PDHonline Course C755 (4 PDH)

Environmental Dredging of Contaminated Sediments

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Contaminated Sediment Remediation Guidance for Hazardous Waste Sites

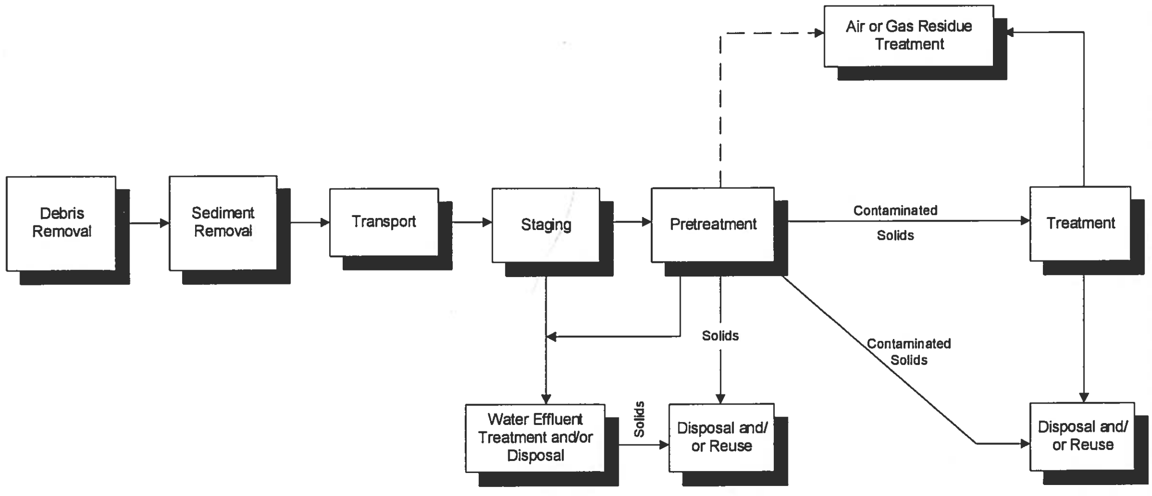
6.0 DREDGING AND EXCAVATION

6.1 INTRODUCTION

Dredging and excavation are the two most common means of removing contaminated sediment from a water body, either while it is submerged (dredging) or after water has been diverted or drained (excavation). Both methods typically necessitate transporting the sediment to a location for treatment and/or disposal. They also frequently include treatment of water from dewatered sediment prior to discharge to an appropriate receiving water body. Sediment is dredged by the U.S. Army Corps of Engineers (USACE) on a routine basis at numerous locations for the maintenance of navigation channels. The objective of navigational dredging is to remove sediment as efficiently and economically as possible to maintain waterways for recreational, national defense, and commercial purposes. Use of the term "environmental dredging" has evolved in recent years to characterize dredging performed specifically for the removal of contaminated sediment. Environmental dredging is intended to remove sediment contaminated above certain action levels while minimizing the spread of contaminants to the surrounding environment during dredging [National Research Council (NRC 1997)].

Some of the key components to be evaluated when considering dredging or excavation as a cleanup method include sediment removal, transport, staging, treatment (pretreatment, treatment of water and sediment, if necessary), and disposal (liquids and solids). Highlight 6-1 provides an sample flow diagram of the possible steps in a dredging or excavation alternative. The simplest dredging or excavation projects may consist of as few as three of the components shown in Highlight 6-1. More complex projects may include most or all of these components. Efficient coordination of each component typically is very important for a cost-effective cleanup. Project managers should recognize, in general, fewer sediment rehandling steps leads to lower implementation risks and lower cost.

Highlight 6-1: Sample Flow Diagram for Dredging/Excavation



Sediment removal by dredging or excavation has been the most frequent cleanup method used by the Superfund program at sediment sites. Dredging or excavation has been selected as a cleanup method for contaminated sediment at more than 100 Superfund sites (some as an initial removal action). At approximately fifteen to twenty percent of these sites, an in-situ cleanup method [i.e., capping or monitored natural recovery (MNR)] was also selected for sediment at part of the site. When dredging is the selected remedy and hazardous substances left in place are above levels that allow for unlimited use and unrestricted exposure, a five-year review pursuant to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) §121(c) may be required (U.S. EPA 2001i).

Project managers should also refer to the U.S. Environmental Protection Agency's (EPA's) *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (U.S. EPA 1994d), and *Handbook: Remediation of Contaminated Sediments* (U.S. EPA 1991c), the NRC's *Contaminated Sediments in Ports and Waterways: Cleanup Strategies and Technologies* (NRC 1997), and *Operational Characteristics and Equipment Selection Factors for Environmental Dredging* (Palermo et al. 2004) for detailed discussions of the processes and technologies available for dredging and excavation.

Although each of the three potential remedy approaches (MNR, in-situ capping, and removal) should be considered at every site at which they might be appropriate, sediment removal by dredging or excavation should receive detailed consideration where the site conditions listed in Highlight 6-2 are present.

Highlight 6-2: Some Site Conditions Especially Conducive to Dredging or Excavation

- Suitable disposal site(s) is available and nearby
- Suitable area is available for staging and handling of dredged material
- Existing shoreline areas and infrastructure can accommodate dredging or excavation needs; maneuverability and access not unduly impeded by piers, buried cables, or other structures
- Navigational dredging is scheduled or planned
- Water depth is adequate to accommodate dredge but not so great as to be infeasible; or excavation in the dry is feasible
- Long-term risk reduction of sediment removal outweighs sediment disturbance and habitat disruption
- Water diversion is practical, or current velocity is low or can be minimized, to reduce resuspension and downstream transport during dredging
- Contaminated sediment overlies clean or much cleaner sediment (so that over-dredging is feasible)
- Sediment contains low incidence of debris (e.g., logs, boulders, scrap material) or is amenable to effective debris removal prior to dredging or excavation
- High contaminant concentrations cover discrete areas of sediment
- Contaminants are highly correlated with sediment grain size (to facilitate separation and minimize disposal costs)

6.2 POTENTIAL ADVANTAGES AND LIMITATIONS

One of the advantages of removing contaminated sediment from the aquatic environment often is that, if it achieves cleanup levels for the site, it may result in the least uncertainty about long-term effectiveness of the cleanup, particularly regarding future environmental exposure to contaminated sediment. Removal of contaminated sediment can minimize the uncertainty associated with predictions of sediment bed or in-situ cap stability and the potential for future exposure and transport of contaminants.

Another potential advantage of removing contaminated sediment is the flexibility it may leave regarding future use of the water body. In-situ cleanup methods such as MNR and capping frequently include institutional controls (ICs) that limit water body uses. Although remedies at sites with bioaccumulative contaminants usually require the development or continuation of fish consumption advisories for a period of time after removal, other types of ICs that would be needed to protect a cap or layer of natural sedimentation might not be necessary if contaminated sediment is removed.

Another advantage, especially where dredging residuals are low, concerns the time to achieve remedial action objectives (RAOs). Active cleanup methods such as sediment removal and, particularly, capping may reduce risk more quickly and achieve RAOs faster than would be achieved by natural recovery. (However, in comparing time frames between approaches, it is important to include accurate estimates of the time for design and implementation of active approaches.) Also, sediment removal is the only cleanup method that can allow for treatment and/or beneficial reuse of dredged or excavated material. (However, caps that incorporate treatment measures, sometimes called "active" caps, are under development by researchers. See Chapter 3, Section 3.1.3, In-Situ Treatment and Other Innovative Alternatives.)

There are also some potential sediment removal limitations that can be significant. Implementation of dredging or excavation is usually more complex and costly than MNR or in-situ capping because of the removal technologies themselves (especially in the case of dredging) and the need for transport, staging, treatment (where applicable), and disposal of the dredged sediment. Treatment technologies for contaminated sediment frequently offer implementation challenges because of limited full-scale experience and high cost. In some parts of the country, disposal capacity may be limited in existing municipal or hazardous waste landfills, and it may be difficult to locate new local disposal facilities. Dredging or excavation may also be more complex and costly than other approaches due to accommodation of equipment maneuverability and portability/site access. Operations and effectiveness may be affected by utilities and other infrastructures, surface and submerged structures (e.g., piers, bridges, docks, bulkheads, or pilings), overhead restrictions, and narrow channel widths.

Another possible limitation of sediment removal is the level of uncertainty associated with estimating the extent of residual contamination following removal that can be high at some sites. For purposes of this guidance, residual contamination is contamination remaining in the sediment after dredging within or adjacent to the dredged area. The mass and contaminant concentration of residuals is generally a result of many factors including dredge equipment, dredge operator experience, proper implementation of best management practices, sediment characteristics, and site conditions.

Residual contamination is likely to be greater in the presence of cobbles, boulders, or buried debris, in high energy environments, at greater water depths, and where more highly contaminated sediment lies near the bottom of the dredge thickness or directly overlies bedrock or a hard bottom. Residuals may also be greater in very shallow waters and when dredging sediment with high water contents. These complicating factors can make the sediment removal process difficult and costly. The continued bioaccumulation of residual contaminants can also affect the achievement of risk-based remediation goals. Dredging residuals have been underestimated at some sites, even when obvious complicating factors are not present. For some sites, this has resulted in not meeting selected cleanup levels without also backfilling with clean material.

Another potential limitation of dredging effectiveness includes contaminant losses through resuspension and, generally to a lesser extent, through volatilization. Resuspension of sediment from dredging normally results in releases of both dissolved and particle-associated contaminants to the water column. Resuspended particulate material may be redeposited at the dredging site or, if not controlled, transported to downstream locations in the water body. Some resuspended contaminants may also dissolve into the water column where they are more available for uptake by biota. While aqueous resuspension generally is much less of a concern during excavation, there may be increased concern with releases to air. Losses en route to and/or at the disposal or treatment site may include effluent or runoff discharges to surface water, leachate discharges to ground water, or volatile emissions to air. Each component of a sediment removal alternative typically necessitates additional handling of the material and presents a possibility of contaminant loss, as well as other potential risks to workers and communities.

