential suitability of the soil in engineering applications. Since we are considering using sediment for construction of fills, we first should look at the raw sediment's characteristics and compare it to traditional fill material (soil). It is generally accepted that soils with a high plasticity index (greater than 40) are considered unsuitable for most construction. This is due in part to the high amount of water held in the matrix, which reduces compressibility.

As illustrated in Table 4.3, most raw maintenance dredged material has a plasticity index outside of the useful range for construction. In fact, when the moisture content exceeds the liquid limit, the material behaves as a fluid mud. Many samples of silty dredged material fall into this category and consequently are not only unsuitable as fill material, but are actually quite difficult to handle. Clays and tills are often considerably better, with the red-brown clay typical of Newark Bay having a plasticity index of 9 to 12 (Maher, 2005b). Glacial tills from the region are primarily composed of this Newark Bay clayey silt and have similar or even better index properties. Both clay and till from New York/New Jersey Harbor have been used successfully with little or no processing or conditioning prior to use.

Source Location[2]	Sample Type	Classification USCS[1]	Sand %	Silt %	Clay %	Moisture Content %	LL-PL[4]	Permeability (cm/sec)
59th St. Pier, NY	Core	OH	15	78	7	95.2	75–34	3.4 x 10-6
Arthur Kill, NJ	Clamshell	OH	10	78	12	181	113–70	-----
Kill v. Kull, NJ[5]	Excavator	GC	59	25	16	12.5	8.8–6.3	-----
Low. Passaic, NJ	Core	OH	4	74	22	143.4	108–60	2.9 x 10-8
Newark Bay, Lower Channel	Core	OH	40	50	2	69.9	54–30	5.5 x 10-8
Newark Bay, NJ[3]	Excavator	CH	6.5	33	60.5	35	38.9–26.1	1.0 x 10-7
Newark Bay, Port Elizabeth	Core	OH	19	72	9	180.5	93.5–54	3.8 x 10-8
			22	70	8	175.4	88–52	
			14	80	6	146.4	100–64	
PANYNJ Terminals	Core	OH	2	85	12	159.4	105–61	2.7 x 10-8
Perth Amboy, New Jersey	Core	OH	8	76	11	169.3	116–64	7.3 x 10-6
Red Hook Chnl, New York	Core	OH	36	58	3	83.5	64 –28	4.1 x 10-7
	Core	OH	25	69	3	95.5	63-31	7.9 x 10-7
	Grab	OH	39	57	3	117.3	80-45	2.8 x 10-6
Weehawken, New Jersey	Core	OH	6	70	24	104.5	85–46	3.7 x 10-8

(1) Unified Soil Classification System
(2) Data from Dunlop, 1996, except as otherwise noted.
(3) Data from Maher, 2005b.
(4) LL–PL = Liquid Limit–Plastic Limit; the difference between these values is the plasticity index
(5) Port Authority of New York/New Jersey, unpublished data
(6) Data from Dermatas, 1999

Table 4.3: Physical properties typical of New York/New Jersey Harbor silt sediments

pH

The pH of raw dredged sediments is slightly on the alkali side, typically 7 to 7.5. Due to high concentrations of chloride and sulfate ions, dredged sediments are corrosive in nature; therefore, concrete or steel materials coming in direct contact with them should be protected.

Compressibility

The compressibility of sediments varies with their age and depth. Aged sediments usually have lower compressibility than new deposits or maintenance dredged material. Based on the information provided in Table 4.2, a compressibility coefficient of 0.2 (defined as Cc/1+eo) is typical of New York/New Jersey Harbor sediments. Newark Bay silt sediments are usually soft (normally consolidated), and thus considerable settlement should be expected if they experience loading. If used as fill at upland sites, preloading or dewatering could reduce their compressibility. Since these silt sediments are relativelyhigh in organic content, long-term settlement (or secondary consolidation) due to the degradation of the organic matter should be considered if sediments are to support loads.

Shear Strength

There is not a wealth of data on the insitu strengths of soft sediment deposits. Nonetheless, the shear strength is expected to be very low to zero for all practical purposes. Aged deposits may demonstrate nominal shear strength, while recent deposits or dredged sediments have practically no shear strength. TORVANE shear strength tests performed on vibracored samples from the Brooklyn Pier area of the East River indicated shear strength of 130 psf or less at natural moisture content (Dunlop, 1996). On the other hand, the shear strength of consolidated clays such as Newark Bay red-brown clays can be as high as 2,000 psf after a minimal period of moisture conditioning (Maher, 2005b).

Permeability

The permeability of silt sediments is similar to silt soils and is in the range of 10-5 cm/sec to 10-7 cm/sec, depending on sand and clay content. Testing performed on New York/New JerseyHarbor sediments by the PANYNJ for samples with particle sizes within the silt range indicated that a permeability of 10-5 cm/sec or less should be expected(see Table 4.3).The low permeability of silt sediments makes them suitable for cap application in landfills or contaminated remediation projects.

Geotechnical Properties of Processed Dredged Material (PDM)

Solidification/stabilization is accomplished by the addition of a given pozzolan (typically lime, ash, or Portland cement) to dredged material ina predetermined ratio based on the either weight (pugmill processing) or volume (in-scow processing) of the dredged material. This ratio is based on the desired properties of the resulting PDM, including(but not limited to) specific PDM strength, compressibility, swell, and permeability characteristics. The desired characteristics depend on the intended beneficial end use, and will dictate the type and amount of additives and conditioning required. Laboratory bench-scale testing of the PDM is conducted prior to full-scale field implementation to determine the type and ratio of the additive(s) needed to meet the project-specific PDM performance characteristics (i.e., the PDM "recipe"). In addition, the additives must solidify the dredged material enough to facilitate the transportation, handling, and placement of the PDM.

We have described the physical properties of PDM with the same convention as soils, using index properties to describe the characteristics of grain size and moisture content, and engineering properties to describe characteristics of compressibility, permeability, and strength. The strength and durability of the PDM product is described using the results of the conventional testing methods of California Bearing Ratio and Resilient Modulus, as well as evaluation of swell potential and freeze-thaw characteristics.

Chemistry of Stabilization/Solidification

Due to the heterogeneity of dredged material, the variety of additives available, the wide range of climatic conditions encountered, and their influence on the process, it is important for the engineer to have a solid understanding of the chemistry underlying the creation of PDM. Since the chemistry of the byproduct reactions is essentially a function of the amount of lime or cement available in them, we only discuss the chemistry of the two parent additives.

Lime

For the purposes of processing dredged material, the two common forms of lime used are quicklime (CaO) and hydrated lime ($Ca(OH)_2$). Quicklime is a coarse-grained powder with a bulk density of approximately 65 poundspercubicfoot (pcf). Lime reacts with water to produce hydrated lime, generating considerable heat in this exothermic reaction:

$$CaO + H_2O \rightarrow Ca(OH)_2 + 65.3 \text{ kJ/mole}$$

Hydrated lime is also used in the form of a powder, with a bulk density of 53 to 66 pcf, or as a slurry with a water content of 80 to 100 percent. Most processors prefer quicklime over hydrated lime.

There are two general types of dredged material–lime reactions: short-term reactions that include hydrationand flocculation/agglomeration, and long-term reactionsthat include cementation or stabilization.During hydration, quicklime will immediately react with water in the dredged material, reducing its moisture content and enhancing its handling characteristics. This process plays a crucial role in drying out dredged material with high initial moisture contents.During flocculation/agglomeration,dredged material particles, sodium, and other cations adsorbed to clay mineral surfaces are exchanged with calcium. Thiscation-exchange process affects the way the structural components of clay are connected together, causingthe clay particles to coagulate, aggregate, and then flocculate. The resulting PDMis more friable and granular than the dredged material (i.e.,plasticity is reduced), making it easier to work and compact with traditional construction equipment. In addition, the swell and shrink potential of the PDMis less than that of the dredged material. Flocculation and agglomeration generally occur in a matter of hours.

Longer term dredged material–lime reactions include cementation and stabilization. During cementation, the reaction of clay and lime removes silica from the clay mineral lattice. The structure of the stabilized clay is an assembly of hard-skinned, lime-poor lumps of clay embedded in a lime-rich, fine-grained soil matrix (Herzog and Mitchell, 1963). During stabilization, silica and alumina are released and react with calcium from the lime to form calcium-silicate-hydrates and calcium-aluminate-hydrates,cementitious products that are similar to those formed in Portland cement.

Cementation is the main contributor to the strength of PDM and is limited by the amount of available silica in the dredged material—increasing the quantity of lime added will increase the strength of the PDM only to the point where all of the silica in the clay component of the dredged material is consumed. This is different than in concrete, where the concrete strength continues to improve with increasing amounts of added cement. Since a high-alkaline condition is required for pozzolanic reactions to occur, the optimum amount of lime required for stabilization is the amount that achieves a pH of 12.4 or higher (Arman and Munfakh, 1970).

In general, the main benefits of lime stabilization of dredged material are improved workability, increased strength, and volume stability. However, the cost and availability of lime products have made them less preferable than Portland cement for most projects.

Portland Cement

Portland cement is the most commonly used additive for the solidification/stabilization of dredged material in the New York/New Jersey Harbor. The reaction of cement and water forms cementitious calcium silicates and aluminates hydrates, which bind dredged material particles together. This hydration reaction releases hydrated lime—Ca(OH)2—which in turn reacts with clay minerals. Hydration occurs immediately upon the introduction of cement to the dredged material, while secondary reactions, such as cementation, occur at a slower rate, similar to the dredged material–lime reaction. Many studies (Oweis, 1998; Parsons Brinkerhoff Quade and Douglas, 1999) suggest that strong bases formed during the hydration of cement dissolve silica and alumina from dredged material, and that calcium ions liberated during the hydrolysis of cement react with the dissolved silica and alumina to form cementitious material. The end result is that thePDM contains both hardened cement particles and hardened dredged material particles.

Index Properties of PDM

The physical properties of PDM that are of particular interest include its moisture (water) content, plasticity index, pH, and organic content.

Moisture (Water) Content

The workability and handling characteristics of dredged material and PDM are greatly affected by moisture content. The typical water content of dredged material is well above the optimum for compaction; thus, significant water reduction is needed to allow for handling and placement of PDM at upland sites. The addition of lime and/or cement consumes some of the excess water as a result of the hydration process.

Moisture content reduction occurs immediately after the addition of lime or cement to the dredged material. The rate of reduction is initially faster when using lime compared to cement due to the higher concentration of available CaO in quicklime. However, once the available CaO is consumed in quicklime, additional moisture reduction methods become necessary. Conversely, withPortland cement the initial moisture reduction rate is slower, but it continues over a longer period of time—water is consumed while pozzolanic reactions between cement and dredged materialcontinue to occur days after the initial mixing of the dredged material and cement. Therefore, PDM made with Portland cement benefits from some amount of curing time prior to placement.

The observed reductions in moisture content after processing silty dredged material from New York/New Jersey Harbor using a variety of additives and mixture ratios are listed in Table 4.4. Significant moisture reduction occurs immediately after mixing of the additives and the dredged material, with additional moisture reduction continuing to occur days later. These data also indicate that quicklime or lime kiln dust is more effective in lowering water content than Portland cement. The additives are also more effective if mixed in dry form rather than slurry.

After five days of mixing, the moisture content of the various PDM recipes are still well above the optimum, and further moisture reduction is required before the PDM can be properly compacted. It is also apparent from these data that simply the enhancement of additive does not necessarily result in as much moisture reduction as curing. Therefore, for further moisture reduction, the PDM should be spread in thin layers and worked continuously in the field during favorable weather conditions. This method is used to expose PDM to the sun to dry, and depending on weather conditions, this process may take several days to complete.

Table 4.4: Water content reduction in dredged sediments from blending additives

Sampling Location	Additive(s)	Percent Additive (on wet weight basis)	Initial Water Content (%)	Moisture Content Immediately after Mixing	Moisture Content (in 5 days)
Arthur Kill, New Jersey[2]	lime, fly ash fly ash	10, 15 15	178-185	91.3 120.9	61.7 80.5
Linden, New Jersey[3]	cement , fly ash cement , fly ash	5, 5 5, 10	142	107.2 95.9	--- ---
Erie Basin, Brooklyn, New York[3]	cement slurry[1]	8.5 13 17.5 22	135	115.7 110 106.5 100.5	109.6 106.3 100.6 96.8
Newark Bay, New Jersey[3]	cement cement, fly ash cement, fly ash	8 5, 5 5, 10	163	125.3 124.8 111.7	105.7 105.2 99.8
Weehawken, New Jersey [(4)]	cement	9 11 13	132	121 113 108	65% reduction
Port Newark, New Jersey[5]	cement lime kiln dust cement kiln dust	8 20 20	73 149 175	55.9 75 111	--- --- ---

(1) Water to cement ratio of 52% was used.

(2) Parsons Brinkerhoff Quade and Douglas, 1999

(3) Data from private dredged jobs, obtained from OENJ Cherokee, Farhad Jafari, 2012.

(4) Dermatas, et. al., 1999

(5) Oweis, 1998

To expedite the drying process and improve handling of PDM, the utility of mixing construction and demolition screenings (CDS) with cement amended dredged materials was investigate in a study by Maher and Soler, 2001. The results of the study showed that addition of CDS, up to 40% by weight, resulted in reduction of water content up to 40% (Figure 4.3) immediately after mixing and hence producing a material that is easier to process and handle in the field.

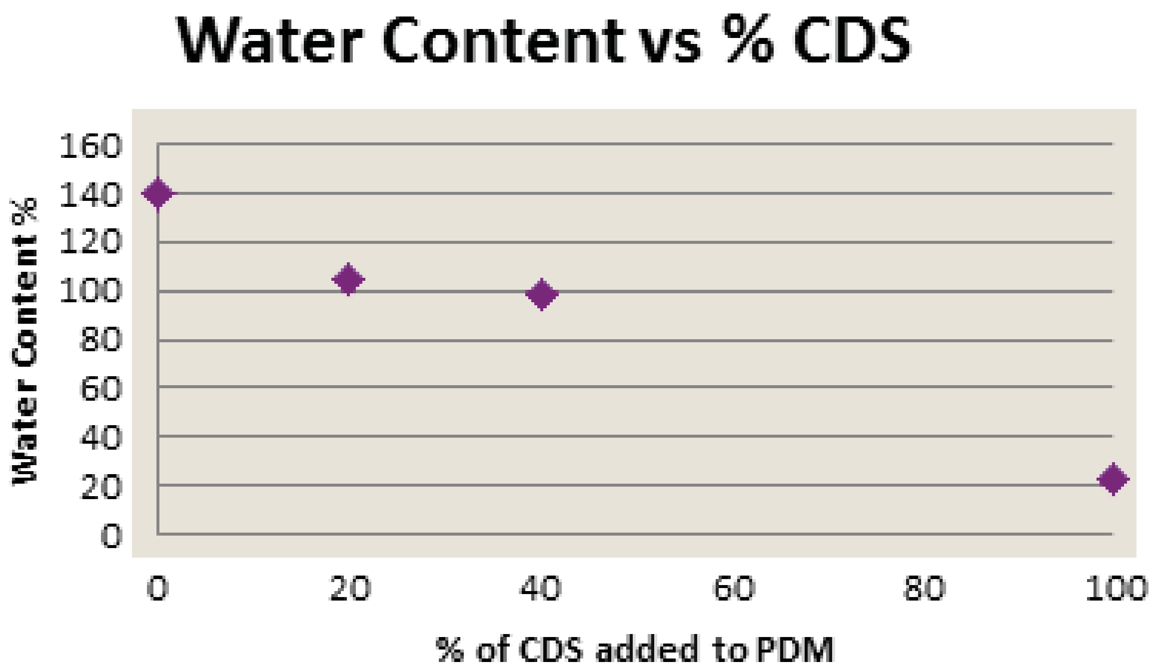


Figure 4.3. - Initial water content vs Percentage of CDS added (Maher and Soler, 2001)

Plasticity Index

The addition of cement or lime to dredged material produces a PDM with a lower plasticity index, particularly if the dredged material is mostly silt/clay. Depending on the particle size distribution of the dredged material, a reduction in plasticity index of PDM could be caused by either a reduction in the liquid limitor an increase in the plastic limit. A reduction in the plasticity index is an indication of improved workability of the PDM.

Table 4.5shows the changes in the plasticity index of siltydredged materialfrom a number of projects following the addition of lime, cement, and/or fly ash. In all cases, the plasticity of the dredged material decreasedafter it was converted into PDM. Although immediate results indicated that lime-based additives were more effective at reducing the plasticity, cement was shown to be just as effective if the PDM was allowed to cure for extended periods of time. PDM made with fly ash providedthe best plasticity reductions, due to the additional silica in the fly ash, which allowed thepozzolanic reactions to continue for a longer period.

Source	Soil Type	Additive	Curing Time	Plasticity Index (Raw Sediments)			Plasticity Index (PDM)		
				LL	PL	PI	LL	PL	PI
Arthur Kill, New Jersey[2]	MH	15% fly ash	2 hours	116	42	74	98	44	54
		15% fly ash	1 day	126	62	64	92	58	34
		15% fly ash	5 days	123	48	75	104	60	44
		15% fly ash +10% lime	2 hours	116	42	74	98	62	36
		15% fly ash +10% lime	1 day	126	62	64	98	63	25
		15% fly ash +10% lime	5 days	123	48	75	91	59	32
	MH	8% lime	7 days	123	56	67	128	96	36
	CH	8% lime	7 days	98	39	59	98	62	36
Newark Bay, New Jersey[3]	MH						64	38	26
		20% LKD	None	99	43	56			
							68		29
								39	
		20% CKD	None						
							110		40
	MH/OH							70	
				101	36	56			
		8% PC	None						
	MH								
Wee-hawken, NJ [4]	OH	9% PC	7	100	38	62	99	79	20
		11% PC					98	77	21
		13% PC					96	75	21
Newark Bay [5]	OH	8% PC	7				65	46.3	
		8% PC + 20% CDS					58.8	NP	
		8% PC + 40% CDS					60.5	NP	
Upper New York Bay, New Jersey[1]	MH	None	NA	104	61	43			
	MH	4% PC	1 months				84	44	40
	MH	4% PC	6 months				57	38	19
	MH	8% PC	1 months				89	72	17
	MH	8% PC	6 months				66	50	16
	MH	8% PC + 10% fly ash	1 months				62	54	8
	MH	8% PC + 10% fly ash	6 months				62	57	5

(1) Maher et al., 2004

(2) Tanal, et. al., 1995

(3) Oweis, 1998

(4) Dermatas, 1999

(5) Maher and Soler, 2001

MH = highly plastic silt, OH = organic silt, CH = highly plastic clay, PC = Portland cement, CKD = cement kiln dust, LKD = lime kiln dust, CDS = Construction Debris Screening, NP = nonplastic, pcf = pounds per cubic foot, LL = liquid limit, PL = plastic limit, PC = plasticity index, NA = not applicable.

Table 4.5: Plasticity index of raw and amended dredged material

pH

Table 4.6 shows the typical pH values for New York/New Jersey harbor dredged material and PDM with various ratios of additives. Following the addition of lime or cement, the pH of the PDM significantly increases compared to the dredged material. Since the optimum lime content in PDM is the amount of lime needed to increase its pH to 12.4 (Arman and Munfakh, 1970), increasing the lime content beyond the optimum amount does not effectively increase the dredged material–lime reactions. However, for cement, the pH of the PDM continues to increase with the amount of cement.

Over time, the pH of the PDM decreases, but it remains higher than that of the original dredged material. This indicates that concrete and steel materials coming in direct contact with PDM must be coated properly to avoid corrosion. Due to its high pH, lime- and cement-based PDM are unable to support vegetation and should not be considered suitable growing media. If vegetation is desired as final cover, a growth layer of topsoil at an appropriate depth must be provided as a cap on the PDM.

Source	Additive	Raw Dredged Material	pH Immediately after Mixing	One Week after Mixing
Arthur Kill, New Jersey[1]		7.4		
	1% Lime		11.8	
	2% Lime		12.3	
	3% Lime		12.22	
	4% Lime		12.27	
	5% Lime		12.35	
	6% Lime		12.38*	
	8% Lime		12.37	
	2% PC		8.48	
	4% PC		8.82	
	6% PC		9.31	
	8% PC		11.35	
	10% PC		11.55	
	12% PC		11.62	
	14% PC		11.83	
	16% PC		11.92	
Newark Bay, New Jersey[2]	20% CKD	7.4	12.4	10.2
Newark Bay, New Jersey [2]	20% LKD	7.4	12.4	11.8
Weehawken, New Jersey [3]	9% PC	6.2		11.9
	11% PC			11.1
	13% PC			11.

* Addition of 6% lime increased the pH to approximately 12.4 which is considered the optimum lime content.

1 Parsons Brinkerhoff Quade and Douglas, 1999

2 Oweis, 1998

3 Dermatas, 1999

MH = highly plastic silt, OH = organic silt, PC = Portland cement, CKD = cement kiln dust, LKD = lime kiln dust, pcf = pounds per cubic foot

Table 4.6: Typical pH values of raw and amended dredged material

Organic Content

Dredged material from New York/New Jersey Harbor maintenance projects usually contains high amounts of organic matter,ranging from 5 to 15 percent.This organic carbon can inhibit the reaction between calcium and the clay minerals by adsorbing calcium ions and preventing them from forming the pozzolanicreaction with the dredged material(Little, 1995).

A study was performed by Rutgers University and the University of Iowa (Schaefer, 2004) to determine whether organic content alters the stabilizing effects of Portland cement on dredged material. Several mixes of sediments from Newark Bay, Portland cement, and varying amounts of motor oil were prepared. The study found that in general, the higher the organic matter content of the dredged material, the higher the ratio of additives required to achieve the same physical properties in the PDM.

Corrosivity

PDM is potentially corrosive to buried steel or concrete due to its high pH and the presence of chlorides and sulfates. In a series of tests on New York/New Jersey Harbor sediments combined with Portland cement at various percentages, lime kiln dust and cement kiln dust, sulfate ranged from 0.15 to 4.1 percent. In the same samples, chloride ranged from 0.36 to 5.7 percent. Sulfate in excess of 0.3 percent and chloride in excess of 0.5 percent is considered severely or extremely corrosive (Oweis, 1998).

Electrical resistivity tests were performed on samples of raw and processed dredged materialfrom New York/New Jersey Harbor in accordance with the ASTM G-51 using Portland cement, lime and cement kiln dusts, quicklime and fly ash as additives. The test results ranged from 50 to 990 ohms-centimeters indicating that the PDMwas "extremely corrosive," regardless of the additives used(Oweis, 1998).

Microbially induced corrosion is not expected to be a factor in PDM, despite the high organic matter content of dredged material. This is due to the high pH of the PDM and the fact that the pozzolanic reaction itself consumes organic matter.