Finally, similar to in-situ capping, dredging or excavation includes at least a temporary destruction of the aquatic community and habitat within the remediation area.

Where it is feasible, excavation often has advantages over dredging for the following reasons:

- Excavation equipment operators and oversight personnel can much more easily see the removal operation. Although in some cases diver-assisted hydraulic dredging or video-monitored dredging can be used, turbidity, safety and other technological constraints typically result in dredging being performed without visual assistance;

- Removal of contaminated sediment is usually more complete (i.e., residual contamination tends to be lower when sediment is removed after the area is dewatered);

- Far fewer waterborne contaminants are released when the excavation area has been dewatered; and

- Bottom conditions (e.g., debris) and sediment characteristics (e.g., grain size and specific gravity) typically require much less consideration.

However, site preparation for excavation can be more lengthy and costly than for a dredging project due to the need for dewatering or water diversion. For example, coffer dams, sheet pile walls, or other diversions/exclusion structures would need to be fabricated and installed. Maneuvering around diversion/exclusion structures may be required because earth moving equipment cannot access the excavation area or double handling may be required to move material outside of the area. In addition, excavation is generally limited to relatively shallow areas.

6.3 SITE CONDITIONS

6.3.1 Physical Environment

Several aspects of the physical environment may make sediment removal more or less difficult to implement. In the remedial investigation, the following types of information should be collected, as they can affect the type of equipment selected and potentially the feasibility of sediment removal:

- Bathymetry, slope of the sediment surface and water depth;
- Currents and tides;
- Bottom conditions, especially the presence of debris and large rocks both on top of and within the sediment bed;
- Depth to and (un)evenness of bedrock or hard bottom (e.g., stiff glacial till);
- Sediment particle size distribution, degree of consolidation, and shear strength;
- Thickness and vertical delineation of contaminated sediment;
- Distance between dredging and disposal locations;
- The presence and maintenance condition of structures such as piers, pilings, cables, or pipes; and
- Land access to water body.

Additionally, sediment removal may change the hydrodynamics and slope stability of the remediation area. These changes should be evaluated to ensure that the removal activity does not cause significant bank or structural instability, shoreline facility damages, or other unacceptable adverse effects in or near the removal operation.

Data on both the horizontal and vertical characterization of the physical and chemical sediment characteristics are generally needed during the remedial investigation to evaluate the feasibility, cost, and potential effectiveness of dredging or excavation. The results of this characterization should help determine the area, depth, and volume to be removed, and the volume of sediment requiring treatment and/or disposal. Some aspects of sediment characterization are discussed in Chapter 2, Section 2.1, Site Characterization.

The project manager should refer to *Evaluation of Dredged Material Proposed for Disposal at Island, Nearshore or Upland Confined Disposal Facilities - Testing Manual* (USACE 2003) and *Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. - Inland Testing Manual* (U.S. EPA and USACE 1998) for further information. In addition, several guidance documents on estimating contaminant losses from dredging and disposal have been developed by the EPA and USACE. For example, the project manager should refer to *Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments* (U.S. EPA 1996e).

6.3.2 Waterway Uses and Infrastructures

Any evaluation of the feasibility of a dredging or excavation remedy should consider impacts to existing and reasonably anticipated future uses of a waterway. Waterway uses that may need to be considered when evaluating a sediment removal alternative include the following:

- Navigation (e.g., commercial, military, recreational);
- Residential/commercial/military moorage and anchorage;
- Flood control;
- Recreation;
- Fishing (e.g., subsistence, commercial, recreational);
- Water supply, such as presence of intakes;
- Storm water or effluent discharge outfalls;
- Use by fish and wildlife, especially sensitive or important aquatic habitats;
- Waterfront development;
- Utility crossings; and
- Existing dredge disposal sites.

Evaluation of the feasibility of a sediment removal remedy should include an analysis of whether impacts to these potential uses may be avoided or minimized both during construction and in the long term.

6.3.3 Habitat Alteration

The project manager should consider the impact of habitat loss or alteration in evaluating a dredging or excavation alternative. As is also discussed in Chapter 5, In-Situ Capping, while a project may be designed to minimize habitat loss, or even enhance habitat, sediment removal and disposal do alter the environment. It is important to determine whether the loss of a contaminated habitat is a greater impact than the benefit of providing a new, modified but less contaminated habitat. For example, a sediment removal alternative may or may not be appropriate where extensive damage to an existing forested wetland will occur. If the contaminated sediment in the wetland is bioavailable and may be impacting wildlife populations, the short-term disruption of the habitat may be warranted to limit ongoing long-term impacts to wildlife. Comparatively, if the wetland is functioning properly and is not acting as a contaminant source to the biota and the surrounding area, it may be appropriate to leave the wetland intact rather than remove the contaminated sediment. Deliberations to alter wetland and aquatic habitats should be considered in the remedial decision process. Appropriate coordination with natural resource agencies will typically assist the project manager in determining the extent of impacts that a dredging project may have on aquatic organisms or their habitat, and how to minimize these impacts.

Another consideration is avoidance of short-term ecological impacts during dredging. This may involve timing the project to avoid water quality impacts during migration and breeding periods of sensitive species or designing the dredging project to minimize suspended sediment during dredging and disposal.

6.4 EXCAVATION TECHNOLOGIES

Excavation of contaminated sediment generally involves isolating the contaminated sediment from the overlying water body by pumping or diverting water from the area, and managing any continuing inflow followed by sediment excavation using conventional dry land equipment. However, excavation may be possible without water diversion in some areas such as wetlands during dry seasons or while the sediment and water are frozen during the winter. Typically, excavation is performed in streams, shallow rivers and ponds, or near shore areas.

Prior to pumping out the water, the area can be isolated using one or more of the following technologies:

- Sheet piling;
- Earthen dams;
- Cofferdams;
- Geotubes, inflatable dams;
- Rerouting the water body using temporary dams or pipes; or
- Permanent relocation of the water body.

Sediment isolation using sheet piling commonly involves driving interlocking metal plates (i.e., sheet piles) into the subsurface, and thereby either blocking off designated areas or splitting a stream down the center. Highlight 6-3 shows an example of where this technology has been used. If a stream is split down its center, then one side of the stream may be excavated in the dry, after pumping out the trapped water. When the excavation of the first side of the stream is completed, water may be diverted back to the excavated side and sediment on the other side may be excavated. Sheet piling may not be feasible where bedrock or hard strata are present at or near the bottom surface. Where sheet piling is used to isolate a dredging or excavation action, project managers should consider potential hydraulic impacts of the diverted flow. Such diversion in most cases will increase natural flow velocity, which may scour sediment outside the diversion wall. If the sediment is also contaminated, as is likely to be the case, the increased dispersion of the sediment should be considered in design choices. Temporarily rerouting a water body with dams is sometimes done for small streams or ponds (Highlight 6-4). This includes the use of temporary dams to divert the water flow allowing excavation of now "dry" contaminated sediment. The ability and cost to provide hydraulic isolation of the contaminated area during remediation is a major factor in selecting the appropriate removal technology.

Once isolated, standing water within the excavation area will need to be removed. Although surface water flows are eliminated, ground water may infiltrate the confined area. The ground water can be collected in sumps or dewatering wells. After collection, the ground water should be characterized, managed, treated (if necessary), and discharged to an appropriate receiving water body. Management of water within the confined area is another important logistical and cost factor that can influence the decision of wet versus dry removal techniques.

Highlight 6-3: Example of Excavation Following Isolation Using Sheet Piling

Source: Pine River/Velsicol, EPA Region 5

Isolation and dewatering of the area is normally followed by excavation using conventional earthmoving equipment such as a backhoe or dragline. Where sediment is soft, support of the excavation equipment in the dewatered area can be problematic because underlying materials may not have the strength to support equipment weight. This also may reduce excavation depth precision. Both factors should be accounted for in design. When the excavation activities are complete, temporary dam(s) or sheet piling(s) are removed, and the water body is restored to its original hydraulic condition.

Another less common type of excavation project involves permanent relocation of a water body (also shown in Highlight 6-4). This, for example, was accomplished at the Triana/Tennessee River Superfund Site in Alabama and is being implemented at the Moss-American Superfund site in Wisconsin. The initial phases of such a project may be similar to excavation projects that temporarily reroute a water body. However, in a permanent stream relocation project, a replacement stream normally is constructed and then the original water body is excavated or capped and converted into an upland area. To the extent the original water body is covered over, direct exposure to residual contamination is generally eliminated.

Highlight 6-4: Examples of Permanent or Temporary Rerouting of a Water Body

A: Permanent River Relocation – Triana/Tennessee River Site

The Triana/Tennessee River site consists of an 11-mile stretch of two tributaries, the Huntsville Spring Branch (HSB) and Indian Creek, which both empty into the Tennessee River. Remedial actions involved rerouting of the channel in Huntsville Spring Branch (HSB mile 5.4 to 4.0), the filling and burial in place of the total DDT (dichloro diphenyl trichloroethane and its metabolites) in the old channel, the construction of diversion structures at the upper and lower end of the stream to prevent stream reversion to the former stream channel, and the diversion of storm water runoff to prevent flow across the filled channel. Remedial actions for HSB mile 4.0 to 2.4 consisted of constructing four diversion structures; excavating a new channel between HSB mile 3.4 and 2.4; filling three areas; constructing a diversion ditch around the fill areas; and excavating portions of the sediment from the channel.

These remedial actions effectively isolated in place 93% of the total DDT in the Huntsville Spring Branch-Indian Creek system of the Tennessee River. These remedial actions began on April 1, 1986, and were completed on October 16, 1987. Through March 1, 2001, the remedial actions have been inspected yearly by a federal and state Review Panel. The remedial action has not required any repair of the structures to maintain their integrity, and monitoring has shown that total DDT concentrations in fish and water continue to decline.

B: Temporary ReRouting of a River – Bryant Mill Pond Project at the Allied Paper, Inc./Portage Creek/Kalamazoo River Site

In EPA Region 5, an EPA-conducted removal and onsite containment action removed polychlorinated biphenyls (PCBs)-contaminated sediment from the Bryant Mill Pond area of Portage Creek. During the removal action, that was conducted from June 1998 - May 1999, Portage Creek was temporarily diverted from its normal streambed so that 150,000 yds^3 of the creek bed and floodplain soils could be excavated using conventional excavation equipment. PCB concentrations remaining after the removal action were below 1 ppm.

Source: U.S. EPA Region 5

Excavation may also include excavation of sediment in areas that experience occasional dry conditions, such as intermittent streams and wetlands. These types of projects generally are logistically similar to upland construction projects and frequently use conventional earthmoving equipment.

6.5 DREDGING TECHNOLOGIES

For purposes of this guidance the term "dredging" means the removal of sediment from an underwater environment, typically using floating excavators called dredges. Dredging involves mechanically grabbing, raking, cutting, or hydraulically scouring the bottom of a waterway to dislodge the sediment. Once dislodged, the sediment may be removed from a waterway either mechanically with buckets or hydraulically by pumping. Therefore, dredges may be categorized as either mechanical or hydraulic depending on the basic means of removing the dredged material. Some dredges employ pneumatic (compressed air) systems to pump the sediment out of the waterway (U.S. EPA 1994d); however, these have not gained general acceptance on environmental dredging projects.

6.5.1 Mechanical Dredging

The fundamental difference between mechanical and hydraulic dredging equipment is how the sediment is removed. Mechanical dredges offer the advantage of removing the sediment at nearly the same solids content and, therefore, volume as the in-situ material. Little additional water is entrained with the sediment as it is removed. Thus, the volumes of contaminated material and process water to be disposed, managed, and/or treated are minimized. However, the water that is present in the bucket above the sediment must either be collected, managed, and treated, or be permitted to leak out, which generally leads to higher contaminant losses during dredging.

The mechanical dredges most commonly used in the U.S. for environmental dredging are the following (Palermo et al. 2004):

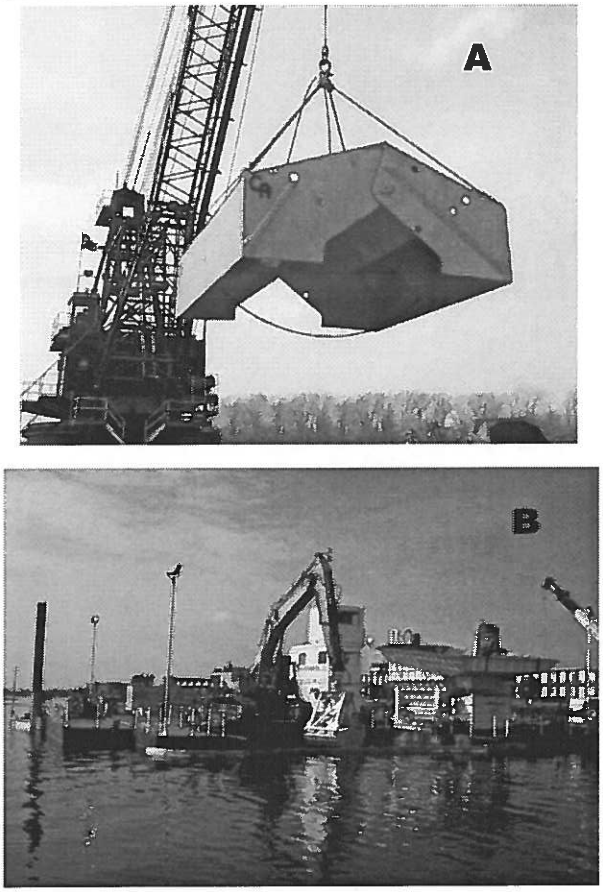
- <u>*Clamshell:*</u> Wire supported, conventional open clam bucket, circular shaped cutting action;
- <u>*Enclosed bucket:*</u> Wire supported, near watertight or sealed bucket as compared to conventional open clam bucket (recent designs also incorporate a level cut capability as compared to a circular-shaped cut for conventional buckets, for example, the Cable Arm and Boskalis Horizontal Closing Environmental Grab); and
- <u>*Articulated mechanical:*</u> Backhoe designs, clam-type enclosed buckets, hydraulic closing mechanisms, all supported by articulated fixed-arm (e.g., Ham Visor Grab, Bean Horizontal Profiling Grab (HPG), Toa High Density Transport, and the Dry Dredge).

The mechanical dredge types listed above reflect equipment used for environmental dredging and generally are readily available in the U.S. The enclosed bucket dredges were designed to address a number of issues often raised relative to remedial dredging including contaminant removal efficiency and minimizing sediment resuspension. However, newly redesigned dredging equipment may not be cost-effective or preferred at every site. For example, in some environments, an enclosed bucket may be most useful for soft sediment but may not close efficiently on debris. A conventional clamshell dredge may have greater leverage and be able to close on or cut debris in some cases; however, material mounded over the top may be resuspended. An articulated mechanical dredge may have advantage in stiffer sediment since the fixed-arm arrangement can push the bucket into the sediment to the desired cut-level, and not rely on the weight of the bucket for penetration. Highlight 6-5 shows two examples of mechanical dredges.

6.5.2 Hydraulic Dredging

Hydraulic dredges remove and transport sediment in the form of a slurry through the inclusion or addition of high volumes of water at some point in the removal process (Zappi and Hayes 1991). The total volume of material processed may be greatly increased and the solids content of the slurry may be considerably less than that of the in-situ sediment although solids content varies between dredges (U.S. EPA 1994d). The excess water is usually discharged as effluent at the treatment or disposal site and often

Highlight 6-5: Examples of Mechanical Dredges



Note: A = Cable Arm Corp. dredge (Source: Cable Arm, Corp.)
B = Bean Company Horizontal Profiling Grab (HPG) dredge, New Bedford Harbor Site (Source: Barbara Bergen, U.S. EPA)

needs treatment prior to discharge. Hydraulic dredges may be equipped with rotating blades, augers, or high-pressure water jets to loosen the sediment (U.S. EPA 1995b). The hydraulic dredges most commonly used in the U.S. for environmental dredging are the following (Palermo et al. 2004):

- Cutterhead: Conventional hydraulic pipeline dredge, with conventional cutterhead;
- Horizontal auger: Hydraulic pipeline dredge with horizontal auger dredgehead (e.g., Mudcat);
- Plain suction: Hydraulic pipeline dredge using dredgehead design with no cutting action, plain suction (e.g., cutterhead dredge with no cutter basket mounted, Matchbox dredgehead, articulated Slope Cleaner, Scoop-Dredge BRABO, etc.);

- *Pneumatic:* Air operated submersible pump, pipeline transport, either wire supported or fixed-arm supported (e.g., Japanese Oozer, Italian Pneuma, Dutch "d," Japanese Refresher, etc.);

- *Specialty dredgeheads:* Other hydraulic pipeline dredges with specialty dredgeheads or pumping systems (e.g., Boskalis Environmental Disc Cutter, Slope Cleaner, Clean Sweep, Water Refresher, Clean Up, Swan 21 Systems, etc.); and

- *Diver assisted:* Hand-held hydraulic suction with pipeline transport.

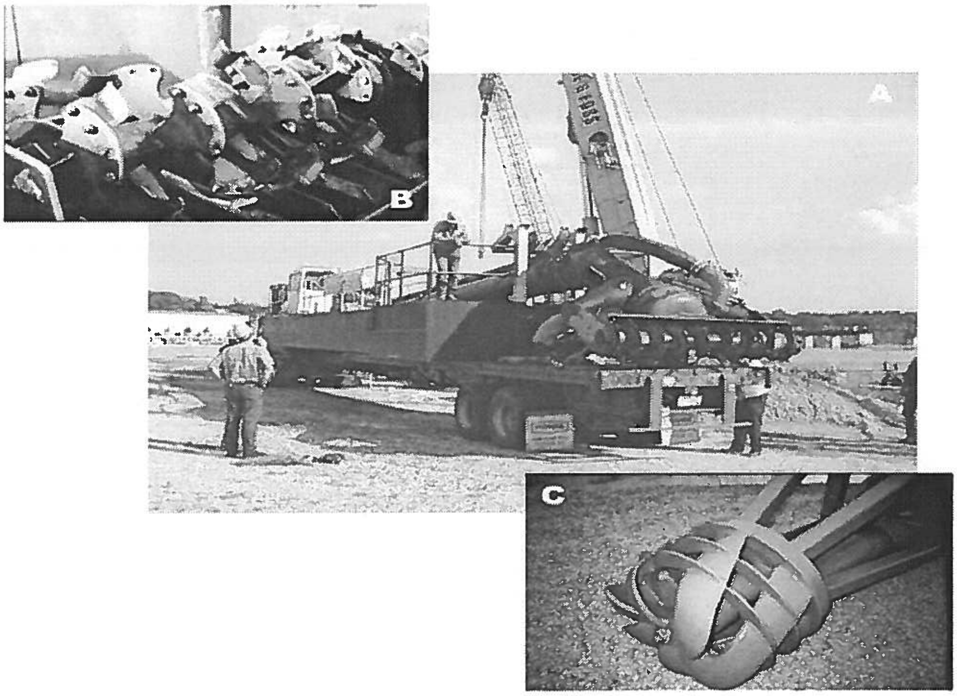
Some of the hydraulic dredges included above have been specifically developed to reduce resuspension during the removal process. As with modified mechanical dredges, project managers should be aware that there may be tradeoffs in terms of production rate and ability to handle debris with many of these modifications. Highlight 6-6 presents examples of hydraulic dredges.