Thus, project managers should consider the need to protect buried steel or concrete that could come in direct contact with PDM. The level and type of protection depends on the degree of corrosivity of the specific PDM.

Corrosion protection measures—including the installation of a protective coatingon steel or concrete, and the use of low-permeability or sulfate-resistant concrete—are commonly specified where PDM is to be placed. The steel design could also consider the use of a thicker than required steel (to include a sacrificial layer of steel). Concrete or steel pipes could be replaced by PVC or HDPE pipes (or coated with same), which are made of more stable chemicals and are less vulnerable to chemical attacks. For further discussion of corrosion protection measures for various periods of design life, seeCorrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes (USDOT/FHWA publication no. FHWA NHI-00-044).

Engineering Properties of PDM

The main reason for producing PDM is to improve the engineering propertiesod raw dredged material so that it can be used beneficially. The following section outlines research and experience with PDM and how processing improves the strength, compressibility, and durability of dredged material.

Moisture-Density Relationship of PDM

CompactingPDM improves its strength, compressibility, and durability, as well as reduces its permeability. If used as structural fill, PDM should be compacted to achieve sufficient strength to support structural loads with acceptable deformations. To achieve proper compaction, PDM must be compacted at or near the optimum moisture content.

Since the majority of contaminated New York/New Jersey harbor dredged material is comprised of silt and clay, its natural moisture content is well above the optimum. Significant moisture reduction is therefore required to achieve proper compaction in either structural or nonstructural applications. In addition to achieving some lowering of the water content, the addition of pozzolanicmaterials increases the optimum moisture content and decreases the maximum dry density. As a result, PDM can be compacted at higher than optimum moisture contents. Table 4.7presents typical dry densities and optimum moisture content of New York/New JerseyHarbor dredged material mixed with various admixtures, and compacted using modified and standard efforts.

In the case where CDS was used to amend PDM to accelerate the drying process and field placement, maximum dry density increased slightly with increasing fraction of CDS in the mix as shown in the table below. Moreover, there was a marginal decrease in the optimum moisture content when the percentage of CDS is in the 0 to 20% range. When then percentage of CDS increases to the 40% range, the optimum moisture content decreases more markedly. The optimum water content decreased by approximately 10% when 40% CDS is added to the mix. This effect, on the other hand, has to be compared with the decrease in moisture content that results from the lower amount of water present in the CDS. The optimum water content necessary to achieve maximum dry density can be reached more quickly in the 40% CDS samples, a reduction which is maintained over time (Maher and Soler, 2001)

Source	PDM Recipe	Maximum Dry Density (pcf)		Optimum Moisture Content (%)	
		Standard	Modified	Standard	Modified
Arthur Kill, New Jersey[1]	untreated	52	80	41	28.5
	7% PC	70	69	40	31
	5%lime	71	80	42.5	29.5
	10% lime		79		31
	10% lime + 15% FA		73		23
Newark Bay, New Jersey[1]	8% PC	68	79.3	47	33.5
	20% CKD	74.5	88.5	40.3	24.5
	20% LKD	79.7	91.6	32.7	22
Unknown NY Harbor source[2]	sandy silt + 8% PC*		119.2	--	10.5
	fine sand + 8% PC*		113.5		15.4
Weehawken, New Jersey [3]	9% PC		58.03		40
	11% PC		61.15		37
	13% PC		56.78		45
Newark Bay, New Jersey [4]	8% PC		78.5		27
	8% PC + 20% CDS		78.5		25
	8% PC + 40% CDS		80		16.5
Upper New York Bay, New Jersey[2]	4% PC		78.5		28.5
	8% PC		78.7		31
	8% PC + 10% fly ash		78.8		28

(1) Oweis, 1998
(2) Maher, 2001
(3) Dermatas, 1999
(4) Maher and Soler, 2001

MH = highly plastic silt, OH = organic silt, PC = Portland cement, CKD = cement kiln dust, LKD = lime kiln dust, FA = fly ash, pcf = pounds per cubic foot

Table 4.7: Typical maximum dry density and optimum water content of PDM

The fact that the optimum moisture content of the various PDM recipes is relatively low suggests the need for further moisture reduction in the field in order to achieve proper compaction. This can be partially achieved through curing at the processing site, and through proper placement procedures and/or moisture conditioning through methods like disking.In cases where PDM is considered for structural fill applications, most transportation agencies recommend modified-Proctor method for determination of moisture-density relationships (ASTM D-1557).

Perhaps the most important observation from these data is that only negligible changes in the maximum dry density, and only marginal increases in the optimum moisture content, were observed by increasing the cement or lime content beyond 8 to 10 percent.This is similar to findings made by Kezdi where the maxi-mum dry densities of cement-treated silts were found to decrease slightly with increasing cement content

(Kezdi, 1979). However, recent experiences with processing dredged material indicate that higher percentages of additives are useful when the weather is cold.

Shear Strength

Shear strength indicates the level of stresses a PDM mass can tolerate before failure. The unconfined compressive strength or California Bearing Ratio (CBR) is usually used to represent shear strength. The CBR value is also an indicator of the suitability of PDMfor use in road sub-base or sub-grade applications (see Table 4.8).

Source	Material Type	Additive	Water Content (%)	Compaction (% Modified)	CBR
Arthur Kill, New Jersey[1]	MH/OH	5% lime	opt. WC: 29.5%	max dry density: 79.5	
			39	95	18
		10% lime	33.9	97	31
			28.3	97	18
			opt. WC: 31%	max dry density: 78.3	
			46.4	88	3
		7% PC	39.4	97	14
			26.3	90	47
			opt. WC: 31%	max dry density: 68.5	
			38.9	66.2	25
			38.9	67.1	20
			32.8	65.3	15
Newark Bay, New Jersey[2]	MH	20% LKD	opt. WC: 22.0%	max dry density: 91.6	
			20	97	45
			26	97	58
			32	97	10
		20% CKD	opt. WC: 24.5%	max dry density: 88.5	
			20	98	28
			28	98	39
			36	98	19
		8% PC	opt. WC: 33.5%	max dry density: 79.3	
				92	32
				92	31
				79	21

MH = highly plastic silt, OH = organic silt, PC = Portland cement, Opt. WC = optimum moisture content

1 Parsons Brinkerhoff Quade and Douglas, 1999

2Oweis, 2003

Table 4.8: California Bearing Ratio (CBR) of compacted dredged material

The natural shear strength of saturated siltydredged material is marginal; therefore, the addition of cement- or lime-based additives is necessary for PDM to be used as structural fill. For cement-treated soils, it is important to place and compact relatively soon after mixing(allowing for a curing period). It has been found that prolonged storage periods after mixing, followed by disturbance for transportation and placement, results in a loss of bonds between dredged material and cement, reducing shear strength (Maher, 2001). When using cement, shear strength is expected to continuously increase as the cement content of the PDM recipe increases. When using lime, however, the optimum lime content occurs when the PDM has a pH of 12.4 (Arman and Munfakh, 1970).The use of additional lime beyond the optimum amount does not yield a significant shear strength increase.

Other important factors affecting PDM shear strength are its degree of compaction, curing conditions, and remolding moisture content, the latter of which occurs when a sample is disturbed. An increase in compaction is expected to increase the PDM shear strength, while an increase in moisture content is expected to decrease the PDM strength. The shear strength of PDM also tends to increase with increased curing time (provided the dredged material is not disturbed). This phenomenon is more pronounced for cement-dredged material PDM mixes since the silica and alumina in Portland cement continue to react with the clay minerals in the dredged material, resulting in additional strength. The addition of fly ash to a dredged material–lime PDM mix provides the silica and alumina needed for a continuation of the pozzolanic reactions, resulting in similar gains in shear strength.

Unconfined compressive and triaxial shear strength data from a number of projects in the New York/New Jersey Harbor region in which PDM was produced are shown in Table 4.9. These data show that shear strength is highly affected by the PDM's degree of compaction and moisture content. The amount and type of additive(s) used to make the PDM have a lesser impact on the short- and long-term shear strength for remolded samples, since during remolding the dredged material–cement bonds in the PDM are broken. As expected, the shear strength tends to increase with curing time, [this is inconsistent with a statement in the previous paragraph] and is less for "soaked" samples. Samples compacted at or above 90 percent of the modified maximum dry density (ASTM D1557) tend to develop strengths of 1000 psfor higher. If PDM is compacted at moisture contents below its shrinkage limit, the potential for the development of tensile cracks, and consequent shear strength loss, could be minimized.

Source	Material Type	Admixture(s)/ Curing Time	Compaction Ratio (%) (Modified)[4]	Curing Time	Unconfined Shear (psf)	Triaxial Shear Strength (psf)	
						φ° [1]	c [1]
Arthur Kill, New Jersey[1]	MH/OH	5% lime,	89 89 95	7 days	5,200 4,500 10,900		
		5% lime,	92 94.7 98.3	28 days	1,300 5,200 8,100		
		soaked	90.5 93 98	28 days	4,100 2,300 6,300		
		10% lime,	85.7 98 99	7 days	1,000 10,400 6,000		
		10% lime,	91 97 98.4	28 days	1,900 5,600 5,100		
		soaked	90 93 94	28 days	5,300 9,000 8,700		
		7% PC	93 92.5 95	7 days	8,000 6,100 11,100		
		7% PC	81.7 83 84	28 days	2,000 3,600 3,900		
		soaked	82 83 85.5	28 days	600 400 800		
		15% fly ash +10% lime	92 93 91.5	none	4,400 6,600 8,200		

Continued on Page 60

Newark Bay, New Jersey[2]	MH/OH	8% PC	90	none	3,736		
			86		2,408		
		20% CKD	98		16,790		
			91		8,286		
		20% LKD	99		9,486		
			94		6,574		
Upper New York Bay, New Jersey[3]	MH/OH	4% PC	85	1 month		28	1,958
			85			26	1,915
			90			31	3,312
			90			33	2,664
		8% PC	85			30	3,643
			90			32	4,939
			90			35	4,744
		8% PC +10% fly ash	85			30	2,030
			85			33	2,721
			90			34	2,203

						φ° (2)	φ'° (3)	c (2)	c' (3)
Weehawken, New Jersey [4]	OH (Initial water content of 90%)	9% PC	85-90	1 month	6,912				
		11% PC	85-90		10,080				
		13% PC	85-90		------				
Newark Bay [5]	MH and OH	8% PC	90	1 month	9,360				
		8% PC + 20% CDS	90		8,928				
		8% PC + 40% CDS	90		6,624				
Upper New York Bay, New Jersey[3]	MH	4% PC	85	1 month		35	39	1,075	1,094
			85	6 months		37	39	1,784	1,490
			90	1 month		28	46	1,343	707
			90	6 months		34	41	1,547	1,205
		8% PC	85	1 month		37	40	1,526	1,504
			85	6 months		26	30	4,826	4,506
			90	1 month		35	36	2,193	2,330
			90	6 months		36	44	3494	2,832
		8% PC + 10% fly ash	85	1 month		37	30	1,512	1,866
			85	6 months		29	34	2,266	2,164
			90	1 month		26	36	847	655
			90	6 months		39	40	1,422	1,500

1 Parsons Brinkerhoff Quade and Douglas, 1999 2 Oweis, 1998 3 Maher, 2001 4 Dermatas, 1999

5 Maher and Soler, 2001

(1) From unconsolidated undrained tests performed on unsaturated remolded samples

(2) Total friction angle and cohesion from consolidated undrained tri-axial tests

(3) Effective friction angle and cohesion from consolidated undrained tri-axial tests

(4) Samples were compacted on the wet side of the optimum

CKD = cement kiln dust, LKD = lime kiln dust, PC = Portland cement, psf = pounds per square ft, ☐ = friction angle, c = cohesion,

Table 4.9: Typical shear strength of PDM

Compressibility

As soft, untreated dredged material is subjected to service loads, it undergoeslarge strain consolidation settlement, which is the primarymechanism for volume change in soft and saturated soils. The treatment of dredged material significantly reduces the potential for consolidation settlement.To avoid excessive deformations, it is imperative to lower the water content of PDM to near optimum before compaction. Compaction reduces the void volume, thus reducing the potential for excessive deformations to occur. The consolidation characteristics of compacted PDM from projects in New York/New Jersey Harbor are summarized in Table 4.10. In these projects, dredged material from the Arthur Kill and Upper New York Bay were mixed with lime, cement, and fly ash, and were subjected to a one dimensional consolidation test.

Source	Admixture(s)	Remolded Moisture Content (%)	Compaction Ratio (% Modified)	Consolidation Parameters			
				Pc (tsf)	$C_c/1+e_o$	Cr	e_o
Arthur Kill, New Jersey[1]	5% lime,	29.5	100	20-30	0.25	0.01	
Material Type: MH/OH	10% lime,	31.0	100	20-30	0.29	0.01	
	7% PC	31.0	100	20	0.30	0.01	
Newark Bay, New Jersey[2]	8% PC	45.1	87	10-20	0.26	0.03	1.54
Material Type: MH	20% CKD	46.1	80	5-10	0.24	0.03	1.37
	20% LKD	39.3	83	5-10	0.20	0.02	1.15
Upper New York Bay, New Jersey[3]	4% PC	68.4	59	0.88	0.24	0.03	
		87.9	61	4.14	0.24	0.04	2.69
		55.7	83	2.54	0.16	0.03	
Material Type: MH/OH		53.9	87	8.7	0.15	0.02	2.67
		40.6	90	2.19	0.19	0.03	
							1.69
							1.61
		74.4	68	2.51	0.17	0.02	
		63.3	75	6.4	0.18	0.02	1.57
		53.5	81	7.45	0.09	0.02	
	8% PC	64.4	60	1.41	0.24	0.03	
		76.7	64	2.38	0.24	0.02	2.06
		86.5	62	2.83	0.23	0.02	1.79
							1.58
		60	64	2.63	0.2	0.03	2.72
		69.5	68	1.92	0.16	0.02	2.43
		79.3	67	0.97	0.16	0.04	2.54
		54.9	82	7	0.13		
		56	87	8.27	0.15	0.02	2.62
		46	86	1.32	0.16		
						0.02	2.4
							2.6
						0.02	1.55
	8% PC						1.77

MH = highly plastic silt, OH = organic silt, PC = Portland cement, CKD = Cement kiln dust, LKD = lime kiln dust, tsf = tons per square foot, Pc = preconsolidation stress, Cc/1+eo = , Cr = compression ratio, eo = initial void ratio

1 Oweis, 2003

2 Oweis, 1998

3 Maher, 2001

Table 4.10: Consolidation characteristics of PDM

Using the data in Table 4.10, it is clear that pre-consolidation stresses are generally higher than 2 tons per square foot for samples compacted to 85 percent of the modified proctor density or higher. Induced settlements are expected to be low for stresses not exceeding pre-consolidation stress. Also, virgin compression could be as high as 0.3, indicating the occurrence of large deformations once applied stresses exceed pre-consolidation pressure.

These finding were further corroborated by a study conducted on the consolidation characteristics of PDM from Weehaken in NJ by by Dermatas, et. al., (1999). In this study, the authors concluded preconsolidation pressures increased with increasing cement content ranging from 9 to 13% of wet weight. The general range of Cv, coefficient of consolidation, for virgin and recompression coefficients ranged between 0.001 and 0.988 cm2/sec. which corresponded well with the unconfined compression test data confirming that "the higher the Cv value and the lower the volumetric starin, the higher the UCS strength for the respective matrix."

When CDS is mixed with PDM to accelerate drying and field placement, Maher and Soler concluded that adding CDS to PDM does not significantly change or affect the consolidation and swell properties of properties of PDM (Table 4.11).

Sample	Compression Index (Cc)	Swell Index (Cs)	Initial void ratio (eo)	$\frac{c}{c}$
PDM(8% cement)	0.22	0.02	1.289	0.09
	0.25	0.02	1.308	0.08
20% CDS + PDM	0.19	0.01	1.253	0.05
	0.2	0.01	1.252	0.05
40% CDS + PDM	0.24	0.02	1.313	0.08
	0.18	0.01	1.262	0.05

Table 4.11 Summary of Consolidation and Swell Test results for PDM amended with CDS, from Maher and Soler, 2001

Permeability

The placement of a low permeability cap over contaminated soil at a site is usually required by the NJDEP as part of the site remediation process, which serves two main functions: to minimize the infiltration of surface runoff into contaminated soil, decreasing leachate volumes, and to eliminate the potential exposure of human and other receptors to the on-site contamination.

In order to maintain the low permeability required for cap material, PDM must be produced from dredged material that is fine-grained in nature, consisting mostly of silt and clay. In addition, the degree of compaction and moisture content at the time of placement and the type and percentage of additives used to produce the PDM will affect its permeability.

The results of permeability tests performed on PDM produced from Upper New York Bay dredged material are provided in Table 4.12. These data show that PDM compacted to 85 percent of its modified maximum dry density can demonstrate permeability of 10-6 cm/sec or less. The addition of fly ash to the PDM recipe reduces the permeability by an additional 40 percent. If a permeability of 10-7 cm/sec or less is required, very fine-grained material, such as bentonite clay,could be used as an additive in the PDM recipe. The lowest permeability is achieved when the PDM is compacted to near, or slightly higher than, the optimum level.

Source	Material Type	Additive/curing time	Compaction (% modified)	Permeability (cm/sec) (ASTM D-5084)
Upper New York Bay, New Jersey	MH	4% PC/1 month	85	6.92×10^{-7}
		4% PC/1 month	90	5.52×10^{-7}
		4% PC/6 months	85	8.02×10^{-7}
		4% PC/6 months	90	6.03×10^{-7}
	MH	8% PC/1 month	85	1.25×10^{-6}
		8% PC/1 month	90	9.27×10^{-7}
		8% PC/6 months	85	8.07×10^{-7}
		8% PC/6 months	90	6.15×10^{-7}
	MH	8% PC+10% FA/1 mo	85	7.4×10^{-7}
		8% PC+10% FA/1 mo	90	4.6×10^{-7}
		8% PC+10% FA/6 mo	85	6.38×10^{-7}
		8% PC+10% FA/6 mo	90	$4.28\ 10^{-7}$

PC = Portland cement, FA = fly ash, MH = highly plastic silt, data from Maher et al, 2004

Table 4.12: Permeability of compacted PDM samples

In the case of CDS mixed with PDM, Maher and Soler (2001) concluded that permeability is increased with increasing CDS content as shown in Figure 4.4.

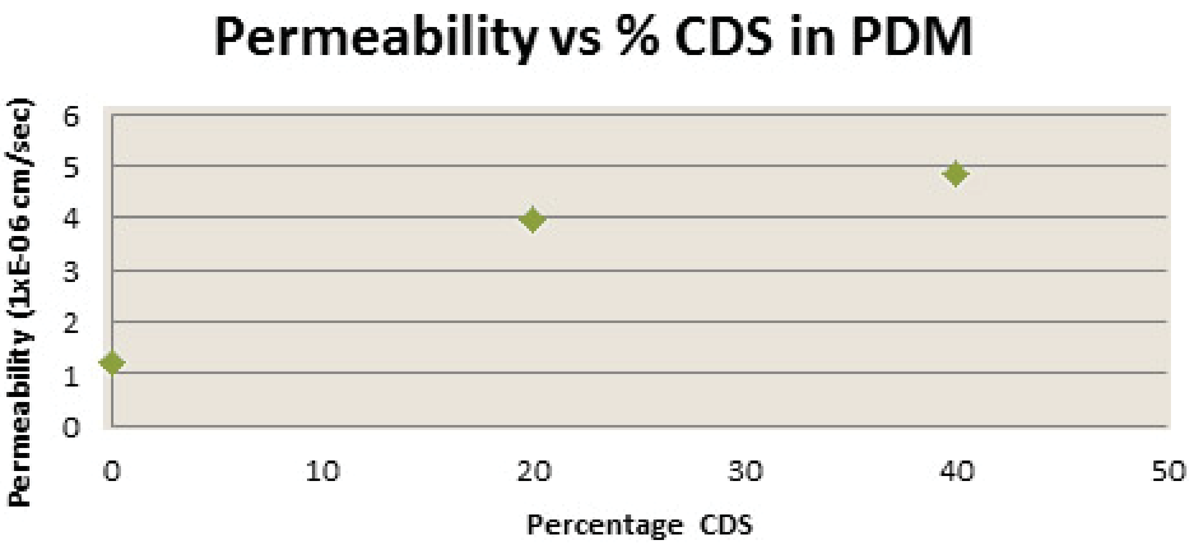


Figure 4.4: Permeability of PDM amended with CDS, data from Maher et al., 2004

Durability

While PDM can be manufactured for a variety of applications, the long-term stability of the material under adverse conditions is a concern, as detailed below. In most cases, it will be important to protect the material from adverse conditions in order to preserve the desired engineering properties.

Swell Potential

Fine-grained dredged material undergoes swelling when it becomes saturated. Should such dredged material support structural loads or roadways, the swell pressure could have adverse effects on their structural stability. In addition, fine-grained dredged material has a flocculated structure at moisture contents below its optimum moisture content. At moisture contents above optimum, dredged material particles form a disperse structure and more of a layered-type formation. For disperse structures, additional moisture does not result in significant volume changes.

Tests were performed to quantify the swell pressure and deformation of PDM produced from New York/New Jersey Harbor dredged material (see Table 4.13). These data indicate a low swell potential for all PDM recipes, and in no cases exceeded 1.2 percent. The swell pressure for the samples compacted on the wet side of optimum were less than 0.2 tons per square foot; but for samples compacted on the dry side of optimum, swell pressure rose as high as 1.95 tons per square foot. Therefore, to avoid potential problems resulting from swell pressure, the PDM should be compacted on the wet side of the optimum level.