6.5.3 Dredge Equipment Selection

The selection of appropriate dredging equipment is generally essential for an effective environmental dredging operation. The operational characteristics of the three types of mechanical and six types of hydraulic dredges presented in the guidance sections above are listed in Highlights 6-7a and 6-7b. This information was reviewed by an expert panel and attendees at a special session on environment dredging at the Meeting of the Western Dredging Association (WEDA XXI) and the 33rd Annual Texas A&M Dredging Seminar in Houston, Texas. The operational characteristics and identified selection factors presented in Highlights 6-7a and 6-7b have been drawn from information compiled for this guidance as well as earlier published reviews of dredge characteristics. Quantitative operational characteristics (both capabilities and limitations) are summarized for conditions likely to be encountered for many environmental dredging projects. The numbers are not representative of all dredge designs and sizes available, but represent those most commonly used for environmental dredging. Qualitative selection factors for each dredge type are presented based on the best professional judgment of the panel and/or their interpretation of readily available data. Site-specific results and supporting references are available in *Operational Characteristics and Equipment Selection Factors for Environmental Dredging* (Palermo et al. 2004).

The information in Highlights 6-7a and 6-7b is intended to help project managers make initial screening assessments of general dredge capabilities and identify equipment types for further evaluation at the feasibility study stage or for pilot field testing. Note that whenever an equipment type receives a rating of "high," it means that a particular dredge type should perform better for that selection factor. It is not intended as a guide for final equipment selection for remedy implementation. There are many site-specific circumstances that dictate which equipment type is most appropriate for any given situation, and each type can be applied in different ways to adapt to site conditions. Project managers should use their own experience and judgment in using this information, and may find it useful to consider other sources of information for purposes of comparison. In addition, because new equipment is being continuously developed and tested, project managers will need to consult with experts who are familiar with the latest in equipment technologies. Experience has shown that an effective environmental dredging operation also depends on the use of highly skilled dredge operators familiar with the goals of environmental remediation, in addition to close monitoring and management of the dredging operation.

Highlight 6-6: Examples of Hydraulic Dredges



Note: A = Fox River, WI; horizontal auger hydraulic dredge deployment (Source: Jim Hahnenberg U.S. EPA)
B = Manistique, MI; closeup of twin-vortex pump, hydraulic dredge cutterhead (Source: Ernie Watkins U.S. EPA)
C = Closeup of swinging ladder hydraulic dredge cutterhead (Source: Ellicott Corporation)

Highlight 6-7a: Sample Environmental Dredging Operational Characteristics and Selection Factors[1]

	EQUIPMENT TYPE[2]									
	Mechanical Dredges (2 to 8 cubic meter buckets)			Hydraulic/Pneumatic Dredges (15 to 30 cm pump sizes)						Dry Excavation
	Conventional Clamshell (Wire)[3]	**Enclosed Bucket (Wire)[4]**	**Articulated Mechanical (Fixed Arm)[5]**	**Cutter-head[6]**	**Horizontal Auger[7]**	**Plain Suction[8]**	**Pneumatic[9]**	**Specialty[10]**	**Diver[11]**	**Various Mechanical Excavators[12]**
OPERATIONAL CHARACTERISTICS[13]										
Operating Production Rate (m^3/hr)[14]	48 (2 m^3 bucket) 95 (4 m^3 bucket) 143 (6 m^3 bucket) 193 (8 m^3 bucket)			23 (15 cm pump) 41 (20 cm pump) 64 (25 cm pump) 93 (30 cm pump)			Site Specific	Equipment Specific	10	Site Specific
Percent Solids (by weight)[15]	Near In-Situ	Near In-Situ	Near In-Situ	5	5	5	15 or Higher	Equipment Specific	<5	In-Situ or Greater
Vertical Operating Accuracy (cm)[16]	15	15	10	10	10	10	15	10	–	5
Horizontal Operating Accuracy (cm)[17]	10	10	10	10	10	10	10	10	–	5
Maximum Dredging Depth (m)[18]	Stability Limitations	Stability Limitations	15	15	5	15	45	15	30	Stability Limitations
Minimum Dredging Depth (m)[19]	–	–	–	1	0.5	1	5	1	0.5	–

	EQUIPMENT TYPE[2]									
	Mechanical Dredges (2 to 8 cubic meter buckets)			Hydraulic/Pneumatic Dredges (15 to 30 cm pump sizes)						Dry Excavation
	Conventional Clamshell (Wire)[3]	Enclosed Bucket (Wire)[4]	Articulated Mechanical (Fixed Arm)[5]	Cutter-head[6]	Horizontal Auger[7]	Plain Suction[8]	Pneumatic[9]	Specialty[10]	Diver[11]	Various Mechanical Excavators[12]
EQUIPMENT SELECTION FACTORS[20]										
Limit Sediment Resuspension[21]	Low	High	High	Medium	Medium	High	High	High	High	High
Control Contaminant Release [22]	Low	High	High	Medium	Medium	Medium	Medium	Medium	High	High
Minimize Residual Sediment[23]	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium	High	High
Transport by Pipeline[24]	Medium	Medium	Medium	High	High	High	High	High	High	Medium
Transport by Barge[25]	High	High	High	Medium	Medium	Medium	Medium	Medium	Low	High
Positioning Control in Currents/Wind/ Tides[26]	High	High	High	High	Medium	High	High	High	Medium	High
Maneuverability[27]	High	High	High	Low	Low	Low	Low	Low	High	High
Portability/ Access[28]	High	High	High	High	High	High	High	Medium	High	High
Availability[29]	High	High	High	High	High	High	Medium	Medium	High	High

	EQUIPMENT TYPE[2]									
	Mechanical Dredges (2 to 8 cubic meter buckets)			**Hydraulic/Pneumatic Dredges (15 to 30 cm pump sizes)**						**Dry Excavation**
	Conventional Clamshell (Wire)[3]	**Enclosed Bucket (Wire)[4]**	**Articulated Mechanical (Fixed Arm)[5]**	**Cutter-head[6]**	**Horizontal Auger[7]**	**Plain Suction[8]**	**Pneumatic[9]**	**Specialty[10]**	**Diver[11]**	**Various Mechanical Excavators[12]**
Debris/Loose Rock/ Vegetation[30]	High	High	High	Low	Low	Low	Low	Low	Low	High
Hardpan/Rock Bottom[31]	Low	Low	Low	Low	Low	Medium	Medium	Medium	High	High
Flexibility for Varying Conditions[32]	High	High	Medium	High	Medium	Low	Low	Low	Low	High
Thin Lift/Residual Removal[33]	Low	Medium	Medium	Medium	High	High	High	High	High	High

Note: For additional information on development and technical basis for the entries in this table refer to: Palermo, M., N. Francingues, and D. Averett. 2004. Operational Characteristics and Equipment Selection Factors for Environmental Dredging. *Journal of Dredging Engineering*, Western Dredging Association.

Highlight 6-7b: Footnotes for Sample Environmental Dredging Operational Characteristics and Selection Factors

1	This table provides some of the currently available general information that can help project managers initially assess dredge capabilities, and screen and select equipment types for evaluation at the feasibility study stage or for pilot field testing. This table is NOT intended as a guide for final equipment selection for remedy implementation, and regions may find it useful to consider other sources of information for purposes of comparison. There are many site-specific, sediment-specific, and project-specific circumstances that will indicate which equipment is most appropriate for any given situation, and each equipment type can be applied in different ways to adapt to site and sediment conditions. In addition, because new equipment is being continuously developed, project managers should consult with experts who are familiar with the latest technologies.
2	Equipment types shown here are considered the most commonly used for environmental dredging in the U.S. Other dredge types are available. Equipment used for environmental dredging is usually smaller in size than that commonly used for navigation dredging. Information presented here is tailored for mechanical bucket sizes from 3 to 10 cubic yards (about 2 to 8 m^3), and hydraulic/pneumatic pump sizes from 6 to 12 inches (about 15 to 30 cm). Larger sizes are available for many equipment types.
3	Clamshell - conventional clamshell dredges, wire supported, conventional open clam bucket.
4	Enclosed Bucket - wire supported, near watertight or sealed bucket usually incorporating a level cut capability.
5	Articulated Mechanical - backhoe designs, clam-type enclosed buckets, hydraulic closing mechanisms, all supported by articulated fixed-arm.
6	Cutterhead - conventional hydraulic pipeline dredge, with conventional cutterhead.
7	Horizontal Auger - hydraulic pipeline dredge with horizontal auger dredgehead.
8	Plain Suction - hydraulic pipeline dredge using dredgehead design with no cutting action.
9	Pneumatic – air operated submersible pump, pipeline transport, either wire supported or fixed-arm supported.
10	Specialty Dredgeheads - other hydraulic pipeline dredges with specialty dredgeheads or pumping systems
11	Diver Assisted - hand-held hydraulic suction with pipeline transport.
12	Dry Excavation - conventional excavation equipment operating within dewatered containments such as sheet-pile enclosures or cofferdams.
13	OPERATIONAL CHARACTERISTICS - quantitative entries, reflecting capabilities and limitations of dredge types, and are solely a function of the equipment itself.
14	Production Rate - in-situ volume of sediment removed per unit time. Rates shown are for production cuts as opposed to "cleanup passes" and are for active periods of operation under average conditions. Rates for two bucket or pump sizes are shown for comparison. For mechanical dredges, the rates were calculated assuming 80% bucket fill with a bucket cycle time of 2 minutes. For hydraulic dredges, the rates were calculated assuming in-situ sediment 35% solids by weight, 5% solids by weight for slurry, and pump discharge velocity of 10 ft/sec. The rate shown for diver-assisted assumes a maximum pump size of 15 cm and roughly 50% efficiency of diver effort while working. Production rate for dry excavation is would be largely dictated by the time required to isolate and dewater the areas targeted for excavation. A variety of factors may influence the effective operating time per day, week, or season, and should be considered in calculating times required for removal.
15	Percent Solids by Weight - ratio of weight of dry solids to total weight of the dredged material as removed, expressed as a percentage. Percent solids for mechanical dredging is a function of the in-situ percent solids and the effective bucket fill (expressed as a percentage of the bucket capacity filled by in-situ sediment as opposed to free water), and near in-situ percent solids is possible for production cuts. A wide range of percent solids for hydraulic dredges is reported, but 5% solids can be expected for most environmental dredging projects.