Source	Additives	Compacted Moisture (%)	% Max. Dry Density	Saturated Moisture (%)	Swell Pressure (tsf)	Percent Swell (%)
Arthur Kill, New Jersey[1]	5% lime	34	100	--	0.1-0.2	0.1
	10% lime	44	100	--	0.12	0.1
Material Type: MH/OH	7% PC	--	100	--	0.06	--
	10% lime+15% FA	22.8	100	--	0.7	1.0
Newark Bay, New Jersey[2]	20% LKD	16.1	94 (dry side)	47.5	0.61	1.0
Material Type: MH	20% CKD	16.6	95 (dry side)	45.8	1.06	1.2
Upper Newark Bay, New Jersey[3]	4% PC	43.7	90 (wet side)	85.7	0.1	0.1
	4% PC	25.9	97 (dry side)	58.8	0.88	1.0
	4% PC	41.4	90 (wet side)	78.7	0.15	0.4
	4% PC	22.6	96 (dry side)	48.8	0.44	0.8
Material Type: MH/OH	8% PC	52.0	88 (wet side)	99.1	0.14	0.3
	8% PC	22.8	95 (dry side)	50.6	1.95	1.1
	8% PC	41.6	90 (wet side)	79.9	0.25	0.6
	8% PC	28.2	97 (dry side)	62.3	0.76	1.0
	8% PC + 10% FA	45.6	87 (wet side)	82.4	0.1	0.2
	8% PC + 10% FA	27.9	94 (dry side)	56.8	1.2	1.2
	8% PC + 10% FA	45	92 (wet side)	88.2	0.1	0.2
	8% PC + 10% FA	21	96 (dry side)	44.8	0.8	0.6

MH = highly plastic silt, OH – organic silt, FA = fly ash, PC = Portland cement, tsf = tons/ square ft, LKD = lime kiln dust, CKD = cement kiln dust

1 Parsons Brinkerhoff Quade and Douglas, 1999

2 Oweis, 1998

3 Maher, 2001

Table 4.13: Swell potential of compacted dredged sediments

Freeze-Thaw Exposure

Prolonged exposure to moisture and freeze-thaw cycles may affect the durability and shear strength of PDM over the long term. During freeze-thaw cycles, PDM experiences volume fluctuations and an associated strength loss. Some dredged material–cement PDM mixtures have the ability to subsequently regain strength, pending the availability of reactive calcium oxide, adequate temperatures, and a high pH environment. However, following the initial curing of PDM, residual calcium oxide is less likely to be present for dredged material–cement bond reformation. As a result of this condition, any strength loss is permanent (Maher et al., 2006).

The freeze-thaw test simulates the internal expansive forces in fine-grained materials such as PDM. Freeze-thaw cycles and moisture exposure effects on PDMwere evaluated in several studies. Samples of PDM with different additives and proportions were prepared and subjected to freeze-thaw cycles following the procedure recommended in ASTM D560. Selected test results are presented below in Table 4.14.

Material Source	Additives	Water Content (%)	Dry Density (pcf)	Maximum Volume Change (%)	Remarks
Newark Bay, New Jersey[1] $W_{opt.}$: 22% $\gamma_{d\ max}$: 91.6 pcf	20% LKD	32.1	74.7	8.5	Specimen collapsed after 2 ½ cycles
		32.1	74.6	10.5	Specimen collapsed after 2 ½ cycles
$W_{opt.}$: 24.5% $\gamma_{d\ max}$: 88.5 pcf	20% CKD	40.8	73.8	7.0	Specimen collapsed after 2 ½ cycles
		40.8	74.0	9.0	Specimen collapsed after 3 ½ cycles
Upper Newark Bay, New Jersey[2] $W_{opt.}$: 31% $\gamma_{d\ max}$: 78.7 pcf	8% PC	52.4	66.9	14.6	Specimen collapsed after 2 cycles
		52.9	66.3	23.6	Specimen collapsed after 2 cycles
		47.6	69.8	32.9	Specimen collapsed after 2 ½ cycles
		48	70.6	18.8	Specimen collapsed after 2 cycles
Natural Clay[3]		25.5	98.5	2.7	Specimen collapsed after 2 ½ cycles

LKD = Lime kiln dust, CKD = Cement kiln dust, PC = Portland cement. Wopt is optimum moisture content, d max is maximum dry density

1 Oweis, 1998, 2 Maher, 2001, 3 Maher, 2005b

Table 4.14: Freeze-thaw cycles of PDM

The data in Table 4.14 show that PDM samples collapsed after experiencing more than threefreeze-thaw cycles. Significant volume changes (ranging from 7 to 33 percent) were reported during the testing. Considering the maximum volume change for the natural clay sample (2.7 percent), the freeze-thaw effect can be three to 10 times more severe for PDM. As a result, PDM should be protected against frost to the maximum extent possible (e.g., placed below the frost line or insulated; the frost depth is approximately 2.5 to 3 feet in New Jersey). For many projects,the high chloride content and pH of PDM requires an overlying layer of topsoil (Parsons Brinkerhoff Quade and Douglas, 1999). This layer can also serve as a protection against frost.

Wet-Dry Cycles

Wet-dry cycle tests were performed on PDM as part of the NJDOT Embankment Pilot Study conducted in 1999 (Maher, 2001). Samples collapsed after being subjected to between eight and 11 wet-dry cycles (see Table 4.15). Prior to failure, volume changes ranged between 31 and 48 percent of the original PDM volume. Therefore, PDM should be protected against frequent wet-dry cycles by keeping it above the groundwater and by capping it with a growth medium of several feet. This strategy was shown to be effective at the Bayonne Golf Course site (unpublished data).

Material Source	Additives	Water Content (%)	Dry Density (pcf)	Maximum Volume Change (%)	Remarks
Upper New York Bay, New Jersey	8% PC	52.5	66.4	39.6	Specimen collapsed after 10 cycles
$W_{opt.}$: 31%		51.3	66.9	31.0	Specimen collapsed after 7.5 cycles
$\gamma_{d\ max}$: 78.7 pcf		47.8	70.2	42.1	Specimen collapsed after 10 cycles
		47.9	70.4	47.9	Specimen collapsed after 11 cycles

PC = Portland cement, Wopt = optimum moisture content, d max = maximum dry density, pcf = pounds per cubic foot Data from Maher, 2001

Table 4.15: Wet-dry cycletest results on PDM samples

Moisture Reduction during Stockpiling

Minimal moisture reduction is expected to occur during the stockpiling of PDM. Water is consumed initially during the hydration of cement, thus reducing the overall moisture content. However, additional moisture reduction becomes negligible after one or two days following the mixing process, as shown in Table 4.16. These moisture content tests were performed on dredged material from Brooklyn, New York (Dunlop, 1996).

Additive/curing time	Sample 1 (MH)			Sample 2 (MH)		
Cement % added ontotal weight basis	11%	16%	21.5%	11%	16%	21.5%
Initial moisture content		133.7			138.2	
Immediately after mixing	109.2	103.5	100.5	112.8	109.6	112.7
1 day of curing	108.1	101.3	97.0	110.6	103.8	101.9
2 day of curing	108.5	98.6	97.5	110.1	100.8	99.5
3 day of curing	106.0	98.9	97.7	111.2	99.8	99.2
4 day of curing	105.1	97.8	97.5	108.9	102.8	97.8
5 day of curing	103.3	98.8	97.0	109.4	102.3	96.5
6 day of curing	105.5	98.0	96.6	110.0	103.8	99.0
7 day of curing	104.1	98.7	95.6	109.4	102.7	97.8
8 day of curing	107.2	99.3	96.6	103.1	100.5	97.0
14 day of curing	106.7	99.8	96.9	105.7	101.6	99.8
28 day of curing	105.1	99.2	95.8	104.1	100.7	99.1

Data from Dunlop, 1999; MH = highly plastic silt

Table 4.16: Moisture reduction of PDM during stockpiling

These data indicate that the decrease inPDM moisture content is insignificant more than two days after mixing. Even whena high percentage of Portland cement (21.5 percent on wet weight basis) is used, the moisture content of the PDM remains well above the optimum level. If lower moisture content is desired, alternative methods must be used.Some potential solutions to meet strict moisture criteria include more rigorous working of the PDM post-placement, decreasing lift volumes and thickness, mixing different source materials to increase the sand content of the dredged material prior to mixing in the additives, or a combination of these. Be careful to determine the appropriate moisture testing method in advance so the correct decisions can be made in the field.

Geotechnical Criteria for PDM Placement

Landfill Caps and Fills

PDM has been effectively used as daily fill and cap material at a number of landfills, and has also served as final cover material in the remediation and closure of older, poorly designedlandfills. Chapter 8 summarizes past experiences with such beneficial uses of PDM (and dredged material).

The type of dredged material that best suits these applicationsis typically comprised of silts and clays. This is because the fine-grained nature of such dredged material allows for the production of low permeability PDM that is ideal for use as a cap and cover material. For most landfill applications, the required permeability typically ranges from 10-5 to 10-8 cm/sec. The permeability specifications vary on a case-by-case basis, and can also vary in consideration of the amount of fill needed on the project site.

In conjunction with the permeability requirements, the PDM must also frequently meet general strength criteria. These specifications are required to ensure that the PDM has the necessary strength to support the use of construction equipment at the landfill site. A requirement to achieve a minimum strength of 1,000 to 2,000 psf within atime period of 48 to 72 hours after PDM placement is not uncommon when beneficially using PDM at a landfill. However, the PDM strength specifications canvary with the project, and in consideration of the geometry and characteristics of the landfill site.

Brownfield Caps and Fills

Similar to a landfill remediation or closure project, dredged material and PDM may be beneficially used to remediate brownfield sites. At highly contaminated brownfield sites, a low permeability PDM cap can prevent the production of leachate, and the transport of contaminants through groundwater infiltration and surface runoff. The low permeability PDM layer acts as a barrier between the soil contamination present on the site and future redevelopment structures and activities. The permeability requirementsfor the use of PDM at brownfield sites typically fall between 10-5 and 10-8 cm/sec, depending on the degree of contamination at the site.

In addition to permeability specifications, it is not uncommon to have a structural requirement for the use of PDM at brownfield sites to accommodate any future infrastructure and buildings that may be placed on the site. A strength requirement of 1,000 to 2,000 psfis not uncommon to support vehicular loads. In general, the structural specifications for using PDM to cap and fill a brownfield site varies with the potential types of activities occurring on the site after it is redeveloped.

Roadway Embankments

Although shown to be an effective use of PDM, the utilization of dredged material and PDM as roadway embankments is not yet a common practice, perhaps due to the ready availability of quarry-run aggregates, which do not carry the stigma of dredged material. The requirementsfor material to be usedfor this purposecan be found in the NJDOT roadway specifications, and include shear strength, compression strength, and freeze-thaw susceptibility criteria.

The acceptability of dredged material and PDM for beneficial use in the construction of a roadway embankment can be evaluated by using slope stability analyses. Typically, dredged material and PDM can be effectively used in embankments with horizontal:vertical slopes of 4:1 and 3:1. Some materials with larger-grained particles can be used to construct embankments with 2:1 slopes, but these are typically not used in roadway projects. The suitability of PDM from New York/New Jersey Harbor from a geotechnical and environmental standpoint are discussed in detail by Maher et al. (2004, 2006) and Douglas et al.(2005).

Controlled Low-Strength Flowable Fills

There exists high potential for the beneficial use of PDM as flowable fill, sometimes also referred to as controlled low-strength materials (CLSM). These materials are designed to be a substitute to traditional fill, and are used extensively as backfill for open excavation projects. This dredged material–cement PDM mixture can be placed without compaction using a conveyor, bucket, or pump. The flowable nature of the PDM is designed to fill all of the voids within a hole, increasing its strength while reducing the potential for the development of air voids.

The American Concrete Institute (ACI) has defined CLSM as having a compressive strength of 1,200 psi or less. Most current applications of CLSM are with materials below the 300 psi threshold, to allow for its excavation in the future (if needed). PDM can be used as an acceptable flowable fill provided strength tests have been conducted on the material. While most of the emphasis is on the compressive strength of the PDM, some attention is also placed on the consolidation characteristics of the CLSM because it is often used as backfill for utility work and trenches to minimize the potential for voids. Any excessive consolidation under sensitive utility lines can be detrimental to CLSM integrity.

In summary, PDM placed as flowable fill can be used as a structural base provided that stresses are in the order of 1,000 psi or less. Settlements at such stress level are not excessive. Silt sediments placed as flowable fill will have a permeability of 10-5 cm/sec or less. Additional testing is required to better define and evaluate the suitability of PDM as a flowable fill.

Conclusion

It is clear that silty sediments, even when moderately contaminated, can provide a suitable material for both structural and non structural applications. However, the process of manufacturing PDM, while not technically complex, does require experience and skill, as does its placement in the field. PDM is not, and should not be expected to behave like, soil. This chapter provided the engineer with the data needed to determine if PDM is potentially capable of providing the needed materials for a project, however a thorough understanding of the material in subsequent chapters on processing and placement is critical to mass producing an acceptable product that will produce the desired results in the field.

Chapter 5: Processing Systems

Overview

In most parts of the country, upland placement of high water content sediments is achieved by hydraulic pumping of sediments to near-shore confined disposal facilities (CDFs). Over time, sediment retained in the CDF dewaters by gravity and forms a semisolid matrix. No additional handling is involved unless the sediment is removed for use as fill in construction projects. This management technique is used on the Jersey Shore and the Delaware River, and is in limited use on the Raritan Bayshore. However, the value and limited availability of land, coupled with high volumes of fine-grained contaminated sediments, make this practice unfeasible in the New York/New Jersey Harbor. In lieu of upland placement, dredged material was historically placed at in-water disposal sites. When the harbor's ocean disposal site was closed in 1997, there were no options for contaminated dredged material other than bringing it upland. Rather than landfilling the material as solid waste, the state sought methods that would allow sediment to be beneficially used.

As outlined in Chapter 3, beneficially using saturated sediment as engineered fill requires substantial improvements in geotechnical characteristics, otherwise handling and compaction of those sediments may not be practical or economically feasible. Blending of pozzolanic additives into dredged material has proven to be very effective in lowering water content and enhancing material-handling characteristics. Several methods have been employed to process navigational dredged material in the decade or more since the practice began in the harbor. The two most popular are in-scow processing and pugmill processing. There are advantages and disadvantages to both methods. All engineers seeking to design a processing facility need to consider the interface of the facility with both the dredging plant and the placement site. Flexibility and redundancy in the processing facility ensures it does not become the weak link in the dredging chain.

Dewatering

Before the material can be processed, it is desirable to remove as much of the water as possible. This not only makes the material easier to handle, it also reduces the amount of additive required to achieve the desired engineering properties, thereby reducing costs.

Dredging permits in the New York/New Jersey Harbor usually require that dredged material remain in the dredging scow for at least 24 hours to provide for adequate settling of suspended solids prior to dewatering. This is sufficient time for a majority of the fine-grained silty particles typical of New York/New Jersey Harbor sediments to reduce the total suspended solids content of the overlying water to less than 60 milligrams per liter. Dewatering of the dredged material in a scow is then usually performed using conventional pumps; with a typical 2,500-cubic-yard scow, this operation takes approximately two hours, assuming a 300- to 400-gallons-per-minute capacity water pump is used. If the dewatering process occurs in the same water body as the dredging project, the decant water can be discharged from the dredging scow directly to surface waters. If the dewatering site is remote from the dredging site, the decant water is pumped into a second holding scow. When this holding scow is full, it is moved back to the dredging site to be discharged (see Figure 5.1).

Typical dewatering

Belt filter press dewatering

If it appears that less settling time is required, the permitee may provide data to the NJDEP definitively showing how much time is required to achieve the regulatory target of 60 milligrams per liter total suspended solids. No permit modifications are required to hold the material longer than 24 hours before decanting the water.

When more extensive dewatering is required, other methods, such as belt filter pressing, have been employed. In these cases, the use of flocculants and chelating agents can improve the efficiency of the dewatering process, but the water must often be treated to remove these agents before it can be discharged to surface waters.

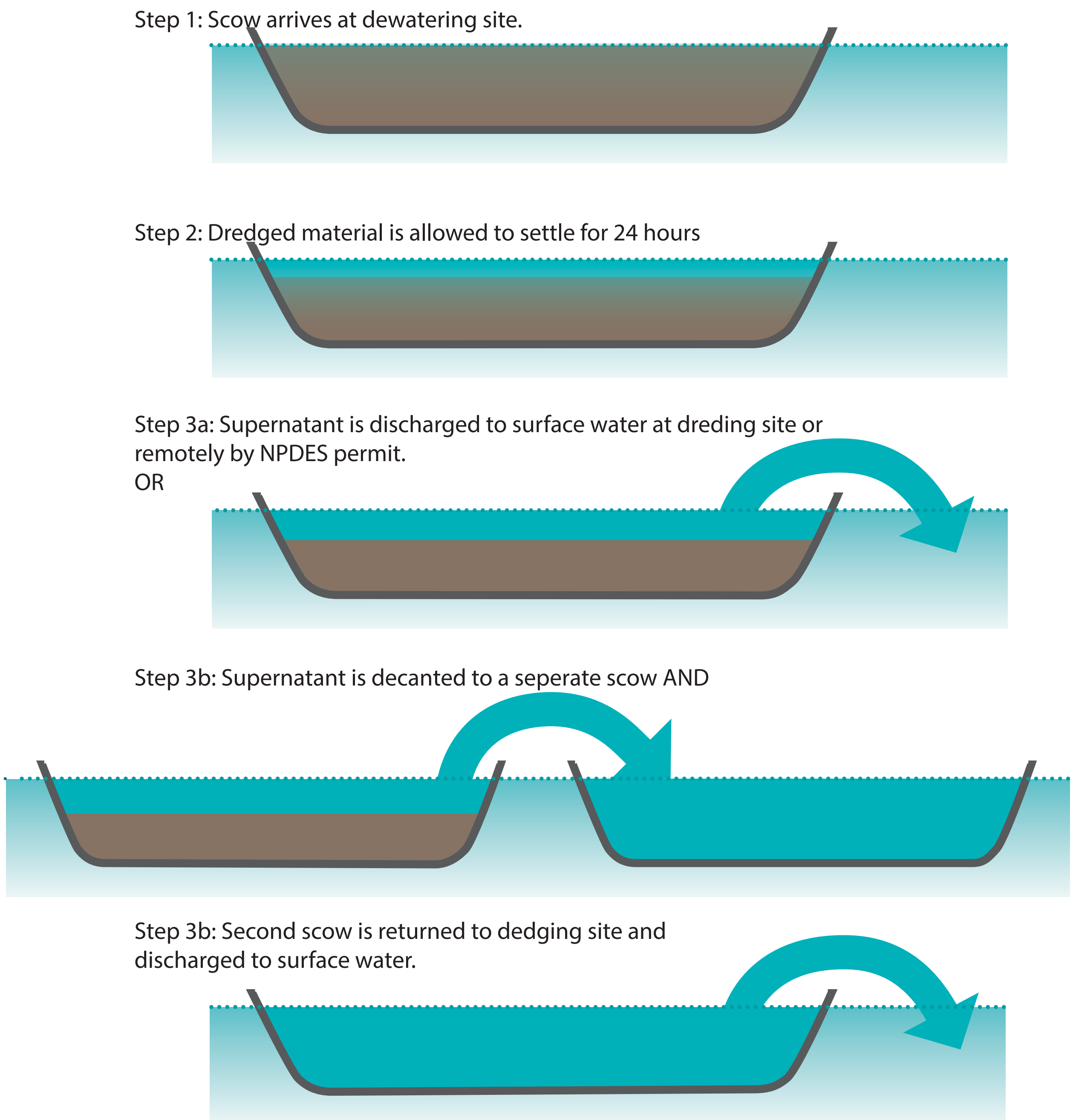


Figure 5.1: Diagram of typical dewatering process options for New York/New Jersey Harbor dredging

Debris Removal

Dredged material frequently contains various amounts and sizes of debris and trash. Large objects in dredged material can include telephone poles, timber, tires, engine blocks, cables, and concrete blocks. Smaller-sized debris can include scrap metal and trash. The removal of debris is required for many beneficial uses of dredged material or is necessary to avoid damage to or clogging of processing equipment.

Debris screening is sometimes performed at the dredging site during a mechanical dredging operation. In some cases, large debris can be removed as individual pieces. More typically, a static grizzly screen is placed over the scow, and the dredged material is poured over the screen, effectively removing large amounts of debris. However, care must be taken to avoid discharging dredged material or debris over the gunwales of the scow. If necessary, debris can be washed while on the grizzly, preventing the rinse water from entering the waterbody. The debris must be collected and properly recycled or disposed of (as solid waste) at an appropriate upland site, necessitating a second scow or scows to hold the material. This technique is rarely used in the harbor.

For most processors, debris is segregated and cleaned at the processing site. For in-scow blending operations, large debris can be segregated using rakes attached to excavators. Smaller-sized debris can remain in the scow since it does not pose a danger to the blending equipment (not accounting for placement site requirements). For dredged material processing systems using a pugmill, even small-sized debris is potentially problematic, as it has the potential to jam the system. Debris segregation in these processing operations is usually achieved by using a stacked vibratory screen assembly, which removes debris down to 2 inches or less.

Typical debris rake

Debris pile from harbor job

Debris screened from the dredged material is placed into a storage container and transported to an appropriate solid waste facility for disposal or, if possible, recycling. If large amounts of debris are collected, it may be necessary to properly clean the debris prior to disposal, taking care not to wash any sediment into the waterway.

PDM Additives

The pozzolans added to amend the dredged material for specific uses are called "additives." The most common additives are Portland cement (type I or II) or lime, or byproducts from the manufacture of either (kiln dust). Other additives, such as fly ash from manufacturing or incineration and residue from coal burning, have also been used. These additives react with the sediment slurry to bind sediment particles together and effectively reduce water content, thus improving the material handling and compaction characteristics, as well as reducing the leaching potential of bound contaminants.

Factors considered in selection of additives include:

- Effectiveness in reduction of water content
- Regulatory requirements and restrictions
- Processing facility configuration
- Applicability to a wide range of sediments and chemical contaminants
- Availability and cost

Quick lime is an effective additive used for solidification of high water content soils (Samtani et al., 1994), though, concern over availability and cost of quick lime has made Portland cement the preferred additive. Additionally, cement's strength gain over time is more prolonged, allowing time for moisture conditioning and grading.

Fly ash is a finely divided residue formed from combustion, usually from coal. It is composed of silicon dioxide, aluminum oxide, iron oxide, and other trace constituents. Fly ash typically has intrinsic cementitious and pozzolanic properties. It is often used in conjunction with Portland cement to improve workability, strength, and durability of processed dredged material (PDM) (OCC , 2010). Fly ash can have high concentrations of heavy metals, and its use has been restricted in New Jersey. Other states have restrictions on additives and require approvals of alternative additives prior to use at processing facilities and the placement sites. Fly ash can be obtained at a substantially lower price than other additives—sometimes even generating a tipping fee—which gives it a key advantage.

Municipal solid waste incinerator ash, or MSW ash, is a fly ash–like waste material that has variable pozzolanic properties. It has been used successfully to help dewater and stabilize dredged material, but it has significant drawbacks that must be considered carefully. Like fly ash, MSW ash can contain contaminants, particularly heavy metals, making it difficult to permit. It also typically contains a fair amount of debris that must be removed before it is added to the dredged material. MSW ash is highly variable in its calcium oxide content, so the amount required to achieve the desired properties can be difficult to determine. In some cases the volume of required MSW ash can significantly bulk up the dredged material, which can impact the transportation and placement costs. On the other hand, MSW ash is a waste product, and as a result, it, too, can generate a tipping fee that may cover or even exceed the increased costs of transportation and placement.

Other additives, including lime kiln dust and cement kiln dust, have been used on an experimental basis by some New York/New Jersey Harbor processors (Sadat Associates, 2000). Lime and cement kiln dust are byproducts of the respective manufacturing processes. While lime or cement byproducts are less expensive than lime or cement, variability in the additives' reactive chemicals—such as calcium oxide, silica, and alumina—makes the physical properties of the end product less predictable. The reactive chemicals vary depending on fuel, kiln operations, and the limestone feedstock. This uncertainty makes it difficult to design a recipe of additive and sediment proportions with predictable physical properties. If adjustments to the additive proportions need to be made in the field, or the moisture conditioning time increased, costs and timing at the placement site may be significantly impacted.

Additive	Range of available CaO[4]	Current Price Range/ton
Quick Lime	90–95%	$75–$125[2]
Portland Cement	65–75%	$70–$80[1]
Lime Kiln Dust	15–30%	$40–$60[3]
Cement Kiln Dust	5–15%	$1[1]
Fly Ash	3–5% +/-	Free to $5*[1]

1 Frederick Ritter, Lehigh Cement Company, 2011, personal communication

2 http://minerals.usgs.gov/minerals/pubs/commodity/lime/mcs-2010-lime.pdf

3 Wattenbach et al, 1999

4 Farhad Jafari, 2009, personal communication

*** some materials generate tipping fees**

Table 5.1: Available CaO and price range

The proportion of reactive or available calcium oxide (CaO) in an additive determines the extent of pozzolanic reaction that will be achieved, and therefore is proportional to the amount of pozzolan required to achieve the desired properties. During mix design, the engineer needs to carefully evaluate the impacts of the amendment choice on the quality of the final product, reliability of processing rate, and the cost of its manufacture, as well as the potential impacts on permit requirements. The percentage of lime and current price ranges are provided in Table 5.1.

There are other amendments and mixtures of pozzolans that can be used to process dredged material. The NJDOT evaluated the use of Propat®, a proprietary mixture of auto shredder residue, for its use as a supplemental additive to dredged material. Propat® is a trademarked product of Hugo Neu Schnitzer East and is manufactured from nonmetallic materials revered from shredding of scrap automobiles, white goods, and other discarded objects, combined with a proprietary mix of additives. Propat® was developed for use as a landfill daily cover where environmental and human interaction issues were not a concern. Because the manufacturers of Propat® currently have to pay for its disposal, if it can be used as an additive, dredged material processing costs could be offset

Clean Earth Dredging Technologies performed a demonstration project using Propat® at their Claremont Dredged Material Recycling Facility using dredged material from the Claremont Channel in Upper New York Bay. The sediment was amended with 30 percent Propat®, 18 percent coal fly ash, and 18 percent KS60 (a Clean Earth Dredging Technology proprietary pozzolanic additive). The study illustrated that Propat®-amended dredged material meets or exceeds the performance criteria for nonstructural fill and capping material. While no adverse environmental impacts were observed (Hart Crowser, 2005), it was shown that the concentrations of various contaminants in the Propat® were highly variable and the amount of additives required for a successful beneficial use product significantly reduced the amount of dredged material used. These observations indicate that while Propat® is indeed usable as an additive, regulatory and beneficial use capacity issues would need to be considered carefully wherever it is used. The NJDEP has ruled that Propat® is a solid waste and that its use in this case did not relieve the product of classification as solid waste, thereby limiting its placement options.

In summary, usage of byproducts may not be cost effective due to:

- Increased additives to achieve the same product quality
- Increased time for processing
- Increased volume for transportation
- Increased volume for placement
- Increased tipping fees

However, some processors have used proprietary mixtures of additives that have proven to be effective. The economics, product characteristics, and environmental suitability must be evaluated on a case-by-case basis.

Various additives can be used to modify other PDM product characteristics, such as permeability and gradation. Clays such as bentonite and attapulgite have been used to decrease permeability for landfill and cap-and-cover applications. The ionic surfaces of bentonite and attapulgite have the ability to stick to sand grains and cause them to bind together. Mixing these materials with sediment excavated from a confined disposal facility (CDF) has been show to decrease permeability (OCC, 2010). Recycled concrete aggregate and crushed glass have been used successfully to amend dredged material gradation to meet construction specifications similar to that of natural aggregate (OCC, 2010; Grubb 2006a,bpapers)).

Additive Blending Systems

There are many possible ways to blend dredged material with pozzolanic additives and amendments, but the two most commonly used in the New York/New Jersey Harbor are pugmills and in-scow blending. Both have been successful, but each has its own distinct advantages and disadvantages. In general, the pugmill operation is slower but provides a better product. The in-scow processing produces outstanding throughput (as high as 18,000 cubic yards per day), but the quality of the product is not as consistent, occasionally causing difficulties at the placement site. Management skill and experience usually override the operational differences, as well as outside influences, such as the nature of the dredged material, temperature, and precipitation. A detailed treatment of processing systems is available in Lawler Metusky and Skelley, NJDOT (2003) and USACE (2006).

Pugmill Mixing System

The pugmill system adapts readily available technology for mixing two streams of solids. The pugmill is an enclosed unit containing paddles or blades. Dredged material and pozzolanic additives are simultaneously introduced and blended. The pugmill provides a uniform product since the mixing is done using a weight-controlled batch process. While the amount of additive needed varies depending on the type of additive and the PDM product desired, additives are typically used at a rate of 8 to 12 percent by weight. Proper blending recipes are determined in the laboratory before dredging begins. In some cases, minimum additive amounts are dictated by permit. Blending operations have also been split between sites, with the offloading site adding just enough additive to eliminate free water, and the placement site adding a second aliquot to produce the

PDM product. This technique only makes sense when an additive is available at the placement end that provides a tipping fee to the process, such as fly ash, that is not available at the offloading end.

Pugmill Mixing Process

The pugmill process begins with a full scow arriving from the dredging site for preprocessing. The first step is to remove the decant water; typically it is pumped to a nearby dedicated water scow before being released back at the dredging site. Since the amount of additive is dependent on the weight of material treated, it is in the best interest of the operator to remove as much water as possible before processing. The dewatered dredged material is then raked using an excavator with a special debris attachment. This is done several times to prevent large debris from damaging the elements of the pugmill processor (screens, conveyors, etc.). Dewatering and debris removal require approximately two hours, depending on dredged material condition and operator experience (see previous sections in this chapter for a more detailed treatment).

Conveyor feed single pugmill system

Gravity feed dual pugmill system

Radial stacker and PDM containment area

Stacked vibratory screens

Following preprocessing, the material is unloaded from the scow using a clamshell bucket or backhoe and passed through a vibratory debris screen before being conveyed to the pugmill via conveyor belt or bucket conveyor. Deflector screens are required between the scow and the screen to ensure that spilled dredged material falls back into the scow. The conveyor system usually contains a weight sensor.

The screened dredged material either falls directly from the vibratory screen into the pugmill, or is delivered to the pugmill entrance via a conveyor. Additives are fed to the pugmill based on a percentage of the dredged material's weight. The amount of blending time in the pugmill is variable and determined by the operator. Immediately following mixing, the PDM is either discharged directly into trucks (for on-site placement) or conveyed to a stockpile for curing prior to being transported to the placement site by scow, truck, or rail.

Since there is limited availability of placement locations with harbor access, most facilities utilize curing stockpiles. During stockpiling, the material ages sufficiently to improve handling and transportation. Different methods of management are possible, provided the piles are properly shaped to shed stormwater and water is collected and treated prior to discharge. It is possible to improve the curing through mixing or "churning" the stockpile. Because this process improves blending and reduces moisture, the desired geotechnical characteristics may be achieved using a lesser amount of additives (within permit allowances). This will result in a product that requires less moisture conditioning at the placement end. In general, stockpiling should not exceed six to seven days before transporting to the final placement site; otherwise, the strength of the final product is reduced (Maher et al., 2006x). Whether or not this strength reduction is significant depends on the intended use of the PDM.

Production rates for pugmill systems vary depending on the nature of the sediment, available redundancy, and the discharge method (stockpile, truck, or scow). Rates observed in the New York/New Jersey Harbor since 1997 vary from 2,000 to 5,000 cubic yards for a single 10-hour shift. A single clamshell assembly has the potential to unload 7,000 cubic yards per eight-hour shift, but reliability in other aspects of the processing limit overall production.

Equipment

The layout of the processing facility is critical to the realized throughput and quality of product. The layout of a typical pugmill processing system including truck access, rail access, and wharf is provided in Figure 5.2. The minimum land requirements are about 950 feet-by-250 feet, with approximately 750 feet of wharf space. Other design considerations involve the inclusion of processing redundancy, small debris segregation and management, and discharge mechanisms.

Capital Equipment	Rental Equipment
Discharge pump	Hydraulic excavator with rake
Decant water pump (2 @ 350 gpm)	Hydraulic excavator with 5cy bucket
Hose/piping for dewatering	Decant water scow
Debris rakes	Cement silos or blimps
Wobbler feeder/screen (3-inch)	Front-end loaders
Reversible screws to dual-belt conveyors or bucket elevators	Debris shipping container
Magnetic separators	Tug boat
Pugmill	
Radial stacker	

Table 5.2: Equipment list for pugmill processing

Pugmill systems can be designed to discharge into rail cars, trucks, or stockpiles. Experience has shown that if the facility is built at the placement site, direct discharge to truck is desirable. However, if the placement location is off site, it is more efficient to use a stockpile configuration. This will result in multiple handling operations, but the product is easier to transport, more consistent, and easier to place. Another important consideration is capacity of the transportation system to the placement site. Multiple options for transportation of PDM product are desirable.

A major difference between the pugmill and in-scow systems is that the pugmill system is capitally intensive (see Tables 5.2 and 5.4). Some items are available as rental equipment, but the mill itself (complete with feed silos, scales, conveyors, and computer controls) is not. While we have placed excavators in the rental category, it is likely these will need to be purchased since the marine environment, coupled with the pozzolanic dust, creates a very corrosive environment that is extremely hard on equipment.

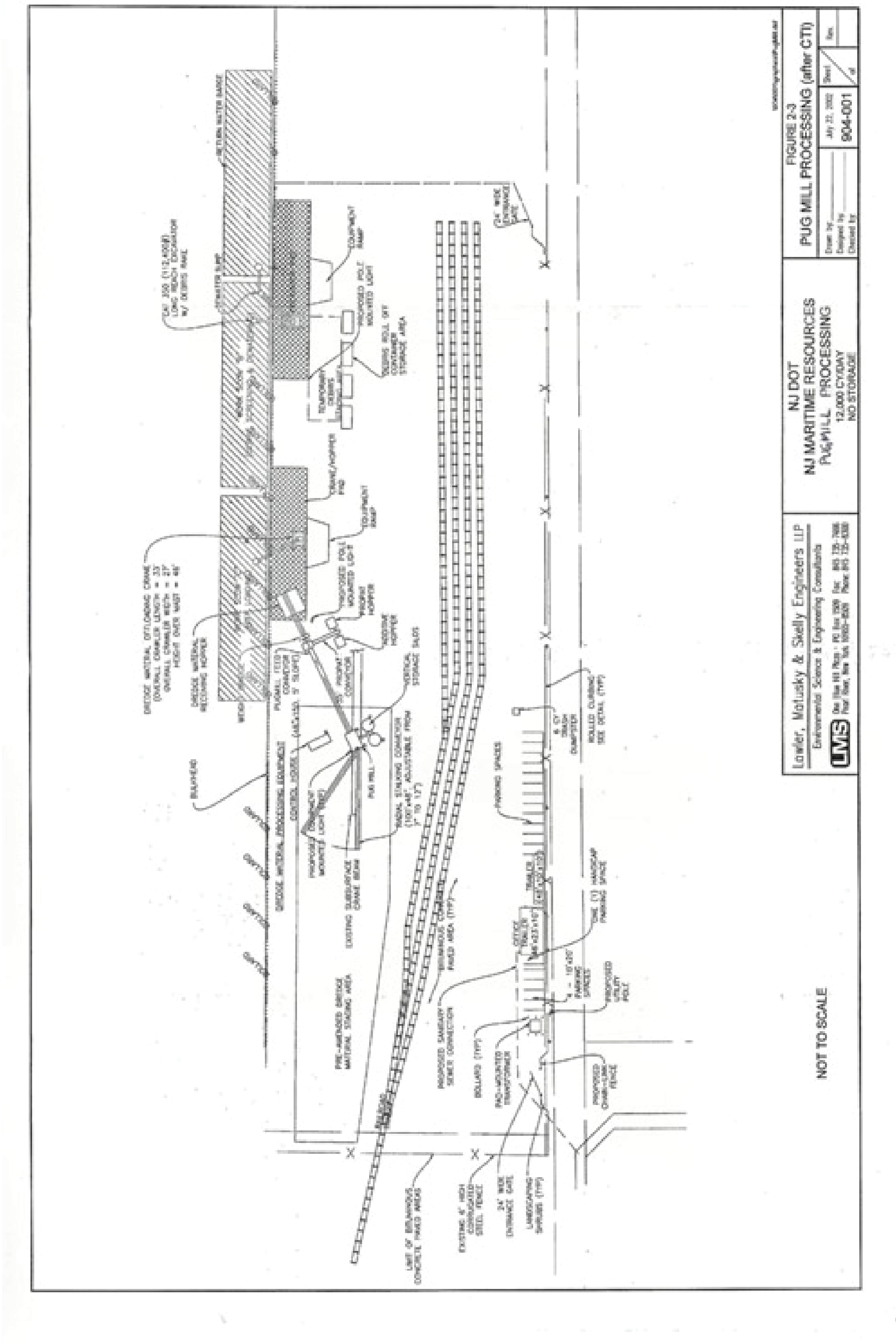


Figure 5.2: Layout of a typical pugmill processing system.

In-scow processing

Pneumatic pozzolan metering system

In-scow Mixing System

The in-scow processing system for PDM is much simpler than the pugmill, but results in a similar product. The additives are introduced to the dredged material directly in the scow and then blended using a special blending wheel attached to an excavator. While the product should be the same as the pugmill product, error is introduced when estimating the amount of additive as well as when estimating the appropriate amount of mixing time. It is difficult to ensure that material from all parts of the scow is fully blended. As with the pugmill operation, it is possible to utilize a two-step system here, but the offloading end would probably require the use of a pugmill or other landside blending operation.

In-scow Mixing Process

The initial preprocessing sequences for in-scow facilities are the same as for pugmills. The process starts with the arrival of a filled scow. Following a 24-hour holding period, standing water is pumped from the scow into a nearby decant scow or discharged to the receiving water via a NJPDES permit. Depending on the experience of the operator, the dewatering process requires approximately one hour. Immediately following the dewatering phase, debris is removed using a rake mounted on a hydraulic excavator. It is particularly important in this method that the operation remove all wire, cable, and hawsers, or they could wrap around and damage the mixing head. It is less critical to remove large debris because it can be removed during curing or at the placement site. Debris removal takes approximately one hour per scow.

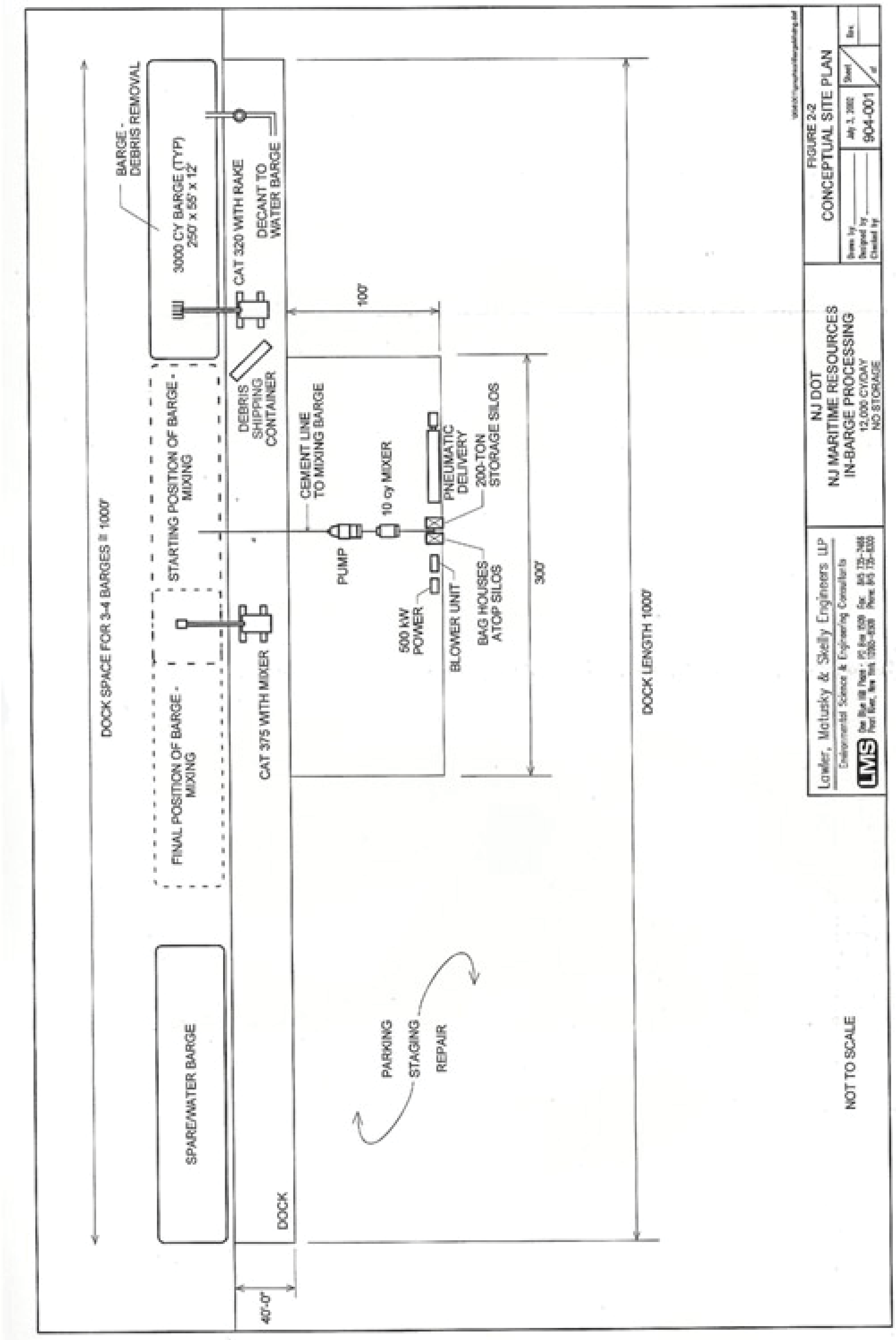


Figure 5.3: Layout of a typical in-scow processing facility.

Sediment/pozzolan mixing head

Pneumatic feed system with misting ring

Because it is impractical to weigh the scow to estimate the appropriate amount of additive to introduce, a volumetric estimate is performed instead. Even with the amount of dredged material and residual water taken into consideration in the calculations, additive ratios are generally less precise using this method. Depending on the type of material being processed, a range of eight to 15 percent of cement by volume is used. Based on observations made by NJDOT, silt sediment typically requires the most cement for processing, while sand and clay sediments require less. Additives can be introduced in both dry and slurry forms. Typically, dry cement is used to avoid the addition of water used in the slurry method. Dry cement feeds use the residual water in the mix to accelerate curing, but there are environmental risks of fugitive emissions when using dry cement. To minimize fugitive dust, the cement can simply be misted during the addition process. Note that some of the variations of this process have been patented.

To incorporate the cement into the sediment, a mixing head is deployed, mounted on the arm of a long-reach hydraulic excavator located on the wharf. The mixing head is submerged into the dredged material and worked slowly through the material to blend the mixture in the scow. The scow is processed in 1/8-length increments, while a tug moves the scow past the stationary mixing excavator(s). The status of mixing is determined visually and is somewhat subjective; unmixed dredged material is black, while thoroughly mixed material is grey. The estimated mixing time for one scow is approximately two hours. Depending on the shape of the scow, it can be difficult to determine if all of the dredged material has been mixed with additives, creating a potential for poorly amended sediment on the outsides and bottom of a load of material. The experience of the operator then becomes a key factor in predicting the quality of the PDM product.

Once the mixing is complete, the PDM remains in the scow for about 24 hours; a longer period could make removal difficult. After this initial curing, the material can either be stockpiled on site or taken directly to the placement site. In either case the material should be placed and compacted within a week in order to avoid loss of strength. As with the pugmill operation, working a stockpile can result in better blending and moisture conditioning. Cure times and moisture loss will vary considerably with temperature.

Because all of the processing and initial curing takes place in scows, docking space is more critical to an in-scow mixing plant than it is for a pugmill processing plant. It is recommended that in-scow facilities have space for at least four scows; space for a fifth scow would allow for some storage of raw dredged material. This translates to a minimum wharf length of 1,000 feet. Use of shorter wharfs requires that scows be "stacked" parallel to the shore. If scows are placed side by side they will extend 110 to 120 feet into the waterbody, which may result in a navigation issue (Lawler, Metusky and SkelleyNJDOT, 2003). Depending on the processing goals of the facility, additional docking space and orientation options may be pursued. Upland space requirements are dependent on the desired level of production, since hydraulic excavators can be either fixed or mobile.

Equipment

One of the major advantages of the in-scow process is that the equipment is less sophisticated and, therefore, less expensive (see Tables 5.3 and 5.4). This is especially attractive when you consider the episodic nature of dredging in most harbors. However, as we said previously, the corrosive environment in most processing plants may make long-term rental of excavators and front-end loaders impractical.

Capital Equipment	Rental Equipment
Discharge pump	Decant water scow
Decant water pump (2 @ 350 gpm)	375 MH CAT excavator set up for raking
Cement feeder and discharge system	375 MH CAT excavator set up for mixing head
Dust collector	Cement silos
Mixing head	Front-end loaders
Hose/piping for dewatering	Debris shipping containers
Debris rakes (2)	Tug boat

Table 5.3: Equipment list for in-scow processing

Comparison of the Two Methods

There are pros and cons with each method (see Table 5.4). In-scow mixing facilities tend to be higher production and are less vulnerable to mechanical breakdowns. On the other hand, a pugmill produces PDM with more uniform characteristics and contains almost no debris. Pugmill operations are more sensitive to the type of material, as well, working best with fluid mud. In-scow facilities can handle a wider range of sediment types and debris content.