Highlight 6-7b: Footnotes for Sample Environmental Dredging Operational Characteristics and Selection Factors

16	Vertical Operating Accuracy - the ability to position the dredgehead at a desired depth or elevation for the cut and maintain or repeat that vertical position during the dredging operation. Although positioning instrumentation is accurate to within a few cm, the design of the dredge and the linkages between the dredgehead and the positioning system will affect the accuracy attainable in positioning the dredgehead. A vertical accuracy of cut of approximately 15 cm (one-half foot) is considered attainable for most project conditions. Fixed arm equipment holds some advantage over wire-supported in maintaining vertical operating accuracy. The accuracies achievable for sediment characterization should be considered in setting performance standards for environmental dredging operating accuracy (both vertical and horizontal).
17	Horizontal Operating Accuracy - the ability to position and operate the dredgehead at a desired location or within a desired surface area. Considerations are similar to those for vertical accuracy.
18	Maximum Dredging Depth - physical limitation to reach below a given depth. Wire-supported buckets or pumps can be deployed at substantial depths, so the maximum digging depth generally is limited by stability of the excavation. Reach of fixed arm supported buckets or hydraulic dredges is limited by the length of the arm or ladder. Conventional backhoe equipment is generally limited to about 15 m reach. Smaller hydraulic dredges are usually designed for a maximum dredging depth of about 15 m. Hydraulic dredges usually also have a limiting depth of removal of about 50 ft due to the limitation of atmospheric pressure, but this limitation can often be overcome by addition of a submerged pump on the ladder. The table entries should NOT be considered as hard and fast limits. Larger dredge sizes and designs are available for deeper depths.
19	Minimum Dredging Depth - constraints on draft limitations of some floating dredges or potential loss of pump prime for hydraulic dredges. Such limitations can be managed if the dredge "digs its way into the area." For smaller dredges, these limitations typically are at approximately the 1m water depth. Pneumatic dredges require a minimum water depth of about 5 m for efficient pump operation.
20	SELECTION FACTORS - qualitative entries, reflecting the potential performance of a given dredge type, and are a function of both the capability of the equipment type and the site and/or sediment conditions. Entries defined as follows: (High) - indicating the given dredge type is generally suitable or favorable for a given issue or concern, (Medium) - indicating the given dredge type addresses the issue or concern, but it may not be preferred, and (Low) - indicating the given dredge type may not be a suitable selection for addressing this issue or concern.
21	Limit Sediment Resuspension - potential of a given dredge type in minimizing sediment resuspension. Clamshell (Low) - Circular-shaped cutting action, cratered bottom subject to sloughing, open bucket design subject to washout and spillage, scows and workboats working in shallow areas. Enclosed Bucket (High) - Seal around the lips of the bucket and an enclosed top when in the shut position, level cut design minimizes sloughing. Articulated Mechanical (High) - Less resuspension as compared to conventional clamshell dredges. Cutterhead/Horizontal Auger (Medium) - Conventional cutterhead dredges and horizontal augers result in less resuspension as compared to conventional clamshell dredges. May be fitted with hoods or shrouds to partially control resuspension. Plain Suction/Pneumatic (High) - No mechanical action to dislodge the material. Specialty (High) - Although designs vary, all the so-called specialty dredges have features specifically intended to reduce resuspension. Diver Assisted (High) - Precision of diver assisted hydraulic dredging, the smaller size of the dredgeheads used, and inherently slow speed of operation. Dry Excavation (High) - Completely isolates the excavation process from the water column.
22	Control Contaminant Release - the inherent ability to control sediment resuspension and dissolved and volatile releases for the given equipment type and associated operation. Clamshell (Low) - Can be operated such that the excavation and water column exposure of the bucket is within a silt curtain containment or enclosure; however, high suspended solids within the silt curtain may be released when the curtain is moved. Enclosed Bucket/Articulated Mechanical (Medium) - can be operated such that the excavation and water column exposure of the bucket is within a silt curtain enclosure with relatively small footprint. Enclosed buckets act as a control and greatly reduce resuspension within the enclosures and potential for release. Cutterhead/Plain Suction/Horizontal Auger/Pneumatic/Specialty Dredgeheads (Medium) - Capable of transporting the material directly by pipeline, minimizing exposure to the water column and to volatilization. Can be operated within enclosures, but the footprint of such enclosures would be necessarily larger than that for mechanical dredges. Diver assisted (High) - scale of diver-assisted dredging would seldom require contaminant release controls. Dry Excavation (High) - Dewatering of the dredging area effectively eliminates dissolved releases. Sediment surface exposed to the atmosphere has lower volatile emission rates as compared to the same surface ponded with elevated suspended sediment concentrations.

Highlight 6-7b: Footnotes for Sample Environmental Dredging Operational Characteristics and Selection Factors

23	Minimize Residual Sediment - efficiency of the dredge is in removing material without leaving a residual, and potentially meeting a cleanup level. Clamshell (Low) - High potential to leave residual sediment because of the circular-shaped cutting action and the tendency to leave a cratered bottom subject to sloughing. Enclosed Bucket/Articulated Mechanical/Cutterhead/Horizontal Auger/Plain Suction/Pneumatic/Specialty Dredgeheads (Medium) - All dredges with active dredgeheads and/or movement in contact with the bottom sediment will leave some residual sediment. The control offered by the articulated arm provides an advantage for removal of thin residual layers. Diver Assisted (High) - Hand-held action of diver-assisted work has a low potential for generating residual sediment. Dry Excavation (High) - Any fallback of sediment excavated under dry conditions can be readily observed and managed.
24	Transport by Pipeline - compatibility of the dredge with subsequent transport by pipeline. Clamshell/ Enclosed Bucket/Articulated Mechanical (Medium) - All mechanical dredges remove material at near in-situ density, and additional reslurry and rehandling equipment must be employed to allow for pipeline transport. Cutterhead/Plain Suction/Horizontal Auger/Pneumatic/Specialty Dredgeheads/Diver Assisted (High) - All hydraulic and pneumatic dredges are designed for pipeline transport. Dry Excavation (Medium) - Additional reslurry and rehandling equipment must be employed to allow for pipeline transport.
25	Transport y Barge - compatibility of the dredge with subsequent transport by barge. Clamshell/Enclosed Bucket/Articulated Mechanical (High) - Material excavated with mechanical dredges is close to in-situ density and may be directly placed in barges for transport. Cutterhead/Plain Suction/Horizontal Auger/Pneumatic/Specialty Dredgeheads/Diver Assisted (Medium) - Barge transport of hydraulically dredged material is inefficient. Although pneumatic and some specialty dredges are capable of removing soft sediment at high water content, intermittent operation for change-out of barges will significantly reduce efficiency. Dry Excavation (High) - Material excavated in the dry may be placed directly in barges using conveyers or front-end loaders.
26	Positioning Control in Currents/Wind/Tides - ability of the dredge to hold a desired position of the dredgehead horizontally with current, wind, or vertically with fluctuating tides. Clamshell/Enclosed Bucket/Articulated Mechanical (High) - Operate with spuds or jack-up piles and are inherently stable against movement by normal winds and currents. Cutterhead/Plain Suction/Specialty Dredgeheads (High) - Equipped with spuds and use "walking spud" method of operation inherently stable against movement by normal winds and current. Horizontal Auger (Medium) - Free floating and operate using an anchor and cable system, subject to movement with longer anchor sets. Pneumatic (High) - Operate from spudded barges or platforms and are inherently stable against movement by normal winds and currents. Diver Assisted (Medium) - Ability of divers to maintain a desired position will be hampered by currents. Dry Excavation (High) - Not affected by wind and currents.
27	Maneuverability - ability of the dredge to operate effectively in close proximity or around utilities and other infrastructure, narrow channel widths, surface and submerged obstructions, and overhead restrictions. Clamshell/Enclosed Bucket/Articulated Mechanical (High) - Buckets are wire supported or fixed-arm articulated and may be operated close in to infrastructure and within tightly restricted areas. Cutterhead/Plain Suction/Horizontal Auger/Pneumatic/Specialty Dredgeheads (Low) - Swinging action of the walking spud method of operation for hydraulic pipeline dredges and the need for long anchor and cable setup for horizontal auger dredges limits their ability to operate near infrastructure or within tightly restricted areas. Diver Assisted (High) - Can be conducted close to infrastructure and within tightly restricted areas. Dry Excavation (High) - Containments for dry excavation can be designed for areas near infrastructure and tightly restricted areas may be completely contained.
28	Portability/Access - ability of the dredge to pass under bridges, through narrow channels, or to be transported by truck and easily launched to the site. Clamshell/Enclosed Bucket/Articulated Mechanical/Cutterhead/Plain suction/Horizontal Auger/Pneumatic/Diver Assisted/Dry Excavation (High) - Dredge types considered here are the smaller size and are generally truck transportable. Specialty Dredgeheads (Medium) - Some specialty dredge designs are too large for truck transport.
29	Availability - this factor refers to the potential availability of dredges types to contractors and the potential physical presence of the equipment in the U.S. Clamshell/Enclosed Bucket/Articulated Mechanical/Cutterhead/Plain Suction/Horizontal Auger/Pneumatic/Diver Assisted/Dry Excavation (High) - Most dredge types are readily available. Specialty Dredgeheads (Medium) - Some specialty dredges are available through only one contractor or may be subject to restrictions under the Jones Act.