Mixing Method	Advantages	Disadvantages
Pugmill Mixing	a. Oversize and small debris is screened prior to mixing b. More uniform mixing c. Various additives can be blended with raw sediments d. Requires less docking space e. Additives mixed based on weight	a. Higher initial equipment cost b. Lower production rates c. More vulnerable to mechanical breakdowns d. Clay chunks could lower the production rates significantly
In-Scow Mixing	a. Less vulnerable to mechanical break downs; higher reliability b. Allows temporary storage and initial curing in scows (2–3 days maximum) c. Mixing head capable of breaking chunks of clay	a. Small debris remains in the mix b. Product not as uniformly mixed as pugmill PDM c. Requires more docking space than pugmill mixing d. Additives measured based on volume

Table 5.4: Advantages and disadvantages of processing methods

Regardless of the mixing system used, the volume of sediments processed daily needs to match or exceed the daily volumes dredged. Otherwise, additional handling and storage is required. Sufficient redundancy is required in either processing system to avoid delays associated with breakdown repairs and/or periodic maintenance, severe weather, and to accommodate changes in dredging schedules.

Preplacement Curing

Curing is a process during which pozzolanic additives react with sediment particles resulting in solidification of the matrix. The curing of PDM is largely a function of the amount of available calcium oxide (CaO), time, and temperature. Solidification begins immediately following the addition of pozzolanic additives. Hydration of CaO supplied by the additives consumes water, changing the semi-liquid consistency of the sediment to more like a soil. Curing, on the other hand, is a long-term process that can take several weeks to months.

Curing will take place whether the PDM is stored in stockpiles or in a scow. The concern for the processor is how long the material can be stored before it either becomes difficult to remove from the scow and/or before the curing process stops. In extreme cases, an excavator bucket has had to be used to remove solidified dredged material from a scow. More importantly, disturbing and rehandling solidified PDM can result in breaking of soil-cement bonds, reducing the strength of the PDM (Sadat, 2000).

PDM curing operation

PDM stockpiles

Another important consideration is temperature. The rate of hydration is highly affected by ambient temperature and initial moisture contents. Cold temperatures slow the hydration process; at temperatures below 40˚F, the pozzolanic reactions between the cement and soil particles slow down. As a result, the improvements associated with the addition of cement, such as moisture content (see Figure 5.4) and improved strength (see Table 5.5) are reduced (Maher et al., 20013). Presumably these reactions will resume when temperatures increase. This has impacted field operations by requiring longer periods of curing prior to transportation or increased storage time on site prior to placement and compaction during winter months.

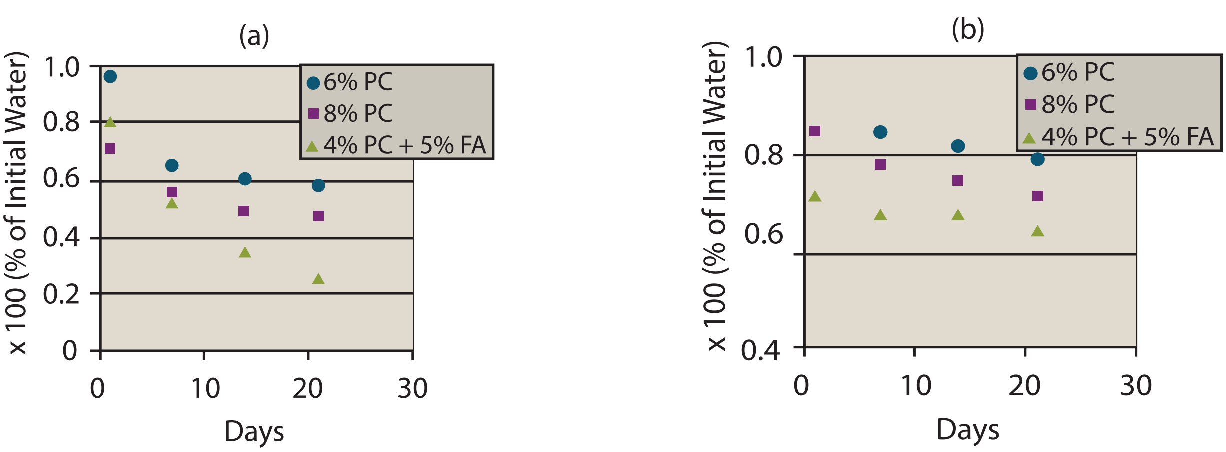


Figure 5.4: Effect of curing temperature on moisture reduction: 70˚F (a), 40˚F (b)

Additive Mixture (weight basis)	Curing Temperature Degrees F	Strength (kPa) of PDM after 1 Day	Strength (kPa) of PDM after 7 Days	Strength (kPa) of PDM after 14 Days	Strength (kPa) of PDM after 28 Days
4% Portland	70°F	10.34	26.21	41.02	56.53
6% Portland	40°F	7.58	17.23	31.71	29.64
6% Portland	70°F	18.61	58.6	84.8	85.49
8% Portland	40°F	12.41	24.13	26.89	28.95
8% Portland	70°F	18.61	59.59	84.8	85.49
4% Portland + 5% Fly ash	40°F	4.82	NA	17.23	20.68

Table 5.5: Effect of temperature on shear strength of PDM

Storage

Storage of PDM should be avoided unless necessitated by weather or considerations at the placement site. Double-handling of PDM breaks soil-cement bonds, thereby reducing the strength (Sadat, 2000). If strength is not a primary concern, such as in nonstructural applications, it may be possible to store and rehandle PDM. There is some evidence that storage of PDM during winter months is less damaging to final strength characteristics of fill than storage during summer (Maher et al., 2004), most likely because, at temperatures below 40˚F, the pozzolanic reactions between the cement and soil particles slow down (see previous section in this chapter). Regardless of the reason, it is important to position and shape stockpiles of PDM to shed stormwater in order to avoid erosion and permanent loss of strength. Site managers should endeavor to place and compact PDM as rapidly as possible after receipt to obtain the best geotechnical properties and avoid environmental compliance issues.

Transportation of PDM

Loading of PDM in truck

Unloading PDM from railcar

Transportation of PDM can be accomplished in a multimodal fashion. Over-the-road dump trucks can carry approximately 10 to 15 cubic yards of material. Rail cars are capable of holding between 75 and 100 cubic yards of material, and scows can handle approximately 1,500 to 2,500 cubic yards. Each means has its own economic and logistical constraints, but each has been used efficiently and effectively in transporting dredged material.

Prior to transporting PDM, it must be cured sufficiently to ensure that free water does not leak onto the road surface. The standard test for this is the paint-filter test. For dredged material to be transported wet, a sealed container designed to hold the water must be used and a plan developed to contain the water at the delivery end. At the other extreme, material that has cured too long may be difficult to remove from the transport vessel. Some processors have lined trucks with loose hay to act as a releasing agent for the PDM and to soak up residual moisture.

It is necessary to control loss of material during loading and transportation of PDM. Spill plates are a proven method of guaranteeing stevedoring procedures do not result in loss of material into the berth area. The plate should be slanted so that spilled material is returned to the scow. For trucks, both dust covers and wheel-wash stations are effective at keeping streets free of dust and mud. In extreme cases, water trucks can spray the loading area with water, and street sweepers can be used to clean up roadways.

Fugitive and Volatile Emissions

The pozzolanic reaction is exothermic, resulting in significant evaporative loss of water from the sediment. Unfortunately, the water can carry with it some of the contaminants that are contained in the sediment. NJDOT has evaluated the loss of polychlorinated biphenyl (PCB) and mercury from PDM. These compounds are released in significant quantities during curing, but this release becomes insignificant as the material cures or is covered (Goodrow, 2005; Miskiewicz, 2008). For navigational dredged material, the concentrations are not a hazard to human health, even for long-term exposure. However, when remedial dredging is performed, a case-by-case evaluation of potential health hazards must be carefully considered.

The addition of Portland cement dramatically increases the pH of the sediment. For sediments that are organically enriched, this can result in the release of significant amounts of ammonia gas. While not harmful in an open environment, the gas can be irritating. As organic enrichment has also been shown to increase the amount of pozzolan needed to achieve geotechnical specifications (Maher et al., 20065), care should be taken to monitor the curing status of organically enriched PDM. There have been some complaints of ammonia irritation by truckers moving freshly mixed PDM, especially among those who used heated beds to move material in the winter. Adequate ventilation during transportation and placement will eliminate health concerns, as will adequate curing time.

Wind-blown dust from the use of Portland cement, kiln dust, and fly ash can be a hazard to both human health and the environment. The state of New Jersey requires processors to install corrective measures to contain, collect, and control fugitive emissions from the additives used to manufacture PDM. These include baghouse filters, spray nozzles, negative pressure systems, and simple equipment covers. Personnel should be required to wear personal protective equipment when working with fugitive dusts and should be trained in the proper operation and maintenance of dust-control measures. Once mixed with dredged material, the loss of dust from the pozzolan ceases, but the PDM itself can be a source of dust once cured. Water trucks can be used to keep dusts down in the work area, and tire scrubbing stations help to reduce PDM spills on local roadways. All spilled PDM should be recovered and returned to stockpiles.

Conclusion

Production of PDM in the New York/New Jersey Harbor enabled the successful management of millions of cubic yards of dredged material while facilitating the remediation of contaminated sites and spurring redevelopment in some of the most blighted parts of northern New Jersey. The techniques used vary from company to company, but can be placed into two distinct camps: either pugmill processing or in-scow processing. Both start with a scow of dredged material that must be dewatered and screened for debris. Additives are either blended with the dredged material in a pugmill or added directly to the scow.. After a curing process, the PDM is transported to the placement site and compacted in place

Both methods have their benefits. Pugmill processing produces a more consistently workable product, but it is slower and more expensive. In-scow processing is quick and less costly, but produces a less refined product that can be harder to work. Both techniques can have down time due to mechanical breakdowns, but the pugmill operation has more moving parts. Redundancy helps resolve breakdown problems, but can add to the costs. There are more handling steps in the pugmill operation, increasing the opportunity for spills, but in-scow mixing has more fugitive emissions. Both operations can be messy, requiring conscientious housekeeping. Sufficient time for curing of the PDM is necessary for efficient placement, but long-term storage can reduce the effective strength of the PDM in structural applications.

Chapter 6: Placement of Processed Dredged Material

Overview

The integration of raw and processed dredged material (PDM) into current construction applications has distinct challenges. Generally, most contractors are unfamiliar with the handling and placement characteristics of the dredged material as it is different than traditional quarry material. The generally higher moisture content in addition to the fine-grained nature of the sediment requires an alternative approach to placement and overall project sequencing. The management approach required for PDM is also different from the management of traditional fill materials in several ways, such as compaction lift thicknesses, moisture management, and strategic stockpiling. This chapter discusses the most common placement procedures of raw dredged material and PDM. The site manager that recognizes these logistical and management considerations will have considerably better results than one who tries to use practices designed for traditional fill.

General Considerations

Stockpile Management

For successful large-scale projects utilizing PDM, efficient stockpile management is essential. PDM relies heavily on the chemical processes of hydration to develop its strength. This is a time-and-temperature dependant function that can vary on a day-by-day basis. Interim stockpiling areas have proven an effective strategy for larger projects.

To ensure the material does not become rehydrated, it needs to be mounded and shaped to shed rainwater. Stockpiles should be separated from each other to reduce ponding of stormwater between piles. Stockpile areas also require some means of environmental control–perimeter containment, a leachate collection system, or both. The perimeter containment may include drainage swales leading to a detention pond. Some projects utilizing contaminated material have lined such stockpile areas with a compacted low permeability soil to reduce groundwater infiltration. It is possible to use compacted PDM for this purpose. If a stockpile is adjacent to a waterbody, additional means of separation may be required.

Since the curing process is ongoing, long-term storage of PDM may result in loss of desirable geotechnical characteristics such as strength or permeability. Because the curing rate is reduced when temperatures are low, storage during winter months many not be as detrimental to PDM characteristics as storage during summer months. There is also some evidence to suggest that particularly large stockpiles retain moisture better and have slower cure rates than smaller piles. In general it is prudent for the site manager to periodically check the condition of PDM stored for periods exceeding several weeks.

Moisture Conditioning

In cases where PDM has been stockpiled, received in an overly wet condition, or when project requirements call for increased strength characteristics, it may be necessary to reduce the moisture content prior to or during placement. This secondary moisture reduction, referred to as moisture conditioning, allows for greater compaction of PDM by lowering the moisture content to near the optimum.

Moisture conditioning of PDM

Interim PDM storage facility

Aeration is a cost-effective method of moisture conditioning (Sadat, 2000; Maher et al., 2006). The process consists of spreading the PDM in loose thin layers of 1 to 2 feet, exposing it to sun and wind. Once the surface is sufficiently dry, the PDM is turned over using harrowing disks to dry the deeper material. The process is repeated until the moisture content within the entire PDM layer is reduced to near optimum. During conditioning, moisture content of PDM is periodically monitored to determine when the material is ready for compaction. At the end of each working day, or if precipitation is expected, the top layer of PDM should be sealed to avoid saturation from dew or precipitation. In the event that PDM becomes saturated by rain, the top inch or two can be scraped off and returned to the stockpile.

The efficiency, and therefore duration, of moisture conditioning depends on environmental factors such as ambient temperature, wind speed, and exposure to sun. What might be accomplished in two to three days in summer may take weeks in winter. Periods of rain and snow or cold weather will significantly lengthen the moisture conditioning process, at times to the extent that it becomes impractical. In that case, PDM should be stockpiled, and work should resume once environmental conditions are favorable.

Placement and Compaction

Typically, moisture content reduction is the most common problem in compacting PDM. Once moisture conditioning has been achieved, material can be spread in thin layers ranging from 6 to 12 inches. If further moisture conditioning is needed, PDM can be displaced continuously using farming disks pulled by bulldozers until it is ready for compaction. Attempting to compact PDM before it has been sufficiently cured and/or conditioned should be avoided since the strength will be inadequate to support heavy machinery. Smooth wheel or sheepsfoot rollers can be used for compacting PDM.

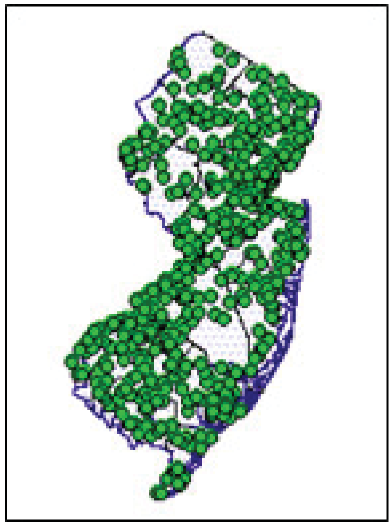
Placing cured PDM in lifts

Compaction of PDM grading layer

Once compacted, PDM should be protected against further moisture loss that could result in the formation of tensile cracks. Compaction of the PDM at moisture contents below the shrinkage limit would help to minimize the formation of tensile cracks. If PDM is being used as liner material, this issue can be avoided by limiting the amount of time that a given area of liner remains uncovered by the first layer of waste. Alternatively, the entire liner can be covered with a layer of cover soil. If the application is for a final cap, the PDM must be protected against extremes of both heat and cold since freeze-and-thaw cycles adversely affect the strength and permeability characteristics of PDM (Maher, 2001). This can easily be accomplished through application of a 2-to-3 foot layer of clean soil. This layer of soil can perform double-duty as a growth layer, since PDM does not support plant growth due to salinity and pH.

Landfill Applications

Landfills require liners during construction, cover material during use, and caps when they are finally closed. Engineers have typically utilized quarried materials for these procedures, but each also presents an opportunity to beneficially use dredged material. While construction of new landfills in New Jersey is limited, the sheer number of existing landfills in New Jersey (see inset) suggests the availability of considerable capacity for the placement of dredged material. In addition, many of these landfills predate strict environmental laws that prescribed proper construction techniques and limited their use. Consequently, these landfills are a threat to New Jersey's environment and quality of life. Remediation using PDM not only allows for a proper closure, it also presents an opportunity for habitat restoration, open space recreation, or economic development.



Landfill Sites in New Jersey

Cap and Liner Applications

Landfill caps (or liners) are designed to minimize long-term infiltration and percolation of rainwater into soils or waste material. Caps (or liners) can be composed of natural or synthetic materials. Natural material caps consist mostly of compacted natural clay, approximately 2 feet in thickness. Regulatory agencies typically require permeability of 10-5 to 10-7centimeters per second, depending on site-specific conditions. Clay for landfill applications is typically mined and transported to the landfill site. The moisture content may require minor adjustment prior to compaction.

The permeability of a capping or lining material is largely a function of its particle grain size. Small particles, such as silt and clay, are ideal for low-permeability applications. Once the sand content exceeds 40 percent, applicability of the dredged material as a cap or liner becomes questionable. Field and laboratory geotechnical testing have shown that PDM can achieve permeability of 1-by-10-7 centimeters-per-second (Maher et al., 2004, 2006). Pleistocene red-brown clay from Newark Bay was successfully used without amendment as a low-permeability cap at a landfill closure in northern New Jersey following moisture conditioning (Maher, 2005b).

Intermediate Cover

Although New Jersey's experience with utilization of dredged material for daily and intermediate cover at landfills is limited to dredged material mined from confined disposal facilities (CDF), there is no reason that PDM could not also be used successfully at active landfill sites. In these cases, moisture conditioning is probably not necessary, since the material is not forming a structural component. However, care must be taken to avoid overly generous lifts and to ensure that the PDM is processed and cured correctly as it will need to withstand movement and some compaction by heavy equipment. Permeability may be an issue for PDM made from particularly fine-grained dredged material, making it more suitable for cap and liner material as mentioned above.

Grading Material and General Fill

Dynamic compaction of waste

Placing PDM layer at landfill

Perhaps the most common use of PDM in landfills involves the placement of high volumes for general fill and grading. A certain amount of grading material is necessary for any landfill closure, to account for differential settlement of the waste as it decomposes. However, larger volumes of PDM can also be used to raise site elevations for redevelopment. In some cases, more PDM than is strictly necessary for these purposes can be accommodated to gain the economic benefit of the tipping fees from PDM. These tipping fees are often the mechanism for funding the remedial measures required for proper closure, making the project financially attractive to investors.

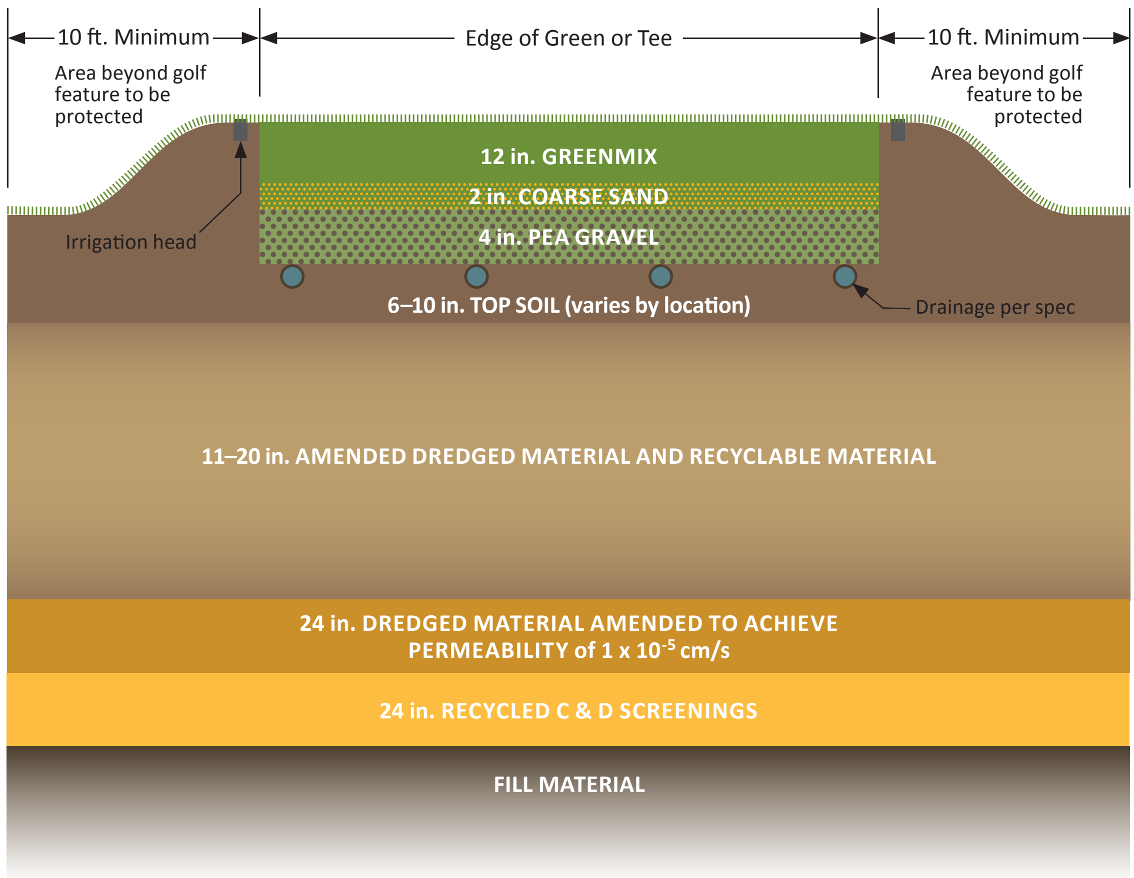


Figure 6.1: Cross-section of Bayonne landfill site

Several considerations are necessary when planning to utilize PDM as general fill and grading material. Foremost, the final use of the site will dictate the appropriate PDM recipe and placement strategy. Structural applications necessitate more care in placement, particularly with regard to moisture conditioning to achieve proper compaction. In addition, since many landfills contain a heterogeneous mixture of waste, it is prudent to consolidate the existing material when contemplating structural applications. This has been successfully done using dynamic compaction prior to placement of PDM. Research has shown that properly prepared PDM will not appreciably settle if placed on a stable surface (Maher et al., 2006`).

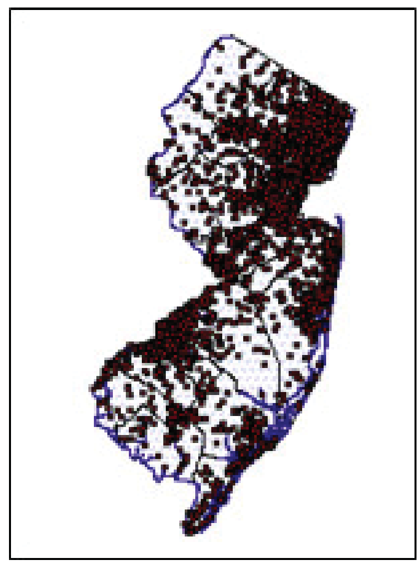
Other nonstructural uses are not so heavily dependent on the PDM recipe and open up other alternative fill scenarios. Figure 6.1 illustrates a cross-section of a remedial project over an abandoned landfill. This site had several fill layers, each with its own characteristics. First, a layer of granular waste (construction and demolition screenings) was placed, followed by a low permeability layer of PDM, isolating the waste from percolating rainwater. This was topped with a much thicker layer of PDM, with less stringent geotechnical requirements. It was followed by a layer of topsoil that served as a final grading and growth layer, since the PDM is both high in chlorides and pH. This site eventually utilized several million cubic yards of dredged material. Some landfill sites have utilized geotechnical membranes as a final cap before the growth layer in applications where there is potential for recreational or residential use.