Highlight 6-7b: Footnotes for Sample Environmental Dredging Operational Characteristics and Selection Factors

30	Debris/Loose Rock/Vegetation - susceptibility of a given dredge type to clogging by debris and subsequent loss of operational efficiency. Clamshell/Enclosed Bucket/Articulated Mechanical (High) - Mechanical dredges can effectively remove sediment containing debris, although leakage may result. Mechanical equipment is the only approach for debris-removal passes. Cutterhead/Plain Suction/Horizontal Auger/ Pneumatic/ Specialty Dredgeheads (Low) - Subject to clogging by debris and are incapable of removing larger pieces of loose rock and larger debris. Loose rock and large debris can also cause inefficient sediment removal. Diver Assisted (Low) - Presence of logs and large debris may present dangerous conditions for diver-assisted dredging. Although divers can remove sediment from around large debris or rocks, this type of operation would be inefficient. Dry Excavation (High) - Dry excavation allows use of conventional excavation equipment. Leakage from buckets caused by debris is not a consideration for dry excavation.
31	Hardpan/Rock Bottom - ability of a dredge type to remove a sediment layer overlying hardpan or rock bottom effciently without leaving excessive residual sediment. Clamshell/Enclosed Bucket/Articulated Mechanical/Cutterhead/Horizontal Auger (Low) - Closing action of buckets and cutting action of dredgeheads result in problems maintaining a desired vertical cutting position and would tend to leave behind excessive residual sediment. Power associated with articulated mechanical has advantage in removing hard materials. Plain Suction/ Pneumatic/ Specialty Dredges (Medium) - Lack an active closing or cutting action and can operate over an uneven hard surface, although removal efficiency may be low. Diver Assisted (High) - May be the most effective approach for precise cleanup of a hard face, since the divers can feel the surface and adjust the excavation accordingly. Dry Excavation (High) - Allows the visual location of pockets of residual remaining on an uneven hard surface.
32	Flexibility for Varying Conditions - flexibility of a given dredge type in adapting to differing conditions, such as sediment stiffness, variable cut thicknesses, and the overall ability to take thick cuts. Clamshell/Enclosed Bucket (High) - Buckets are capable of taking thin cuts or thicker cuts in proportion to the bucket size, and bucket sizes can be easily switched. Articulated Mechanical (Medium) - Ability to change bucket sizes for articulated mechanical is limited. Cutterhead (High) - Capable of taking variable cut thicknesses by varying the burial depth of the cutter. Different cutterhead sizes or designs can be used to adapt to changing cut thicknesses or sediment stiffness. Horizontal Auger (Medium) - Designed for a set maximum cut thickness, and attempts to remove thick cuts may result in plowing actions with excessive resuspension and residual. Plain Suction/ Pneumatic (Low) - No cutting action limits ability to take thicker cuts or remove stiffer materials. Specialty Dredgeheads (Low) - Specialty dredges are designed for a specific application and have limited flexibility. Diver Assisted (Low) - Removal is limited to thin cuts. Dry Excavation (High) - Allows use of a full range of conventional excavation equipment.
33	Thin Lift/Residual Removal - ability of a given dredge type to removal thin layers of contaminated material without excessive over dredging. Clamshell (Low) - Circular shaped cut not suited for efficient removal of thin layers. Enclosed Bucket/Articulated Mechanical (Medium) - Level cutting action is capable of removing thin layers, but the buckets would be only partially filled, resulting in inefficient production and higher handling and treatment costs. Cutterhead/Horizontal Auger (Medium) - Capable of removing thin layers, but the percent solids is reduced under these conditions. Plain Suction/Pneumatic (High) - Well suited for removal of thin lifts, especially loose material such as residual sediment. Specialty Dredgeheads (High) - Some specialty dredges are designed specifically for removal of thin lifts. Diver Assisted (High) - Precision of diver-assisted dredging is well suited for removal of thin layers, especially residuals. Dry Excavation (High) - Allows for a precise control of cut thickness, amenable to removal of thin layers.

Source: Palermo et al. 2004

6.5.4 Dredge Positioning

An important element of sediment remediation is the precision of the dredge cut, both horizontally and vertically. Technological developments in surveying (vessel) and positioning (dredgehead) instruments have improved the dredging process. Vertical control may be particularly important when contamination occurs in a relatively thin or uneven layer to avoid an unnecessary amount of over-dredging and excess handling of uncontaminated sediment. Video cameras are sometimes useful in monitoring dredging operations, although turbidity effects and lack of spatial references may present limitations on their use. The working depth of the dredgehead may be measured using acoustic instrumentation and by monitoring dredged slurry densities. In addition, surveying software may be used to generate pre- and post-dredging bathymetric charts, determine the volume of dredged sediment, locate obstacles, and calculate linear dimensions of surface areas (see, e.g., St. Lawrence Centre 1993). Also available are digital positioning systems that enable dredge operators to follow a complex sediment contour (see, e.g., Van Oostrum 1992).

Depending on site conditions (e.g., currents, winds, tides), the horizontal position of the dredge may need to be continuously monitored during dredging. Satellite- or transmitter-based positioning systems, such as differential global positioning systems (DGPS), can be used to define the dredge position. In some cases, however, the accuracy of these systems is inadequate for precise dredging control. Where the accuracy of site characterization data or the high cost of disposal warrant very precise control, it is possible to use optical (laser) surveying instruments set up at one or more locations on shore. These techniques, in conjunction with on-vessel instruments and spuds (if water depths are less than about 50 ft) and anchoring systems may enable the dredge operator to more accurately target specific sediment deposits. The effectiveness of anchoring systems diminishes as water depth increases.

The positioning technology described above enhances the accuracy of dredging. The accuracies achievable for sediment characterization should be considered in setting performance standards for environmental dredging vertical and horizontal operating accuracy (Palermo et al. 2004). However, project managers should not develop unrealistic expectations of dredging accuracy. Contaminated sediment cannot be removed with surgical accuracy even with the most sophisticated equipment. Equipment may not be the only factor affecting the accuracy of the dredging operation. Site conditions (e.g., weather, currents), sediment conditions (e.g., bathymetry, physical characteristics), and the skill of the dredge operator are all important factors. In addition, the distribution of sediment contaminants may be only defined at a crude level and there could be a substantial margin for error. Accurately dredging to pre-established cut-lines is an important component of meeting remedial action objectives for sediment, but alone is not generally sufficient to show that the objectives have been met. Generally, post-dredging sampling should be conducted for that purpose. The section below describes the equally important factors of controlling dredging losses and residual contamination.

6.5.5 Predicting and Minimizing Sediment Resuspension and Contaminant Release and Transport During Dredging

Sediment resuspension and the resulting unwanted contaminant release and transport in the water body arise due to a variety of activities associated with a dredging remedy. These frequently include resuspension caused by operation of the dredgehead, by operation of work boats and tug boats, and by deployment and movement of control measures such as silt screens or sheet piles. Contaminated sediment may also be lost from barges used during the dredging operation. In environments with significant water movement due to tides or currents, resuspended sediment may be transported away from a dredging site; therefore, limiting resuspension or increasing containment (so that resuspended sediment is later redeposited and dredged) can be an important consideration in remedy selection and design. Storm events may also result in transport of contaminants beyond the dredging area. Use of containment barriers to limit transport of resuspended contaminated sediment is discussed in Section 6.5.6 of this chapter.

When evaluating resuspension due to dredging, it generally is important to compare the degree of resuspension to the natural sediment resuspension that would continue to occur if the contaminated sediment was not dredged, and the length of time over which increased dredging-related suspension would occur. Typically, two types of contaminant release are associated with resuspended sediment:

particulate and dissolved. Particulate release refers to the transport of contaminants associated with the particle phase (i.e., sorbed to suspended sediment). Dissolved refers to the release of dissolved contaminants from the particles into the water column. This latter form of release can be significant because dissolved contaminants are the most readily bioavailable and are more easily transported away from the site. Consequently, resuspension can result in the release of bioavailable organic and inorganic contaminants into the water column, which may cause toxicity or enhanced bioaccumulation. Research is currently being performed to address the risk associated with resuspension at contaminated sites and some existing models have been developed by the USACE. Until further guidance is available, at most sites, the project manager should monitor resuspension during dredging and to evaluate its potential effects on water quality. Project managers should be aware that most engineering measures implemented to reduce resuspension also reduce dredging efficiency. Estimates of production rates, cost, and project time frame should take these measures into account.

Some contaminant release and transport during dredging is inevitable and should be factored into the alternatives evaluation and planned for in the remedy design. Releases can be minimized by choice of dredging equipment, dredging less area, and/or using certain operational procedures (e.g., slowing the dredge clamshell descent just before impact with the sediment bed). Generally, the project manager should assess all causes of resuspension and realistically predict likely contaminant releases during a dredging operation. The magnitude of sediment resuspension and resulting transport of contaminants during a dredging operation is influenced by many factors, including:

- Physical properties of the sediment [e.g., grain size distribution, organic carbon content, Acid Volatile Sulfides (AVS) concentration];
- Vertical distribution of contaminants in the sediment;
- Water velocity and degree of turbulence;
- Type of dredge;
- Methods of dredge operation;
- Skill of operators;
- Extent of debris;
- Water salinity; and
- Extent of workboat/tugboat activity.

To compare various remedies for a site, to the extent possible, the project manager should attempt to estimate the downstream mass transport and the degree of increase (if any) in downstream surface water and surface sediment contaminant concentrations. However, at present, no fully verified empirical or predictive tools are available to quantify the predicted releases accurately. As research in predicting resuspension and contaminant release associated with dredging progresses, project managers should watch for verified methods to be developed to assist in this estimate. Although the degree of resuspension will be site specific, recent analyses of field studies and available predictive models of the mass of sediment resuspended range from generally less than one percent of the mass dredged (Hays and Wu 2001, Palermo and Averett 2003) to between 0.5 and 9 percent (NRC 2001). The methods contained in EPA's *Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments* (U.S. EPA 1996g), may be useful to estimate the dredgehead component of resuspension losses. To the extent possible, the project manager should estimate total dredging losses on a site-specific basis and consider them in the comparison of alternatives during the feasibility study.