Geotextile membrane on landfill

Completed landfill remediation

Brownfields/Contaminated Site Applications

"Brownfields" are, by definition, sites where industrial or commercial activities took place and where there is either actual or perceived contamination of soil, surface water, or groundwater. For the purposes of this discussion, we also include abandoned mines in this definition. There are literally thousands of brownfield sites in New Jersey, but many are not eyed for redevelopment due to the costly remediation required. This creates blighted neighborhoods, promotes the development of greenfields, and discourages businesses from locating in New Jersey. Properly managed, PDM can be used to cap contaminated soils, bring sites to grade, and provide a safe depository for millions of cubic yards of navigational dredged material that is too contaminated for ocean placement.



NJ Brownfield Sites

Depending on the nature of the contaminated site and the desired end use, there are many potential uses for PDM. Primarily, PDM is used as a low permeability barrier layer over the contaminated soil or fill on the site. But because of the need to take in large volumes of PDM to offset the cost of remedial engineering such as leachate collection systems and slurry walls, the vast majority of PDM that enters these sites is for general fill. In some cases, this has amounted to several millions of cubic yards. When one considers abandoned mines, the potential capacity is literally in the hundreds of millions of cubic yards. The commonwealth of Pennsylvania estimates the need for fill to properly close abandoned coal mines at as much as a billion cubic yards. Major considerations for the engineer are as follows:

- Anticipated final use of the site
- PDM recipe(s) needed to achieve the desired geotechnical requirements
- Required engineering controls
- Nature of contamination on the site
- Contamination in the PDM itself

As with landfill sites, PDM engineering and placement management depend on its use as either fill or cap material. Cap material must meet stricter geotechnical requirements for permeability and compaction than general fill, but both types of material must be properly blended to ensure they can be safely transported and placed. A key factor in determining placement of large volumes of PDM from navigation projects is whether the site was previously contaminated, and whether engineering controls are in place to contain not only existing contamination but any potential loss of contaminants from PDM itself. Fortunately, there is no evidence to date that PDM leaches contaminants (Douglas et al., 2005).

Brownfield remediation with PDM

Completed site redevelopment

Engineering Controls

There are numerous engineering controls that may be installed on a contaminated site in order to prevent contaminants from migrating offsite. Leachate collection, slurry wall containment, and reduced permeability caps are the controls most commonly used in sites that received PDM. Leachate collection systems are not only used to intercept infiltrated water, but also serve as a monitoring point for both site contamination and leachate from imported fills. To date, no contamination attributable to contaminated harbor sediment that exceeds surface water criteria has been found in leachate from a site that received PDM (Douglas et al., 2005).

Used in concert with leachate collection systems, slurry walls are usually constructed using bentonite, creating an impermeable boundary that retains any water that might slip by the leachate collection system. This technique is highly effective at arresting the migration of contaminated groundwater off site. In the case of harbor sites, this means that pollutant inputs to the harbor are reduced when a site is remediated using PDM.

The final technique is reduced permeability caps. As discussed earlier, clean PDM can be used to construct the cap, providing even more space for dredged material management, while reducing the potential for contaminant migration. Both harbor dredged material processed with pozzolans and dredged clay have shown a permeability of less than 10-5 to 10-6 centimeters per second required by the NJDEP for low permeability caps (Maher, 2005; Maher et al., 2004). If the end use of the site requires planting, it is necessary to utilize a source of non-saline material as a growth layer above the PDM. The thickness of this growth layer should be enough to ensure the roots of the plant do not penetrate the PDM cap.

Utilization of PDM and engineering controls in tandem results in a viable way to reduce the risk posed by unremediated contaminated sites. As illustrated in Figure 6.2b, the containment, capping, and leachate collection effectively isolate contaminants from both the existing soils and from materials such as PDM, which is often contaminated as well (albeit usually to a lesser extent). Since some sites generate hundreds of thousands of gallons of contaminated surface and groundwater for every acre, this technique also serves to assist in the gradual recovery of an industrial watershed. As an added bonus, the reduction in contamination sources also serves to reduce the amount of contaminated sediment that must be dredged to maintain navigational waterways.

Regulatory Oversight

A remedial action workplan (RAW) is required by the NJDEP prior to the remediation of a known contaminated site, if the owner is trying, through the remediation, to obtain a "no further action" letter. The RAW details the procedure that will be used to evaluate the condition of the property and to remediate the contamination, as well as to define the nature of the material that may be used in the remediation (including PDM), the engineering and institutional controls that will be installed, and the ongoing monitoring of those controls. The Brownfield Law not only limits liability for those who carry out a RAW, but it also provides for the application of alternative remedial standards that can be helpful when seeking to utilize PDM. Although opportunities to use alternative standards are limited, the NJDEP has approved them when the higher standard causes no increase in the contamination on the site. This "like on like at like concentrations" policy has been utilized at a number of sites, but it is limited by the overriding policy of ensuring the protection of human health and the environment. The only way to determine the standards that will be utilized for a particular site is to go through the RAW process. The project engineer is referred to the technical requirements on site remediation, which can be found at http://www.state.nj.us/dep/srp/regs/techrule/. Engineers looking to evaluate potential sites for the placement of dredged material should contact the NJDEP Office of Dredging and Sediment Technology for a list of currently permitted sites for PDM. Note that changes to this process have been instituted as part of the Licensed Site Remediation Professionals program, and sites managed by an LSRP may have different rules than those stated above.

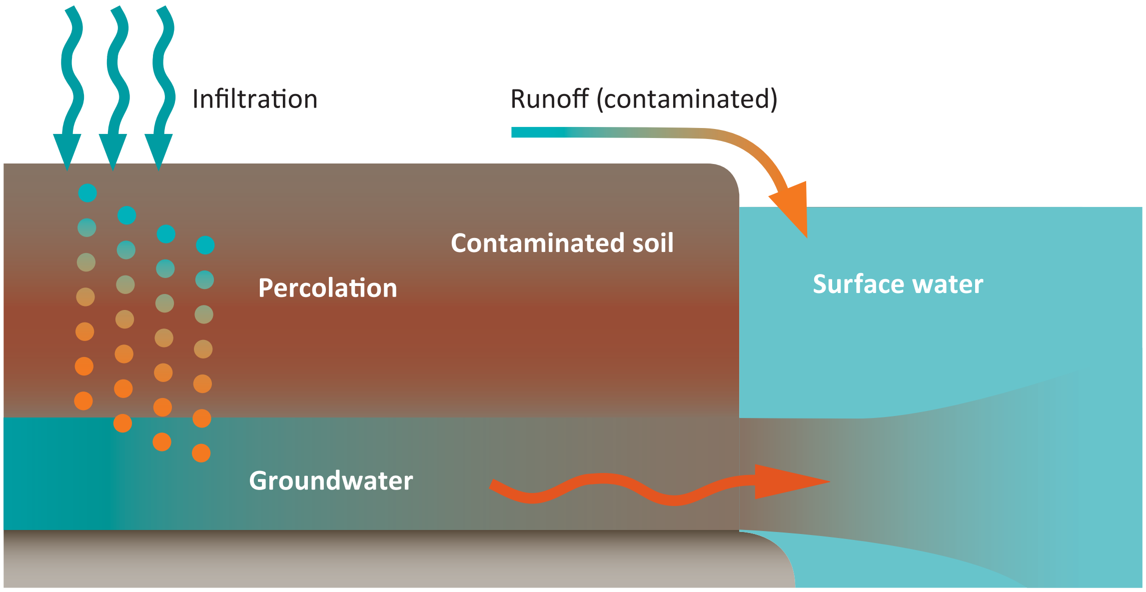


Figure 6.2a: Conceptual model of pre-remediated site condition

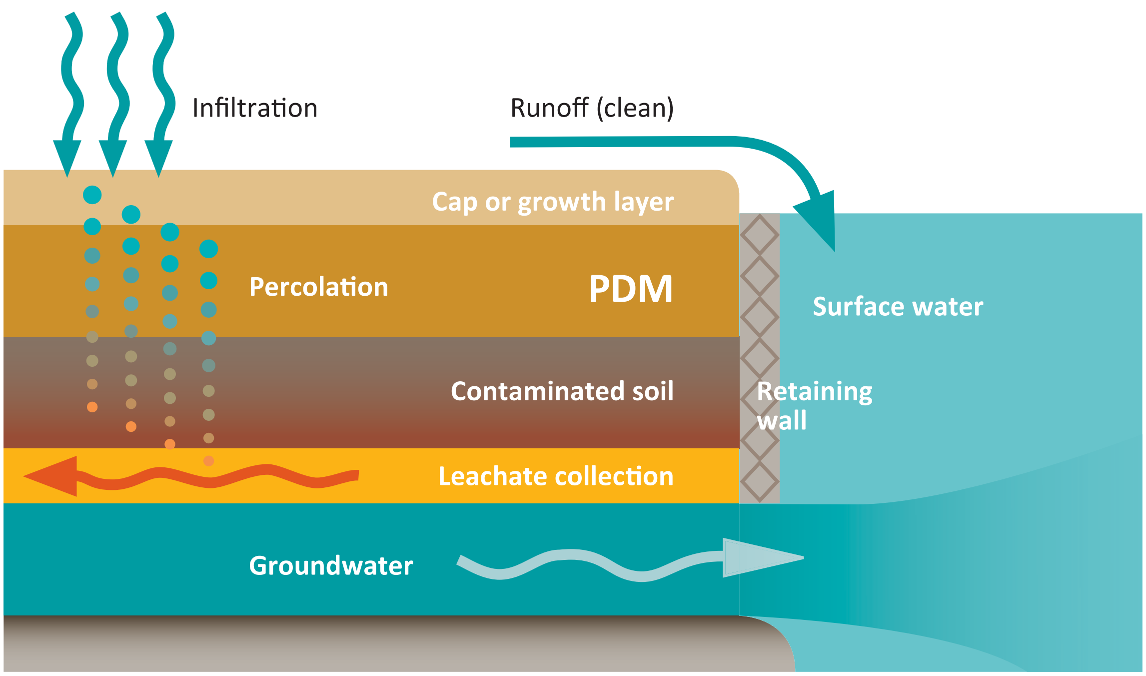


Figure 6.2b: Conceptual model of site condition following remediation with processed dredged material.

Institutional Controls

In many cases, the performance of a remediation requires that the site be placed under an easement, which restricts its future use. This also guarantees that PDM and other materials placed on the site are not spread to other, less controlled locations. The site manager (either state employee or LSRP) must collect chemical data on all of the material brought to the site, which becomes part of the site's permanent record. This ensures that future owners are aware of the nature and extent of PDM placement.

By far the greatest potential for placement of PDM at brownfield sites is through the placement of nonstructural fill. Many sites require filling and/or shaping in preparation for development and assurance that the site is above the 100-year floodplain. PDM is particularly suitable for this application, provided the operator understands the nature and limitations of PDM. It is important that the material be placed in thin layers and be allowed to cure in place, or that it is allowed to cure before placement. Moisture conditioning may be required to either speed curing in wet/cold conditions, or to achieve desired performance standards prior to compaction. Once cured, compaction can proceed using standard earthmoving equipment, such as a sheepsfoot roller. The degree of compaction depends on the desired end use—but realize that curing will continue to take place over time, even after compaction. It is easier and more appropriate to use performance standards for geotechnical properties of interest, such as strength or compaction, than to use standard material standards. Desired strength characteristics can often be achieved at much higher moisture contents with PDM than with soil, due to the cement content (Maher et al., 2004, 2006). Compaction metrics such as Modified Proctor can be tricky to interpret when applied to PDM; it has been found to be more suitable to use a performance standard like the California Bearing Ratio instead (Maher et al., 2006). For more details, see discussion in Chapter 4.

Placement of a low permeability cap may be required for brownfield sites where the existing soils are contaminated as a result of past industrial activities. Requirements of cap systems for brownfield sites are similar in principal to those of sanitary landfills. However, cap profile or permeability requirement of the impervious layers could vary depending on the site-specific conditions and the regulatory agency requirements. Utilization of PDM in a brownfield may trigger the need for environmental controls such as perimeter containment or a leachate collection system.

Millions of cubic yards of PDM have been successfully beneficially used at brownfield and landfill sites throughout the state for a variety of end uses (Table 6.1). This practice isolates contaminants, reduces leaching, and provides either structural or nonstructural fill for future development and/or restoration. Several key case studies on the use of PDM in remediation of industrial and abandoned mine sites are provided in Chapter 8.

Type of Beneficial Use	Volume of PDM Used
Commercial Development	4,729,389
Open Space and Parkland	4,337,870
Habitat Reclamation	400,000

Table 6.1: Beneficial use of PDM in greater NY/NJ metro area

Transportation Applications

PDM has been sparingly used in NJDOT roadway or embankment applications. This is contributed mostly to the excellent availability of quality aggregates in proximity to many of our roadways. For transportation analyses specifically, materials are selected on a gradation basis instead of a performance-based criterion. Any material being used for a transportation function is to be designated as a structural fill. Regardless of the use in a given facet of a transportation project (embankment, roadway base, etc.), PDM must be handled similarly to other methods outlined above. Moisture reduction is to take place before placement and compaction.

As for contaminated PDM, due to regulatory restriction for usage at sites without perimeter containment, PDM has not been used in full-scale transportation applications. In addition, silty PDM's undesirable engineering properties, such as frost susceptibility, moisture sensitivity, and high natural moisture content, make placement of PDM in a large-volume road construction application challenging. A large-scale pilot study, discussed in detail in Chapter 8, was conducted in 1999 in Elizabeth, New Jersey.

Chapter 7: Sediment Decontamination

Overview

This chapter provides information and resources regarding potential alternative beneficial use products derived from New York/New Jersey Harbor dredged material through the use of decontamination technologies. The work presented here is part of a larger effort to evaluate decontamination technologies nationwide through the Water Resources Development Act Decontamination Program of the United States Environmental Protection Agency (USEPA).

Chemical Fixation in PDM

The simplest form of decontamination is chemical stabilization or fixation, observed following the processing of sediment with Portland cement or other pozzolans. Chemical fixation and solidification (CFS), also commonly referred to as solidification/stabilization treatment (S/S), is a widely used treatment process for the management and disposal of a broad range of waste materials, especially those classified as hazardous. For example, liquid radioactive and hazardous tank wastes have been stabilized with a cement-based system that satisfied USEPA hazardous waste regulations (USEPA, 1993). The USEPA considers S/S an established treatment technology, and has identified it as the best demonstrated available technology (BDAT) for 57 RCRA-listed wastes. It is estimated that 25 percent of the CERCLA (Superfund) remediation sites include the use of S/S (USEPA, 1993). There is an ample body of technical literature documenting the fundamentals for applying S/S, as well as practical experience using this technology in projects involving a wide variety of waste materials, contaminants, and chemical matrices (Conner, 1990; USEPA, 1999).

The main purpose of adding pozzolanic admixtures to navigational dredged material to produce processed dredged material (PDM) is for dewatering and geotechnical enhancement, not chemical fixation. However, because the additives lower the permeability and increase the pH of the PDM, there are a number of positive side effects. The reduction in permeability decreases the leaching potential of all contaminants in the PDM compared to the dredged material. The increase in pH results in a reduction in the solubility of metals, further reducing their leaching potential, as well as reducing their bioavailability (Douglas et al., 2005).

The Harbor Sediment Decontamination Program

The technical and economic feasibility of using decontamination technologies to "process" dredged material was evaluated by the USEPA and the NJDOT in an extensive research program that ran from the early 1990s through the first decade of the 21st century. Since some of these technologies were originally developed to decontaminate soils, the program was called the Sediment Decontamination Technology Demonstration program. While the USEPA was interested in finding treatments for highly contaminated sediments, NJDOT's role in the program was to evaluate a select number of promising decontamination technologies for the purpose of processing navigational dredged material. The goal of NJDOT's program was to identify technologies that could demonstrate the ability to:

- Produce a beneficial use product that would meet regulatory criteria
- Decontaminate without loss of contaminants to surrounding environment
- Be scalable to a rate of at least 500,000 cubic yards per year
- Be economically practicable and able to compete with PDM processors without subsidy

The hope was to find a technology that could produce a saleable product that would not only pay for itself, but also provide essentially unlimited capacity for the management of dredged material.

The program was conducted on five technologies in two phases. Phase I was a pilot phase, designed to treat a relatively small amount of material (up to 800 cubic yards), and Phase II was a demonstration phase designed to treat a larger volume of material (up to 15,000 cubic yards) to illustrate scalability. Several promising technologies were evaluated in the program including chemical oxidation, thermal treatment, and sediment washing. Only three of the five technologies piloted also conducted a demonstration. A brief summary of the more promising technologies is provided in Table 7.1; a full report on each technology demonstration is available at www.state.nj.us/transportation/airwater/maritime. More information on the larger sediment decontamination program can be found at www.bnl.gov/wrdadcon.

Vendor	Technology	Product	Volume Treated
		Pilot Scale	
BEM Systems[1]	Georemediation™	Manufactured Soil	0.5 cyd
BioGenesis Enterprises	Sediment Washing	Manufactured Soil	800 cyd
ENDESCO/ Clean Harbors	Thermal Destruction	Blended Cement	100cyd
Harbor Resources Environmental Group	Chemical Oxidation	Manufactured Soil	3.2 cyd
JCI Upcycle	Thermal Destruction	Lightweight Aggregate	4 cyd
		Demonstration Scale	
BioGenesis Enterprises	Sediment Washing	Manufactured Soil	15,000 cyd
ENDESCO/ Clean Harbors	Thermal Destruction	Blended Cement	44 cyd
Harbor Resources Environmental Group	Chemical Oxidation	Manufactured Soil	325 cyd

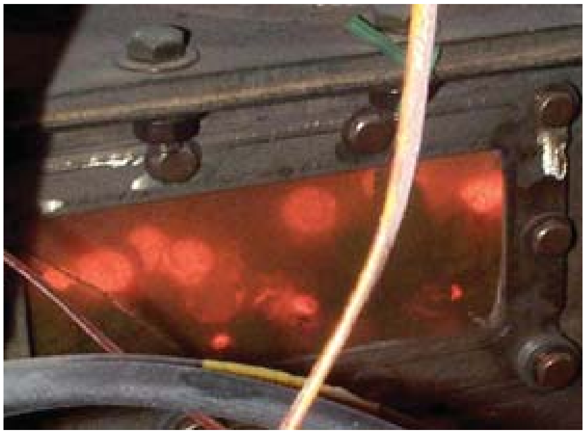
1This technology did not prove effective; for more information the reader is referred to the NJDOT website

Table 7.1: Summary of NJDOT sediment decontamination technology demonstration program

Thermal Treatment

Several methods use intense heat to both destroy chemical contaminants and transform the physical properties of dredged material to produce a valuable PDM product such as lightweight aggregate, glass, or blended cement. The products are typically devoid of contamination, and those metals that may remain are not leachable. While this technology has proved highly successful from a strictly decontamination standpoint, from a logistical standpoint, kilns are expensive and difficult to site (due to air pollution concerns) and prone to breakdowns that reduce throughput.

The most promising thermal processes utilize rotary kiln technology, which operates at temperatures of over 2,000°C. The intense heat in this technology is different from incineration, which typically only heats the waste to 800°C or less. This higher temperature does a much better job destroying contaminants transferred to vapor phase, and an extensive treatment train is used to capture any contaminants that resist burning, such as volatile metals. We evaluated two thermal processes: one produced a blended cement product, the other produced lightweight aggregate. Both products meet ASTM criteria and can be readily used in construction.



Lightweight aggregate kiln

Lightweight aggregate product

The production of lightweight aggregate was evaluated at the pilot scale only—about 4 tons of aggregate were produced utilizing a testing facility in Catasaqua, Pennsylvania. Lightweight aggregate manufacture is a complex process, requiring that the dredged material be blended with crushed shale and molded into pellets prior to firing. Firing the pellets causes the organic matter inside the pellets to burn, creating air cavities that remain after the pellets have cooled. All organic contaminants present in the dredged material are destroyed, and metal contaminants are either fixed into the mineral matrix of the aggregate pellet or captured in vapor phase (see Table 7.2). The resulting product is ASTM compliant for strength and density and does not leach contaminants (see Table 7.3).

The production of blended cement was evaluated using a pilot plant designed to process up to 30,000 cubic yards of sediment per year. The mineralogy of the dredged material was modified by adding alumina and other materials to ensure the product would have the proper pozzolanic properties. Due to severe design flaws, the plant was never able to operate at full capacity, and only treated about 100 tons of dewatered sediment. The pilot plant actually produced two products: one when the plant was operating normally—a glass-like pellet called Ecomelt™—and the other when the plant was operating at less than optimal temperature—a clean, granular material called EcoAggMat™. Ecomelt™ was used to produce an ASTM-compliant concrete that met or exceeded all environmental criteria (see Table 7.2, 7.3), and is the basis of the treatability and economic analyses. EcoAggMat™ was suitable for use as a general purpose aggregate and also met or exceeded applicable environmental criteria, despite being considerably less valuable. Air emissions from the kiln, even when operating at full temperature, clearly showed that while very little organic contamination escaped the treatment train, volatile metals like lead, arsenic, and mercury can be problematic. Full-scale applications will either need to be permitted with an upper limit on these metals in the feedstock, or the treatment train must be modified to remove these contaminants from emissions.

Rotary kiln air treatment system **Ecomelt product**

Rotary kiln technology, whether used to produce lightweight aggregate or blended cement, requires extensive preprocessing of the dredged material. The material must be dewatered first, and modifiers are usually required to achieve rigid geotechnical requirements. In the case of lightweight aggregate, the dewatered material must be mixed with quarry fines at 50 percent or more by volume and then pressed into pellets. Both methods are relatively slow and require substantial storage to handle the surge from a commercial navigation dredging operation (5 to 15,000 cubic yards per day). In addition, both methods are energy intensive and have air pollution concerns for conventional pollutants (SOx and NOx), as well as contaminants from the dredged material, that make them difficult to permit and site.

Assuming the technical and permitting issues could be overcome, proponents of rotary kiln technology suggest that costs for sediment treatment might be reduced by adding electronic waste or waste solvents/oils or tires to the input stream. Small-scale tests (not funded by NJDOT) indicated that adding in other waste streams does not negatively impact the product quality. Unfortunately, adding other waste streams does reduce the processing rate of dredged material. Compensating for this requires additional kilns, which would further increase capital costs. Another way to lower processing costs without sacrificing processing capacity for dredged material might be to scavenge waste heat from the process and use it to generate electricity.