If conventional clamshell dredges may cause a high level of resuspension, a special purpose dredge may be considered. These dredges generally resuspend less material than conventional dredges, but associated costs may be greater, and dredges may not be usable in the presence of significant debris or obstructions. As in the case of conventional dredges, the selection of a special purpose dredge will be likely dictated by site-specific conditions, economics, and availability (Palermo et al. 1998b). Other factors unrelated to resuspension, such as maneuverability requirements, hydrodynamic conditions, or others listed in Section 6.5.3, Dredge Equipment Selection, may also dictate the type of dredge that should be used. The strategy for the project manager should be to minimize the resuspension levels generated by any specific dredge type, while also ensuring that the project can be implemented in a reasonable time frame. The EPA's Office of Research and Development (ORD) and others are in the process of evaluating resuspension and its effects, both in field and modeling studies. The results of this research should help project managers to understand better and control effects of resuspension during future cleanup actions.

Another potential route of contaminant release during dredging or excavation may be the volatilization of contaminants, either near the dredge or excavation site or in a holding facility like a confined disposal facility (CDF) (Chiarenzeli et al. 1998). At sites with high concentrations of volatile contaminants, dredging or excavation may present special challenges for monitoring and operational controls if they may pose a potential risk to workers and the nearby community. This exposure route may be minimized by reducing dredging production rates so that resuspension is minimized. Covering the surface of the water with a physical barrier or an absorbent compound may also minimize volatilization. At the New Bedford Harbor site, a cutterhead dredge was modified by placing a cover over the dredgehead that retained polychlorinated biphenyl (PCB)-laden oils, thus reducing the air concentrations of PCBs during dredging to background levels; see *Report on the Effects of the Hot Spot Dredging Operations: New Bedford Harbor Superfund Site, New Bedford, MA* (U.S. EPA 1997e and available through EPA's Web site at http://www.epa.gov/region01/nbh/techdocs.html). In addition, the CDF that the dredged sediment was pumped into was fitted with a plastic cover that effectively reduced air emissions. To minimize the potential for volatile releases further, dredging operations were conducted during cooler weather periods and at night. During excavation, volatilization could be of greater concern as contaminated materials may be exposed to air. Care should be taken during dewatering activities to ensure that temperatures are not elevated (e.g., cautious application of lime or cement for dewatering), and other control measure should be taken as needed (e.g., foam).

6.5.6 Containment Barriers

Transport of resuspended contaminated sediment released during dredging can often be reduced by using physical barriers around the dredging operation. Barriers commonly used to reduce the spread of contaminants during the removal process include oil booms, silt curtains, silt screens, sheet-pile walls, cofferdams, and bubble curtains (U.S. EPA 1994d, Francingues 2003). Under favorable site conditions, these barriers help limit the areal extent of particle-bound contaminant migration resulting from dredging resuspension and enhance the long-term benefits gained by the removal process. Conversely, because the barriers contain resuspended sediment, they may increase, at least temporarily, residual contaminant concentrations inside the barrier compared to what it would have been without the barriers.

Structural barriers, such as sheet pile walls, have been used for sediment excavation and in some cases (e.g., high current velocities) for dredging projects. The determination of whether these types of barriers are necessary should be made based on a thorough evaluation of the site. This can be accomplished by evaluating the relative risks posed by the anticipated release of contaminants from the dredging operation absent use of such structural barriers, the predicted extent and duration of such releases, and the potential for trapping and accumulating residual contaminated sediment within the barrier. The project manager should consult the ARCS program's *Risk Assessment and Modeling Overview Document* (U.S. EPA 1993c) and *Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediment* (U.S. EPA 1996e) for further information about evaluating the need for structural barriers.

Sheet pile containment structures are more likely to provide reliable containment of resuspended sediment than silt screens or curtains, although at significantly higher cost and with different technological limitations. Where water is removed on one side of the wall, project managers should be aware of the hydraulic loading effects of water level variations inside and outside of these walls. Project managers should also be aware of the increased potential for scour to occur around the outside of the containment area, and the resuspension that will occur during placement and removal of these structures. In addition, use of sheet piling may significantly change the carrying capacity of a stream or river and make it temporarily more susceptible to flooding.

Oil booms are appropriate for sediment that may likely release oils or floatables [i.e., light non-aqueous-phase liquids (LNAPL)] when disturbed. Such booms typically consist of a series of synthetic foam floats encased in fabric and connected with a cable or chains. Oil booms may be supplemented with oil absorbent materials, such as polypropylene mats (U.S. EPA 1994d). However, booms do not aid in retaining the soluble portion of floatables [i.e., polycyclic aromatic hydrocarbons (PAHs) from oils].

Silt curtains and silt screens are flexible barriers that hang down from the water surface. Both systems use a series of floats on the surface and a ballast chain or anchors along the bottom. Although the terms "silt curtain" and "silt screen" may be frequently used interchangeably, there are fundamental differences. Silt curtains are made of impervious materials, such as coated nylon, and primarily redirect flow around the dredging area. In contrast, silt screens are made from synthetic geotextile fabrics, which allow water to flow through, but retain a large fraction of the suspended solids (Averett et al. 1990). Silt curtains or silt screens may be appropriate when site conditions dictate the need for minimal transport of suspended sediment, for example, when dredging hot spots of high contaminant concentration.

Silt curtains have been used at many locations with varying degrees of success. For example, silt curtains were found to be effective in limiting suspended solids transport during in-water dike construction of the CDF for the New Bedford Harbor pilot project. However, the same silt curtains were ineffective in limiting contaminant migration during dredging operations at the same site primarily as a result of tidal fluctuation and wind (Averett et al. 1990). Problems were experienced during installation of silt curtains at the General Motors site (Massena, New York) due to high current velocities and back eddies. Dye tests conducted after installation revealed significant leakage, and the silt curtains were removed. Sheet piling was then installed around the area to be dredged with silt curtains used as supplemental containment for hot spot areas. A silt curtain and silt screen containment system were effectively applied during dredging of the Sheboygan River in 1990 and 1991, where water depths were 2 m or less. A silt curtain was found to reduce suspended solids from approximately 400 mg/L (inside) to 5 mg/L (outside) during rock fill and dredging activities in Halifax Harbor, Canada (MacKnight 1992). At some sites, changes in dredging operating procedures may offer more effective control of resuspension than containment barriers.

The effectiveness of silt curtains and screens is primarily determined by the hydrodynamic conditions at the site. Conditions that may reduce the effectiveness of these and other types of barriers include the following:

- Significant currents;
- High winds;
- Changing water levels (i.e., tidal fluctuation);
- Excessive wave height, including ship wakes; and
- Drifting ice and debris.

Silt curtains and screens are generally most effective in relatively shallow, undisturbed water. As water depth increases and turbulence caused by currents and waves increases, it becomes difficult to isolate the dredging operation effectively from the ambient water. The St. Lawrence Centre (1993) advises against the use of silt curtains in water deeper than 6.5 m or in currents greater than 50 cm/sec.

The effectiveness of containment barriers is also influenced by the quantity and type of suspended solids, the mooring method, and the characteristics of the barrier. To be effective, barriers should be deployed around the dredging operation and remain in place until the operation is completed, although it may need to be opened to allow transport of barges in and out of the dredge site, which may release some resuspended contaminants. For large projects, it may be necessary to relocate the barriers as the dredge moves to new areas. Where possible, barriers should not impede navigation traffic. Containment barriers may also be used to protect specific areas, for example, valuable habitat, water intakes, or recreational areas, from suspended sediment contamination.

6.5.7 Predicting and Minimizing Dredging Residuals

All dredging operations leave behind some residual contamination in sediment, usually both within the dredged area and spread to adjacent areas. This residual contaminated sediment is often soft, unconsolidated, has a high water content, and may exist, at least temporarily, as a "fluid mud" or nephloid layer. The primary sources of the dredging residuals typically include: 1) contaminated sediment below the dredge line that was not removed, 2) sediment loosened by the dredge head or bucket, but not captured and removed, 3) sediment on steep slopes that fall into the dredged area, and 4) resettling of sediment from the dredging operation. Similar to resuspension releases discussed in Section 6.5.5, the extent of the residual contamination is dependent on a number of factors including:

- Skill of operator and type and size of dredging equipment;

- Steepness of dredge cut slopes;
- Amount of contaminated sediment resuspended by the dredging operation;
- Extent of controls on dispersion of resuspended sediment (e.g., silt curtains, sheet piling);
- Vertical profile of contaminant concentrations in sediment relative to the thickness of sediment to be removed;
- Contaminant concentrations in surrounding undredged areas;
- Characteristics of underlying sediment or bedrock (e.g., whether over-dredging is feasible); and
- Extent of debris, obstructions, or confined operating area (e.g., which may limit effectiveness of dredge operation).

Project managers should factor a realistic estimate of dredging residuals into their evaluation of alternatives. Field results for some completed environmental dredging pilots and projects suggest that average post-dredging residual contamination levels have not met desired cleanup levels. However, aside from past experience, there is no commonly accepted method to predict accurately the degree of residual contamination likely to result from different dredge types under given site conditions. Additional guidelines are needed in this area and are likely to be developed in the future. Some preliminary research has shown that the residual concentration may be expected to be similar to the average contaminant concentration within the dredging prism (Desrosiers et al. 2005). In situations where more highly contaminated sediment is removed in a first dredging pass and deeper lower-level contamination is removed in a second dredging pass, lower residuals may be attainable. If the buried sediment is significantly more contaminated than the near-surface sediments, and if over dredging into "clean" sediment is not accomplished or feasible, the residual concentration may be greater than the average baseline surface concentration although significant contaminant mass may have been removed. When comparing alternatives and selecting of the best risk reduction alternative for the site, project managers should consider whether conditions are favorable for achieving desired post-dredging residual concentrations.

In cases where residuals may cause an unacceptable risk, additional passes of the dredge may be needed to achieve the desired results. Placement of a thin layer (e.g., 6–24 in) of clean material designed to mix with underlying sediment or the addition of reactive/sorptive materials to surface sediment can also be used to reduce the residual contamination. Project managers should consider developing a contingency remedy if there is sufficient uncertainty concerning the ability to achieve low cleanup levels. Where a contingency remedy involves containment of residuals by in-situ capping, project managers should consider whether containment without dredging may be a more appropriate solution to manage long-term risks in that area.