Chemical Treatment

Contaminated sediment can also be treated using a combination of chemical additives and separation technologies to destroy, reduce, or segregate contamination for the purpose of producing a manufactured soil. The soil product might be used as a cap or fill material much like PDM, or it may be suitable as final cover or topsoil, depending on the technology and the feed material. Several chemical technologies of varying complexity were evaluated in the USEPA/NJDOT research program.

At the present time, the most accepted and proven technology for managing contaminated dredged material is PDM and upland placement. One of the challenges with this method is meeting site-specific chemical criteria, particularly for commonly encountered harbor contaminants like PCBs and PAHs. If site-specific criteria cannot be met, then the PDM cannot be placed on the site. In most cases, sites with less stringent criteria for a given contaminant are available. From a management standpoint, this creates a problem because much of the sediment that needs to be managed is not suitable for all locations. This reduces capacity and decreases competition, driving up costs. Pretreating the sediment to reduce the contaminant of concern until it meets criteria or fully cleaning the sediment so that it is suitable for all or most sites and applications might solve the problem

Pretreating the Sediment

The first solution was proposed by the Harbor Resources Environmental Group (HREG). A strong oxidant (potassium permanganate) was introduced to the raw dredged material to reduce organic contamination (see Table 7.2). After a six-hour contact period, the dredged material was dewatered using a belt filter press, followed by blending with 7.6 percent Portland cement to produce a standard PDM product. The belt filter press effluent was sand, filtered and taken off site for treatment. As with many treatment technologies, the logistics of preprocessing and sediment handling proved difficult. Even though approximately 2,400 cubic yards of sediment were provided to the project team, only 325 cubic yards of material were able to be treated before time and budget constraints shut the project down. Contaminant reduction was highly variable, and averaged only 10 to 20 percent for all measured constituents. Variability in the results was so high, in fact that it was not possible to prove statistical significance. Consequently, a number of important questions regarding the applicability of this technology remain:

- What is the spectrum of treatable contaminants and concentrations?
- Would better material homogenization, greater contact time, or higher oxidant concentrations improve treatment?
- What are the equipment requirements for full scale applications?
- Are the costs recoverable given the availability of alternative sites for moderately contaminated sediment?
- For more highly contaminated sediments, does the dewatering process produce an effluent that requires extensive treatment?

HREG chemical mixing tank

HREG filter press

Selected Analytes (dry wt)	2008 NJ RSRS	2008 NJ NRSRS	Upcycle Aggregate[2] Initial	Upcycle Aggregate[2] Final	Cement Lock[3] Initial	Cement Lock[3] Final	BioGenesis[3] Initial	BioGenesis[3] Final[1]	Chemoxidation[2] Initial	Chemoxidation[2] Final
As mg/kg	19	19	10.9	3.4	15.57	7.91	13.44	7.96	14.71	7.86
Cd mg/kg	78	78	1.4	0.2	62.65	0.34	6.58	0.95	12.4	7.79
Hg mg/kg	23	65	2.3	0.2	4.63	0.015	4.88	1.59	3.65	3.3
Pb mg/kg	400	800	113.3	3.6	362.23	19.8	376.23	82.74	289.6	147.62
Benzo(a)anthracene ug/kg	600	2000	540.0	(330)	1682.23	0.42	1687.69	597.27	762.1	649
benzo(b)fluroanthene ug/kg	600	2000	750.0	(330)	1846.73	0.8	2040.77	770.00	681.6	601.7
benzo(a)pyrene ug/kg	200	200	530.0	(330)	1625.07	0.43	1731.54	668.18	750	650.3
indeno(123-cd)pyrene ug/kg	600	2000	(830)	(330)	814.67	0.43	1056.92	481.82	391.9	295.9
dibenz(ah)anthracene ug/kg	200	200	(830)	(330)	98.83	0.23	316.08	154.55	254.3	181.2
dieldrin µg/kg	40	200	(20)	(10)	16.11	0.516	16.50	0.15	1.72	1.37
total PCB mg/kg	0.2	1	130.0	(20)	2.58	0.000241	0.46	0.10	0.736	0.622
Aroclor 1248 ug/kg	200	1000	130.0	(20)	NA	NA	NA	NA	NA	NA
Aroclor 1254 ug/kg	200	1000	106.7	(20)	NA	NA	NA	NA	NA	NA
Aroclor 1260 ug/kg	200	1000	40.0	(20)	NA	NA	NA	NA	NA	NA
2,3,7,8-TCDD pg/g	NA	NA	119.3	0.6	689.2	0.51	651.43	68.97	154	263.9
TEQ dioxin pg/g	NA	NA	186.0	1.0	802.9	210.04	751.43	49.37	201	331.2

RSRS = Residential soil remediation standards, NRSRS = Non-residential soil remediation standards

1 Results are for end of treatment train; actual manufactured soil met RSRS through dilution

2 Sediment from northern Newark Bay commercial berth

3 Sediment from Passaic River dredging demonstration

Table 7.2: Selected bulk sediment chemistry results of decontamination demonstration projects from various harbor locations. Grayed cells indicate exceedence of either the residential (light gray) or nonresidential (dark gray) remediation standards

Metal	New Jersey Groundwater Criteria	BioGenesis highest	BioGenesis last	Chemoxidation highest	Chemoxidation last	Upcycle Aggregate highest	Upcycle Aggregate last	Cement-Lock highest	Cement-Lock last
Ag ug/L	40	(5)	(5)	1	(1.5)	(5)	(5)	(10)	(10)
As ug/L	3	17.7	8.1[1]	4.5	3.7	23	(15)	9.06	9.06
Ba ug/L	2000	28.9[1]	25.7[1]	340	26	229	229	133	(100)
Cd ug/L	4	(2)	(2)	0.4	(1.2)	(3)	(3)	(4)	(4)
Cu ug/L	1300	27.2	29.3	85	5.3	156	81	(10)	(10)
Hg ug/L	2	0.29	0.46	0.033	(0.05)	0.5	(0.2)	(0.29)	(0.29)
Mn ug/L	50	27.8	46.6	4970	430	107	72	(10)	(10)
Ni ug/L	100	(40)	(40)	5.1	0.7	81	37	(40)	(40)
Pb ug/L	5	25.9	23.1	4.1	(2.2)	(3)	(6)	6.28	(5)
Se ug/L	40	5.7	1.7[1]	5	(4.7)	(10)	(10)	(20)	(20)
Zn ug/L	2000	38.8	39.6	130	29	4490	2160	(20)	(20)

Parentheses indicate that chemical was not detected at that concentration

1 Blank contamination observed

Table 7.3: Results of multiple extraction procedure (MEP) tests on decontaminated sediment from northern Newark Bay. Reported concentrations are either the highest observed concentrations or the last extract performed. Grayed cells are probable exceedences of New Jersey groundwater protection standards

Fully Cleaning the Sediment

The most promising of the chemical treatments studied was sediment washing using the BioGenesis™ treatment technology. The basic treatment train involved slurrying the dredged material, then separating the particles using high energy, then mixing it with oxidants, and finally separating the solids into organic and mineral fractions. The completely disaggregated mineral fractions are then mixed with suitable, clean organic amendments to create clean manufactured topsoil with the necessary nutrients to promote plant growth. The organic and ultra-fine grain fractions, as well as the effluent, must be disposed of or treated off site.

BioGenesis™ oxidant injection

BioGenesis™ centrifuges

BioGenesis™ was utilized to treat approximately 15,000 cubic yards of dredged material from three different locations in the harbor. The technology was clearly able to improve the contaminant profile of the dredged material; however, New Jersey's residential soil remediation standards were not met for some PAHs (see Tables 7.2 and 7.3). Meeting PAH criteria was later shown to be possible by adding steps for screening organic debris and using surfactants to "float" oily contaminants. The concern regarding marginal contaminant levels in the treated material is relevant if the material is to be placed as general fill without further processing. However, if the decontaminated material is used as a base for manufacturing soil, all criteria can easily be met for residential applications since only 40 percent treated dredged material is used in the manufactured soil mixture.

This technology provides a high degree of flexibility in creating products to meet various needs, as well as to segregate and destroy dredged material contaminants at varying initial and final concentrations. The complexity of the treatment process does limit capacity and throughput; therefore, storage is required if dredging is to proceed at normal production rates. Storage for the manufactured soil product would also be required. With economies of scale—and assuming a continuous feed of material over many years—an 80-cubic-yard-per-hour facility could treat 500,000 cubic yards of dredged material per year at a price of $50 to 60 per yard, assuming similar contaminant levels and the salability of manufactured soil product is maintained. Costs for more contaminated material might require additional treatment steps that would drive up the cost per cubic yard.

Conclusion

For all of the technologies evaluated in this program, there are several key conclusions that can be drawn:

- Most decontamination technologies are capable of treating navigational dredged material to meet applicable upland standards.
- All technologies are capable of performing without creating additional pollution, but some do produce waste products that must be properly disposed.
- Material handling is the most difficult and time-consuming part of the process.
- Raw material storage is required for commercial applications in order to allow dredging to proceed at normal rates.
- Processing costs could be competitive with conventional PDM, but most proponents require a "guaranteed flow" of material at a rate of 250 to 500,000 cubic yards per year over 10 to20 years in order to ensure recovery of capital costs.
- Siting of decontamination facilities may prove contentious, particularly for thermal technologies.
- Most technologies produce a product that will need to obtain acceptance in the market to ensure success.

To date, none of the tested technologies has been able to establish a presence in the New York/New Jersey Harbor, due to a combination of funding constraints, high real estate and labor costs, and the difficult market conditions (no long-term contracts).

Chapter 8: Case Studies

Overview

In this chapter, we will examine four cases studies that beneficially used PDM from New York/New Jersey Harbor—two golf courses, a shopping center, and an abandoned mine. We also summarize each situation by outlining what was learned from each experience .

Jersey Gardens Mall

Overview

The Jersey Garden Mall Site (the former Kapkowski Landfill) is located in Elizabeth, New Jersey, and is bound by the New Jersey Turnpike to the west, Newark Bay to the east, and North Avenue to the north. The Kapkowski Landfill received waste from the city of Elizabeth from 1960 through the early 1970s. When waste disposal activities ceased, a 6-to-8-inch layer of soil was placed over the waste material. No environmental controls such as perimeter containment, leachate collection, or gas collection were installed during or after waste disposal operations.

In 1995, the NJDEP approved a remedial action workplan (RAW) for the closure and redevelopment of the Kapkowski Landfill. As part of the RAW, a fill protocol was devised to allow for diverse recyclable materials such as crushed glass, pulverized masonry, and recycled soil and PDM to be deposited on the site as structural fill.

The Jersey Gardens Mall site was the first project in New Jersey where PDM from New York/New Jersey Harbor was beneficially used. Dredged material was amended with Portland cement, lime kiln dust, cement kiln dust, or fly ash, and the resulting PDM was used as construction fill for grading of the parking areas and sub-grade fill. Over a two-year period, approximately 800,000 cubic yards of dredged material from various reaches of Newark Bay and New York Bay was processed and used to grade the project site. PDM was used as sub-grade fill within the paved areas and was covered by 2 feet of granular soil and the pavement structure. In addition to PDM, 2.4 million cubic yards of non-dredged material fill was placed over 100 acres of the site to raise the grades approximately 20 feet above the pre-construction elevations. The mall parking areas have been in service since late 1998. To date, the performance of the pavement has been satisfactory.

Processing

Half of the dredged material (or approximately 400,000 cubic yards) placed at the Jersey Garden Mall site was processed on site and on a neighboring property using a pugmill system. The other half of the dredged material was mixed in-scow at a Port Newark facility and transported to the site by truck. The additive of choice was Portland cement, but cement kiln dust, lime kiln dust, and fly ash were also used.

Two processing plants were used for processing of sediments at the site, one within the mall site and the second on a neighboring property. Major operational problems (discussed below) were experienced as a result of the poor design of the first processing plant, resulting in significant delays in PDM processing. The second pugmill system was designed to address the shortcomings of the first plant.

The site did not have deep-water access. Therefore scows transporting raw dredged material had to anchor in deep waters approximately 1,500 feet away from the shoreline. Dredged material was pumped through a pipeline into the pugmill. In order to pump the sediment, significant amounts of water had to be added. The additional water made handling and placing the PDM difficult, which resulted in increased additive and operational costs. Days or weeks of moisture conditioning were required before the PDM could be compacted. The pumps were later replaced by piston pumps capable of pumping sediments with a solids content of up to 40 percent, reducing the magnitude of these operational problems.

Another challenge for pumping sediments was debris. Dredged material from areas within Newark Bay contained significant amounts of scrap metal. Large debris was segregated at the dredging site, and segregation of smaller debris is not practical. During pumping, the smaller-size scrap metal clogged the pipeline many times, significantly delaying the processing operation.

First pugmill operation with tent

Jersey Gardens Mall

Another operational problem related to the storage and conveyance of additives to the pugmill. Additives were initially stored inside a tent and transferred into the pugmill by a conveyor belt. Fugitive dust emissions during unloading of additives in a semi-open tent proved a major issue: human exposure to dust was a significant health concern. After processing approximately 100,000 cubic yards of poorly mixed PDM, the operation was stopped and a second-generation plant was constructed at the neighboring property with deep-water access.

For the second processing plant, pumping of sediments was eliminated. Sediment was transported via scow to a bulkhead, where it was unloaded by clamshell bucket directly into the processing plant. A screen system was placed above the feed hopper to screen debris larger than 2 inches. Additives were stored in and continuously fed by gravity via closed silos mounted on top of the pugmill. Generally, 8 to 10 percent Portland cement on the total weight basis was used. Once mixed, the PDM was transferred into off-road trucks and transported within the site for final placement. That plant successfully processed 2,200 to 3,000 cubic yards in eight-hour shifts and processed approximately 200,000 cubic yards of PDM.

Placement

Portland cement was the preferred admix used for stabilization/solidification due to its consistency and availability. During the first few months of operation with the first plant, the PDM was spread over large areas in thin layers (6 to 12 inches) and exposed to air and sun in order to lower the moisture content. A set of farming disks pulled by a bulldozer constantly displaced the material. The moisture content was continuously monitored until it reached values near optimum. During favorable weather conditions, this process took four to five days. In the cold season, however, moisture conditioning was so unsuccessful that placement had to stop until weather conditions improved.

Evaluation

The primary usage of PDM at the Jersey Garden Mall site was structural fill for grading and contouring and as subbase material within the paved areas. The mall building is supported on steel piles, and no PDM was placed within the footprint of the building due to concerns regarding the PDM's corrosivity. Outside the footprint and within the parking areas, PDM was placed in 1-foot layers and compacted. The criterion initially used for compaction was 92 percent of Modified Proctor (ASTM D1557) density. While this criterion is typically used for conventional construction fill, it is perhaps not a good criterion for PDM. To achieve this compaction, extended periods of disking and aeration were required. To avoid the excessive operational expenses, engineers revisited the compaction criteria.

Pavement design requires a minimum California Bearing Ration (CBR) of 10 for the sub-grade if conventional soils are used. Laboratory testing revealed that a CBR value of 10 or higher could be assigned to PDM if compacted to 88 percent of modified proctor density. Therefore the target density was relaxed from 92 to 88 percent. The moisture content was limited to 50 percent (the shrinkage limit) for prevention of tensile cracks. At the time of the printing of this manual, the pavement had been in place for 15 years with satisfactory performance.

Summary

Lessons learned from the Jersey Garden Mall project:

1) PDM can be successfully used as structural fill for grading and sub-grade of paved areas.

2) The placement and compaction criteria must be tailored for the end use and on a project–by-project basis.

3) Pumping of raw dredged material through pipelines is infeasible due to the presence of debris.

4) Additives with predictable properties are more efficient for solidification of PDM.

5) Following the addition of cement or lime, moisture conditioning is required to ensure proper compaction and achievement of target engineering properties.

Bayonne Golf Course

Overview

The Bayonne Golf Course site was comprised of the former city of Bayonne municipal landfill and a brownfield site owned by the Public Service Electric and Gas (PSE&G). In total, approximately 125 acres of upland space and 260 acres in open water were available. The site is located on Upper New York Bay, south of the Military Ocean Terminal of Bayonne. Surrounded by oil refineries, warehousing, and industrial establishments, this brownfield property seemed an unlikely choice for a golf course. However, the former 400-acre Military Ocean Terminal was targeted for mixed-use redevelopment. This, along with the potential for spectacular views of Manhattan (not to mention easy travel by water), made the golf course project more viable.

To contour the site to a golf course, approximately 5 million cubic yards of fill was required. PDM was the preferred option since tipping fees for acceptance of PDM would partially compensate for the cost of environmental remediation required by the agencies. Soil and ground water within the site were contaminated due to past industrial use on and off site. Environmental remediation included a perimeter containment system (slurry wall and steel sheetpile), leachate and gas collection systems, and placement of an engineered cap. NJDEP approved utilization of PDM as grading and cap material, with differing chemical contamination allowed in each layer.

PDM Processing

Deep-water access to the site was provided to allow for direct unloading of dredged sediments into a processing plant. Approximately 180,000 cubic yards of mudflats were dredged to construct the access channel. This material was beneficially used on site.

Approximately three acres of open water at the northeast corner of the site was filled with large stone fill to construct an off-loading platform for receipt and unloading of raw dredged material. The stone-and-rock fill were contained by 206 meters (700 feet) of steel-sheet piling. The platform was designed to accommodate a third-generation processing plant and unloading equipment. The new plant included two separate pugmills to build redundancy and minimize down time. The previous plant design was modified by lowering the loading hopper to a level at which a hydraulic excavator with a clamshell bucket could unload the dredged material much faster than a crane. The plant was rated to process 500 cubic yards per hour. Large debris was screened out at the dredging site, and a vibratory screen system removed debris larger than 2 inches before the sediment entered the pugmills. Collected debris was disposed of as municipal solid waste.

Dredged material was partially dewatered prior to delivery to the site. Portland cement was stored in silos mounted above the pugmill and fed by gravity into the pugmill at predetermined ratios. Portland cement was the sole additive mixed with sediments at 8 to 10 percent on total weight basis. Once amended, PDM was transported to the designated areas within the site for placement.

Bayonne site during remediation

Bayonne golf course

Placement

USACE and PANYNJ projections for delivery of dredged material were on the order of 10,000 cubic yards per day (this was never actually achieved). Steep side slopes on the east and the northern boundaries of the site, and a 30-foot-wide manmade ditch bisecting the property, limited the acreage available for spreading and air-drying of PDM. These factors, combined with the challenges of compacting PDM with high water content experienced during unfavorable weather conditions at the Jersey Gardens Mall project, inspired new methods for placement of PDM.

During favorable weather conditions, approximately one week of moisture conditioning is needed before PDM can be successfully compacted. For this project, the area required for moisture conditioning would be 6 acres per day or 40 acres every week. This area could be even larger during unfavorable weather conditions. Since the site could not accommodate this, uncured PDM was placed in 4- to 5-foot layers and allowed to cure without further disturbance (flowable fill). After one week, a layer of pulverized masonry was placed over the PDM to allow trucks to access the area for placement of additional PDM. Approximately 2 million cubic yards of PDM was placed in this fashion to a height of 50 feet. The material was later disrupted to grade and shape the golf course.

Evaluation

Stability concerns were limited to side slopes, therefore the reduced strength of disrupted PDM was still adequate to achieve a 2.5 horizontal to 1 vertical slope at a height of 50 feet or more. A comprehensive slope stability analysis demonstrated that a factor of safety of 1.5 under static loading was achieved. Strength of PDM was estimated to be 1,000 pounds per square foot or higher based on the cone penetration test (CPT) and laboratory tests.

Monitoring of slope movements by inclinometers showed no significant movement within PDM or underlying soils. There have been no significant slope failures observed to date. Interestingly, minor slope failures following severe rain events on slopes covered by material other than PDM have been reported.

As part of landfill closure, the entire site was required to have 2 feet of PDM with permeability of 10-5 centimeters per second or less. PDM placed as flowable fill did not meet this criterion. Additional PDM was placed in two 1-foot layers, fully moisture conditioned and compacted. Cap permeability was verified with field tests.

Summary

Lessons learned from the Bayonne Golf Course:

1) Pugmills can successfully process dredged material at rates of 500 cubic yards per hour, as long as redundancy is provided to account for breakdowns and routine maintenance.

2) Hydraulic excavators are more efficient than cranes for unloading dredged material from scows.

3) PDM can be placed as flowable fill in 4-to-5-foot-thick lifts and allowed to cure in place. However this method may impact the ability to meet permeability criteria.

4) PDM placed as flowable fill provided sufficient strength for construction of 1V:2.5H side slopes approximately 50 feet high.

5) In order to meet reduced permeability criteria for capping, moisture-conditioned PDM should be placed in 1- to 2-foot lifts and compacted between lifts.

Encap Golf Site

Overview

The Encap Golf Site is comprised of four landfills (Lyndhurst, Avon, Rutherford, and Kingsland), totaling approximately 700 acres in the New Jersey Meadowlands. Waste material from municipal, industrial, and commercial sources was deposited in these landfills from the 1950s to the 1980s. While waste no longer flows to these sites, none of them were properly closed. Once the landfills are remediated, the site will be developed into golf courses, hotels, conference centers, and residential, commercial, and recreational areas.

NJDEP approved the beneficial use of PDM as a grading and barrier layer fill. Approximately 1.2 million cubic yards of PDM was placed at the site from October 2004 to September 2007. Dredged sediments from New York/New Jersey Harbor were mixed with Portland cement (8 to 10 percent on wet weight basis) in processing facilities at Port Newark (in-scow mixing) and Jersey City (pugmill mixing). PDM was allowed to cure for 48 hours at the processing facilities and then transported to the site for beneficial use. Based on previous experience, this moisture conditioning, or curing, would increase workability and facilitate efficient placement. The plans call for an estimated 3 million cubic yards of PDM. Approximately half of this is required for the 2-foot-thick, low-permeability barrier layer.

Since a considerable amount of fill material is needed to grade the site, PDM that exceeds remediation standards was accepted as long as it was placed below the barrier layer. Site-specific standards were developed for this alternative fill material based on existing contamination and proposed engineering controls. Engineering controls previously installed on some portions of the site included a cover system, gas venting system, leachate collection system, and groundwater barrier wall. Remediation activities completed or remaining to be completed on the site include:

- Full cap and cover system
- Site-wide leachate collection system
- Complete vertical hydraulic barriers
- Comprehensive landfill gas collection system

The cap systems include PDM, geosynthetic liner, soil, and pavement cover. A PDM cap is proposed for the Kingsland, Lyndhurst, and Rutherford landfills. The geosynthetic cover system (consisting of 40-mil low-density polyethylene liner and geocomposite drainage layer on top) will be constructed at the Avon Landfill. Rutherford, Lyndhurst, and Kingsland landfills will receive PDM and other recycled materials.

Processing

PDM was processed using both in-scow and pugmill systems. Based on field observations, dredged material processed in the pugmill system was more uniformly mixed and contained less moisture than the in-scow processed PDM. On occasion, pockets of raw dredged material, poorly mixed material, or cement were observed in the in-scow mixed PDM, more commonly in the first two months of PDM delivery. During favorable weather conditions, the pugmill-mixed PDM required two to three days of moisture conditioning prior to compaction, while in-scow–mixed PDM required four to five days.

Slurry wall installation

PDM placement

Placement

Prior to the initiation of fill-placement operations, a term sheet was prepared specifying the physical conditions of PDM acceptable for placement. The following list summarizes the term sheet:

- Dewatered prior to processing
- Screened of all debris greater than 4 inches in size
- Maximum hydraulic conductivity (permeability) of 10-5 centimeters-per-second (cm/sec) for low-permeability barrier layer application
- Minimum unconfined compressive strength of 1,000 pounds per square foot (psf) in 72 hours and 2,000 psf in 28 days
- Maximum particle size of 4 inches
- Trafficable within 72 hours as determined by test method TM 5-530/NAVFAC MO-330/AFM (must support fully loaded highway trucks without excessive rutting or the trucks becoming stuck)
- Minimum daily delivery rate of 5,000 cubic yards

Based on the limited number of permeability tests performed, the compacted PDM met the NJDEP-required permeability criterion of 10-5 cm/sec. More permeability tests will be performed to confirm that the PDM cap meets the criterion. Past experience with PDM used as barrier layer fill indicated that PDM has a high potential for meeting the 10-5 cm/sec permeability criterion within a wide range of moisture content and density.

Of the 1.2 million cubic yards of PDM received at the site as of September 2006 , only half was placed and compacted as grading fill or as a barrier layer; the rest was stockpiled. The PDM received at the site during the summer was immediately spread and compacted, while PDM received during cold months was stockpiled. The PDM placement contractor chose to stockpile PDM during cold weather because three days of curing was not sufficient to meet the trafficability test requirement.

Evaluation

Stockpiling of PDM is not the preferred method of PDM handling. PDM should be placed at the final designated location within two to three days of mixing and not be disturbed. Double handling of PDM results in breaking of soil-cement bonds, reducing the strength of the soil (Maher et al., 20010). The PDM should have been placed in layers, sloped to allow drainage, moisture conditioned, and compacted.

While trafficability requirements were part of the original term sheet, this requirement is unrealistic for year-round operations in the Mid-Atlantic. Additional costs of handling, placement, or extra additives should be considered if PDM is placed during cold seasons.

Shear strength of 2,000 pounds per square foot was initially required to ensure that the PDM would safely support structural loads of proposed buildings near the edge of the slopes. The strength requirement was waived once it was decided to limit the use of PDM to barrier layer fill and grading fill for the golf courses. Although the PDM was placed on side slopes and not compacted to reach a target density and strength, no evidence of slope failure or excessive movement was observed. This ability to place PDM on side slopes was previously demonstrated at the Bayonne Golf Course.

Summary

Lessons learned from the Encap Golf Site:

1) Realistic specifications should be set based on previous experiences with PDM to avoid stockpiling that reduces strength.

2) If stockpiling is used, care must be taken to ensure that the material is properly stored to avoid erosion, compaction, and moisture loss.

3) PDM that does not meet the strictest specifications can often be used in other ways on the site.

4) PDM clearly is able to achieve 10-5 cm/sec or less permeability as required by NJDEP for low-permeability caps.

Pennsylvania Mines Demonstration

Overview

The coal mining industry in Pennsylvania has left behind a legacy of environmental damage ranging from acid runoff to surface collapse. More than 3,000 miles of streams and rivers have been rendered sterile by acid mine drainage and runoff from exposed rock faces and pyrolitic spoil piles. To remediate the 5,600 abandoned mines would require an estimated one billion cubic yards of fill. The Bark Camp mine site in Clearfield County, Pennsylvania, was targeted by the Pennsylvania Department of Environmental Protection (PADEP) Bureau of Abandoned Mines as a site to demonstrate remediation technology. The site is 1,200 acres of linear highwall, stripped to remove the coal seam and exposing pyrolitic rock. The Bark Camp Run traverses the site, which was rendered completely sterile by a combination of deep mine drainage and surface runoff.

The Office of Maritime Resources contracted with Consolidated Technologies Inc in 1998 to demonstrate the use of amended dredged material in abandoned mine reclamation. More than 425,000 cubic yards of sediment were dredged from a municipal marina in Perth Amboy, New Jersey, and from the Port Authority berths in Newark Bay to demonstrate the technology between 1998 and 2002.

Processing

Dredged material was excavated conventionally from navigation channels and shipping berths in the Port of New York and New Jersey. The material was dewatered, raked for debris, and processed with 15 percent coal fly ash by volume or municipal solid waste incinerator ash, and cured for shipment to Bark Camp by rail. Processing was accomplished by Consolidated Technologies Inc. (now Clean Earth Dredging Technologies) at two locations over the project; first at the Construction Marine facility in Elizabeth, New Jersey (40,000 cubic yards pilot) and the remainder at the dredged material processing facility located on the Claremont Channel in Jersey City, New Jersey. Processing started in 1998 and was completed in 2002.

The objective of the dockside processing was to further dewater the material and facilitate shipping and handling. The Claremont facility was able to process as much as 4,300 cubic yards per day. A similarly constructed secondary processing facility was erected at the placement site to prepare the material for final placement. The additional coal ash was added using a comparable pugmill system. Dredged material was dewatered at the Claremont facility, and the decant water was discharged to the channel under a NJPDES permit. Debris was removed using a vibrating screen system in advance of the pugmill. The material was mixed using a pugmill system with dual-feed material hoppers. Additives included both fly ash from fluidized bed combustion and municipal waste incinerator ash (MWIA).

PDM was first shipped from the port to the Bark Camp site by rail using 400 rail cars, each holding approximately 110 tons of PDM. The material was removed using a bridge-mounted excavator, and placed into heavy-duty mining trucks for transport 2 miles by unimproved road to the secondary processing facility. At the secondary facility, an additional 25 percent coal ash (by volume) and 15 percent high lime kiln dust was added to the material. This brings the total additive mixture to 55 percent by volume.

Pennsylvania mines railhead

Placing PDM on highwall

Placement

Processed material was trucked to the mine highwall and placed in stockpiles. Once enough material was moved for a 1- to 2-foot lift, the material was bulldozed in place and compacted using standard earthmoving equipment. Each subsequent lift was slightly less in area, resulting in a stepped final grade to restore the original grade of the land. The steps were then filled in with topsoil, graded, and seeded.

Evaluation

Raw dredged material was evaluated by NJDEP and PADEP prior to permitting. The material was subjected to bulk sediment, TCLP, and SPLP testing according to standard laboratory procedures for a target analyte list (see Appendix). One sample for every 10,000 cubic yards of material was required for PADEP approval. Geotechnical criteria for placement were typical of nonstructural fill; a strength of 35 pounds per square inch to withstand use of heavy equipment, and a permeability of less than 1 x 10-6 centimeters per second.

Over 50 monitoring points were located around the site for the evaluation of potential impacts to ground and surface water. Based on seven years of monitoring, the only measurable impact to water quality was slight increases in chloride concentrations, which were well below water-quality standards. These exceedences were only apparent during placement activities, and quickly dissipated. Impacts from chloride laden MWIA were slightly higher, but also dissipated quickly. Despite this, PADEP has discontinued the use of MWIA as an additive for dredged material. Partway through placement activities, the PADEP was able to document a return of a healthy benthic ecosystem, and overwintering trout were documented in the previously sterile Bark Camp Run. The highwall area itself has returned to a meadow condition providing attractive habitat for native wildlife. Eventually the area will be indistinguishable from the surrounding hillside.

Summary

Lessons learned from the Bark Camp:

1) After seven years , there were no detectable contaminants in either surface or groundwater that were in excess of background contamination.

2) Coal ash is a suitable additive for dredged material, but MWIA is not.

3) There were no impacts to drinking water, and highwall remediation significantly improved surface water conditions.

4) Highwalls can be remediated with PDM.

5) Both aquatic and terrestrial ecosystems can be restored at abandoned mine sites using amended dredged material.

6) PADEP has approved the use of PDM as a fill at other abandoned mine sites in eastern Pennsylvania.

7) Aside from high transportation costs, the costs of sediment management at mine sites are not appreciably different from those charged at other beneficial use sites.

Chapter 9: Quality Control/ Quality Assurance

Overview

The purpose of this section of the manual is to discuss effective quality control and quality assurance procedures in projects using PDM. The inherent variability in properties of dredged material, coupled with the fact that few operators have experience with the product, creates an opportunity for serious problems if a proper quality control plan is not in place during the operation.

Enhancing the dredged material through solidification and stabilization is the primary mechanism of strength development for large applications. Management of water content is typically the most cumbersome, time-intensive, and expensive part of the process; yet it is this operation that will be most critical for success. Other characteristics, such as in place permeability, trafficability, and chemical makeup, are also important; methods for addressing these will be included. Careful attention to these methods ensures a smooth, effective, and profitable project for all parties.

The quality control program presented here involves a series of tests or checks on the material to be dredged, the product as it is produced, or the characteristics of the placed material. While some tests may be conducted in the field, most need to be verified using laboratory-based methods. We cannot stress highly enough that the heterogeneous nature of dredged material makes it important to test frequently in order to confirm that design criteria are being met.

A formal quality control and quality assurance (QA/QC) plan not only ensures a consistent product and/or reliable application, but also ensures that all groups involved are using the appropriate test methodology and sampling frequencies. The USEPA and USACE recommends the following information should be included in the QA project plan for dredged material evaluation unless a more abbreviated plan can be justified (USACE, 1995).:

Laboratory Testing Options

Laboratory testing of materials is standard practice for all projects contemplating the use of dredged material. Since dredged material is a product of sedimentation and natural shoaling in rivers and estuaries, it is typified by an abundance of fine silt and clays, especially in the New York/New Jersey Harbor. Raw fine-grained dredged material has such low strength that it is virtually unusable in the construction industry. However, the addition of pozzolanic admixtures gives the raw sediment the required strength and handling qualities to perform as well as traditional materials. Processed dredged material (PDM) differs from upland soils in gradation, moisture content, and strength, but can be effectively used in many nonstructural, and some structural, applications. However, a different array of tests is required than those used for clean upland soils. It is very important that all engineers and field managers understand the unique properties of PDM and how to properly manage its storage and placement on site.

In many cases, dredging proponents will wish to determine beneficial use opportunities prior to the start of dredging. Appropriate geotechnical characteristic tests can be used to evaluate the sediment in situ. The typical tests are outlined in Chapter 42. Since in situ testing is required as part of the permitting process, many geotechnical tests can also be performed at this time. Both raw sediment and PDM can be evaluated if a bench-scale batch of PDM is prepared according to the recipe proposed for each specific application. Since the exact method (type of additive and mix percentage) of stabilization may not be known at the time of permitting, environmental characteristics are determined using a standardized method (8 percent Portland cement). If the final method used differs, it may be prudent to retest the sediment prior to the start of processing. Samples of raw sediment collected during the pre-permit phase should be retained for this contingency. While holding times and conditions for geotechnical properties are not critical, it is recommended that organic silts and clays be held in the dark at 40°F to ensure the organic content does not degrade.

Placement of PDM is highly dependent on moisture content and temperature. Since the amount of pozzolonic additive directly affects the performance of the product, it is necessary to carefully monitor the amount of additive and the adequacy of mixing. Furthermore, because the amount of moisture in the sediment is a function, to some extent, of the dredging on any given day, there is no reason to expect that the sediment being processed has the same amount of moisture as the sediment sampled in situ. The process of decanting excess water will standardize the moisture content somewhat, but it is still important to evaluate the moisture content of the product after processing. Additional steps to condition the PDM prior to final compaction may be prudent. These include, but are not limited to: increasing the amount of additive used, increasing the cure time at the processing site, increasing the cure time at the placement site, decreasing the depth of each lift, aeration of PDM in place using appropriate machinery, and increasing the time between lifts. Analysis of moisture content can be accomplished on site, as needed, and adjustments made accordingly.

Site Evaluation

If PDM is going to be used as fill in the remedial process, site evaluation is the first step to success. The site must be carefully evaluated for the nature and extent of chemical contamination, as well as for natural resources such as wetlands, biota, and water sources. This information is the basis of the remedial action workplan (RAW), which details how and where PDM will be used. The full scope of the testing required for a remedial action is beyond the scope of this document; the engineer is directed to the Technical Regulations for Site Remediation (NJDEP, 2009). In 2011, the NJDEP published new guidelines regarding the characteristics of acceptable fill at New Jersey remediation sites that specifically address dredged material. This policy allows site managers to calculate acceptable PDM chemical characteristics that may dramatically impact the amount of available PDM.

While the remedial investigation process provides a significant amount of information designed to direct the use of PDM, it leaves out several important steps. Many sites are former landfills, and the stability of the waste layers is questionable. The amount of compaction needed will vary; the engineer can use cone penetrometer testing (CPT) to evaluate the relative density of waste layers. If necessary, dynamic compaction can be used to stabilize the base on which PDM will be placed. This will minimize the potential for differential settlement. In some cases, it may not be possible to stabilize the site sufficiently, especially where waste has been placed over meadow mat. In these situations, geotextile fabrics can be used to allow application of PDM to proceed.

Many landfills also feature saturated clay layers, which will consolidate slowly when surcharged with dredged material. Wick drains are successful at reducing porewater and provide a more stable surface for the placement of PDM. Once the final design parameters of the fill are known, the engineer can calculate the potential for a given clay layer to consolidate and determine the appropriate actions to take.

Placement Site Testing

Once PDM has been placed, it is important to evaluate whether or not the fill has achieved the desired specifications prior to final cover. As mentioned before, the range of tests for quality control depend on its final use. Based on the specific end use, Table 9.1 outlines the common ranges for testing and the frequency of testing. Each project has specific site characteristics that may require the engineer to suggest different ranges and frequencies; this table serves as typical values found using PDM past projects.

Table 9.1 is broken up into four categories: nonstructural fill, structural fill, barrier layers, and liner material. These categories encompass most of the dredged material currently placed in New Jersey. Most sampling frequencies for post-placement testing occur every 3,000 cubic yards because a typical dredging scow has approximately a 3,000-cubic-yard capacity, and this testing frequency will detect any changes in material characterization or processing quality.

. .	Nonstructural Fill		Structural Fill		Barrier Layer/Cap		Liner Material	
Preparation	**Range**	**Frequency**	**Range**	**Frequency**	**Range**	**Frequency**	**Range**	**Frequency**
Moisture	<80%	3000 cyd[1]	<50%	3000 cyd	<50%	3000 cyd	<40%	3000 cyd
Particle Size	<4 inch	3000 cyd	<4 inch	3000 cyd	<2 inch	3000 cyd	<1 inch	3000 cyd
Gradation	NA	NA	NA	NA	Sandy silt, silt, clay	3000 cyd	Silty clay or clay	3000 cyd
Placement	Range	Frequency	Range	Frequency	Range	Frequency	Range	Frequency
CBR	NA	NA	>10	3000 cyd[2]	NA	NA	NA	NA
Strength	500-1500 psf	3000 cyd	1500-3000 psf	3000 cyd	<1000 psf	3000 cyd	<1000 psf	3000 cyd
Permeability	NA	NA	$>10^{-5}$ cm/sec	3000 cyd	$<10^{-5}$ cm/sec	3000 cyd	$<10^{-7}$ cm/sec	3000 cyd
Density (modified)	NA	NA	85-95%	10000 ft^2	85-95%	10000 ft^2	85-95%	10000 ft^2
Trafficability	NA	NA	72 hr	3000 cyd	72 hrs	3000 cyd	72 hrs	3000 cyd

1 3,000 cubic yards is approximately the volume of one standard dredge scow

2 Alternative would be to perform once per lift

Table 9.1: Example of geotechnical specifications and frequency of sampling for PDM preparation and placement. These are suggestions; project-specific criteria should be developed to fit processing, material, and site requirements .

The best indicator for changes in material quality is strength. Strength testing is recommended every 3,000 cubic yards regardless of beneficial use. Intuitively, nonstructural fill has the least strength requirements, and structural fill often has the most stringent. These requirements are easily met with many dredging and processing programs in place today.

Permeability and in situ density testing provide an ideal final indicator on the performance of the PDM. Permeability data can fluctuate depending on compaction levels and additive concentrations, as will compaction density. Most beneficial uses wish to restrict the level of permeability to prevent the migration of contaminants or pollutants through the soils, but for structural reasons a level of permeability higher than 1x10-5 centimeters per second is ideal to prevent cyclic freeze/thaw damage. For that reason, PDM used for structural benefits should have adequate drainage, while those used as a separation layer between exposure and contamination recommend a lower permeability. The compaction levels for PDM have been suggested in a range of 85 to 95 percent optimum compaction. Compaction standards outside of this range could have adverse effect on strength, permeability, or both. These ranges are the recommended values for final site placement.

Quality Assurance Project Plan (QAPP)

Quality assurance is best achieved by preparing a QAPP prior to initiation of work. This chapter provides the basis for such a plan, if used in conjunction with permit and engineering specifications. A complete QAPP includes analytical methods, detection limits, and frequency of testing as well as processing procedures, type and source of amendments, placement procedures, locations, depths, and criteria. The QAPP should also include contingency for failure to meet criteria for either chemistry or engineering properties/performance. Proper training should be defined, as should be equipment and maintenance. It is appropriate for both the processing facility and placement site to have a generic facility plan that can serve as the basis for a project-specific plan.

It is essential that participants in a project utilizing PDM agree and adhere to a pre-developed QAPP to ensure that both the dredging project and the remedial project can be successful. Dredged material is, by nature, heterogeneous and difficult to handle.

The quality of sediment provided by the dredger may not have been adequately characterized by the sampling and testing performed for the dredging permit, resulting in an inability to achieve engineering criteria without modifying either processing or placement procedures. Having clear and transparent records, as well as a willingness to discuss issues between the processor and placement site engineer is critical for a successful project (Maher, 2007).

Project	Barge	Truckload	Stockpile	Lift	Final
Grain size	Settling time	Weight	Curing time	Permeability	Permeability
In situ bulk and bench-scale PDM chemistry	Dewatering (volume, pump rate)	Odor	Stormwater management	Strength	Strength
Water content	Water content	Moisture content (no free water)	Moisture content	Moisture conditioning (if needed)	
Organic matter	Heterogeneity	Heterogeneity	Chemistry (if necessary)	*In situ* density	
Debris	Debris	Debris		Trafficability	
Sediment heterogeneity	Weight of raw sediment			Compaction (equipment and time)	
Corrosivity and pH	Percent additive				
Amendment recipe	Mixing time				
Engineering properties	Curing time				
Suitability and capacity at placement site	Final moisture content				

Table 9.2: Quality control concerns for processing and placement of PDM

Table 9.2 outlines the points during the various steps in the dredging and management of dredged material where quality control checks should be made. Since every dredging project and placement site is unique, the project manager will need to determine appropriate criteria for each point. The following paragraphs explain each step in detail.

Dredging Project Basis

Ensure that the sediment will be able to meet placement site–specific permitting and engineering criteria and that there is available capacity. Determine both the type and ration of the amendment. Bench-scale samples should be tested for engineering properties if structural applications are anticipated. Amount and nature of expected debris must be compared to equipment limitations. Determine expected bulking factor by material type to predict settling and dewatering time. High organic matter content can impact pozzolanic reactions. Marine sediments are likely to be corrosive.

Barge Basis

Record settling time from arrival to initiation of dewatering (24 hours or greater, unless otherwise specified in permit). Dewatering procedure, time, and discharge point must be recorded on each barge. Record time required for debris removal and nature of debris. Record any observations of sediment heterogeneity (e.g., clay balls, gravel, rocks). Heterogeneity can impact pugmill processing; if it cannot be reduced by mixing, quality of PDM may be impacted. Record raw sediment weight by direct measurement (pugmill) or estimated by volume survey (in-scow). Record the mass of additive required (minimum 8 percent additive or as required by engineering specification). Record actual mass and type/source of additive used, as well as mixing time. Record the curing time (in-scow and/or in piles) prior to transporting off site. Record any post-processing moisture conditioning or mixing performed prior to transportation. Record results of visual inspection for debris and heterogeneity. Avoid mixing material from different projects even if bound for the same placement site.

Load Basis

Each trucked load should be weighed prior to transportation. Record weight, visual observation for debris, free water and heterogeneity, and any noticeable chemical or ammonia odor Unacceptable levels of these factors might warrant rejection/reprocessing of load. Notes should be transmitted to the placement site with a bill of lading.

Stockpile Basis

Record time of stockpiling and purpose (e.g., awaiting placement approval, sequencing, moisture conditioning, etc.). Record shaping/grading or covering method employed to avoid moisture gain (provide for rapid drainage of stormwater to collection basin). If verification chemical or geotechnical tests are required, ensure batches are segregated by volume as per permit or site requirements. For stockpile periods of more than two weeks, or in periods of excessive rain or snow, test and record moisture content prior to placement. Under no circumstances should stockpiled material be compacted or spread into lifts until placed at final location. Moving previously compacted PDM will result in loss of strength.

Lift Basis

Provide elevation markers to ensure proper lift height. Remove any debris prior to compaction. Record compaction procedure (equipment and time), verify that in situ density is sufficient to meet project specifications, and re-compact and/or moisture condition as necessary to achieve proper compaction. Evaluate permeability, trafficability, and strength after each lift, and compare to project specifications and permit (see Table 9.2 for example specifications). Report results back to processing facility to modify procedure as necessary.

Placement Project Basis

For structural applications, ensure that moisture is low enough to allow compaction of soil, and wick drain if necessary. Ensure that existing waste or soil layers are sufficiently compacted to handle PDM loading, and compact as necessary with static or dynamic compaction. Clearly document source, volume, and placement location of all PDM taken onto site. When placement is complete, guarantee that permeability and strength parameters have been met (see Table 9.2 for example specifications).

Quality Assurance Issues

Paperwork

Proper records for each batch of PDM are essential if quality objectives are to be achieved. Paperwork will also ensure that disputes regarding the quality of PDM can be quickly addressed. Cross checking paperwork claims against field observations can be useful as well.

Training

Proper training of operators is essential for successful processing and placement of PDM. PDM is not soil, and it requires experience to properly process and place. It is incumbent on the facilities to provide adequate training for operators and inspectors and document it.

Contingency Planning

For some applications, pre-placement quality control checks reveal a batch or batches that do not meet specification for either chemical or geotechnical specifications. In the case of geotechnical requirements, it may be possible to simply hold the material.

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