It is generally important to conduct post-dredging sampling to confirm residual contamination levels. If resuspension and transport is expected, generally, it is also important to sample outside of the dredged area to assess contaminant levels to which biota will be exposed from these areas. These data are often needed to assess the likelihood of achieving all RAOs.

6.6 TRANSPORT, STAGING, AND DEWATERING

After removal, sediment often is transported to a staging or rehandling area for dewatering (if necessary), and further processing, treatment, or final disposal. Transport links all dredging or excavation components and may involve several different modes of transport. The first element in the transport process is to move sediment from the removal site to the disposal, staging, or rehandling site. Sediment may then be transported for pretreatment, treatment, and/or ultimate disposal (U.S. EPA 1994d). As noted previously, where possible, project managers should design for as few rehandling operations as possible to decrease risks and cost. Project managers should also consider community concerns regarding these operations (e.g., odor, noise, lighting, traffic, and other issues). Health and safety plans should address both workers and community members.

Modes of transportation may include one or more of the following waterborne or overland methods:

- *Pipeline:* Direct placement of material into disposal sites by pipeline is economical only when the disposal and/or treatment site is located near the dredging areas (typically a few kilometers or less, unless booster pumps are used). Mechanically dredged material may also be reslurried from barges and pumped into nearshore disposal sites by pipeline;

- *Barge:* A rehandling facility located on shore is a commonly considered option. With a rehandling facility, dredging can be accomplished with mechanical (bucket) dredges where the sediment is excavated at near in-situ density (water content) and placed in a barge or scow for transport to the rehandling facility;

- *Conveyor:* Conveyors may be used to move material relatively short distances. Materials should be in a dewatered condition for transport by conveyor;

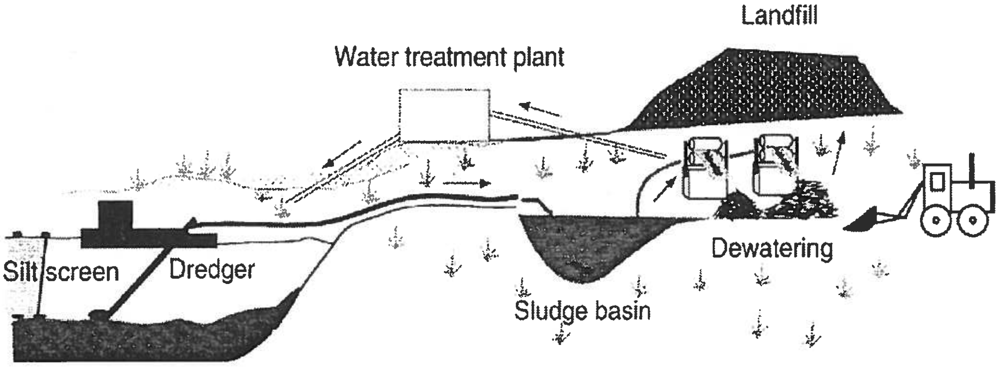
- *Railcar:* Rail spurs may be constructed to link rehandling/treatment facilities to the rail network. Many licensed landfills have rail links, so long-distance transport by rail is generally an option; and/or

- *Truck/Trailer:* Dredged material can be rehandled directly from the barges to roll-off containers or dump trucks for transport to a CDF by direct dumping or unloading into a chute or conveyor. Truck transport of treated material to landfills may also be considered. The material should be dewatered prior to truck transport over surface streets. In some smaller sites where construction of dewatering beds may be difficult or the cost of disposal is not great, addition of non-toxic absorbent materials such as lime or cement may be feasible.

A wide variety of transportation methods are available for moving sediment and residual wastes with unique physical and chemical attributes. In many cases, contaminated sediment is initially moved using waterborne transportation. Exceptions are the use of land-based or dry excavation methods. Project managers should consider the compatibility of the dredge with the subsequent transport of the dredged sediment. For example, hydraulic and pneumatic dredges produce contaminated dredged-material slurries that can be transported by pipeline to either a disposal or rehandling site. Mechanical removal methods typically produce dense, contaminated material hauled by barge, railcar, truck/trailer, or conveyor systems. The feasibility, costs of transportation, and need for additional equipment are frequently influenced by the scale of the remediation project (Churchward et al. 1981, Turner 1984, U.S. EPA 1994f).

Temporary storage of contaminated sediment may also be necessary in order to dewater it prior to upland disposal or to allow for pretreatment and equalization prior to treatment. For example, a temporary CDF may be designed to store dredged material for periods when dredging or excavation is not possible due to weather or environmental concerns, while the treatment process may continue on a near 24-hour operating schedule. Storage may be temporary staging (e.g., pumping onto a barge with frequent off-loading) or more permanent disposal (e.g., moving the sediment to a land-based CDF where it may be dewatered and treated). A typical dewatering schematic is shown in Highlight 6-8.

Highlight 6-8: Sample of Dredging Dewatering Process



Depending upon the quality of the water after it is separated from sediment and upon applicable or relevant and appropriate requirements (ARARs), it may be necessary to treat water prior to discharge. Where water treatment is required, it can be a costly segment of the dredging project and should be included in cost estimates for the alternative. Water treatment costs may also affect choices regarding dredging operation and equipment selection, as both can affect the amount of water entrained.

The project manager should consider potential contaminant losses to the water column and atmosphere during transport, dewatering, temporary storage, or treatment. For example, conventional mechanical dredging methods and equipment often rely on gravity dewatering of the sediment on a dredge scow, with drainage water and associated solids flowing into the surrounding water. Project managers should evaluate what engineering controls are necessary and cost-effective, and include these controls in planning and design. Implementation risks, both to workers and to the community, differ significantly between the various transport methods listed above. These risks should be evaluated and included when comparing alternatives. Best management practices for protection of water quality should also be followed.

The risks associated with a temporary storage or staging sites are similar to those associated with CDFs, as discussed in Section 6.8.2, Sediment Disposal. In particular, in-water temporary CDFs can prove to be attractive nuisances, especially to waterfowl, by providing attractive habitat that encourages use of the CDF by wildlife and presenting the opportunity for exposure to contaminants. For highly contaminated sites, it may be necessary to provide a temporary cover or sequence dredging to allow for coverage of highly contaminated sediment with cleaner sediment to minimize short-term exposures. This method of control has proven effective for minimizing exposures at upland sanitary landfills. In addition, because some holding areas may not be designed for long-term storage of contaminated sediment, the risk of contaminant transport to ground water may need to be evaluated and monitored.

6.7 SEDIMENT TREATMENT

For the majority of sediment removed from Superfund sites, treatment is not conducted prior to disposal, generally because sediment sites often have widespread low-level contamination, which the NCP acknowledges is more difficult to treat. However, pretreatment, such as particle size separation to distinguish between hazardous and non-hazardous waste disposal options, is common. Although the NCP provides a preference for treatment for "principal threat waste," treatment has not been frequently selected for sediment. High cost, uncertain effectiveness, and/or (for on-site operations) community preferences are other factors that lead to treatment being selected infrequently at sediment sites. However, treatment of sediment could be the best option in some circumstances and innovations in ex-situ or in-situ treatment technologies may make treatment a more viable cost-effective option in the future.

The treatment of contaminated sediment is not usually a single process, but often involves a combination of processes or a treatment train to address various contaminant problems, including pretreatment, operational treatment, and/or effluent treatment/residual handling. Some form of pretreatment and effluent treatment/residual handling are necessary at almost all sediment removal projects. Sediment treatment processes of a wide variety of types have been applied in pilot-scale demonstrations, and some have been applied full scale. However, the relatively high cost of most treatment alternatives, especially those involving thermal and chemical destruction techniques, can be a major constraint on their use (NRC 1997). The base of experience for treatment of contaminated sediment is still limited. Each component of a potential treatment train is discussed in the next section.

6.7.1 Pretreatment

Pretreatment modifies the dredged or excavated material in preparation for final treatment or disposal. When pretreatment is part of a treatment train, distinguishing between the two components may be difficult and is not always necessary. Pretreatment is generally performed to condition the material to meet the chemical and physical requirements for treatment or disposal; and/or to reduce the volume and/or weight of sediment that requires transport, treatment, or restricted disposal. Pretreatment processes typically include dewatering and physical or size separation technologies.

Most treatment technologies require that the sediment be relatively homogeneous and that physical characteristics be within a relatively narrow range. Pretreatment technologies may be used to modify the physical characteristics of the sediment to meet these requirements. Additionally, some pretreatment technologies may divide sediment into separate fractions, such as organic matter, sand, silt, and clay. Often the sand fractions contain lower contaminant levels and may be suitable for unrestricted disposal and/or beneficial use if it meets applicable standards and regulations. Selection factors, costs, pilot-scale demonstrations, and applicability of specific pretreatment technologies are discussed in detail in EPA's *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (U.S. EPA 1994d).

6.7.2 Treatment

Depending on the contaminants, their concentrations, and the composition of the sediment treatment of the sediment to reduce the toxicity, mobility, or volume of the contaminants before disposal may be warranted. Available disposal options and capacities may also affect the decision to treat some sediment. In general, treatment processes have the ability to reduce sediment contaminant concentrations, mobility, and/or sediment toxicity by contaminant destruction or by detoxification, by extraction of contaminants from sediment, by reduction of sediment volume, or by sediment solidification/stabilization.

Treatment technologies for sediment are generally classified as biological, chemical, extraction or washing, immobilization (solidification/stabilization), and thermal (destruction or desorption). In some cases, particle size separation is also considered a treatment technology. The following treatment technologies are among those which might be evaluated.

Bioremediation

Generally, bioremediation is the process in which microbiological processes are used to degrade or transform contaminants to less toxic or nontoxic forms. In recent years, it has been demonstrated as a technology for destroying some organic compounds in sediment. The project manager should refer to EPA (1994d), Myers and Bowman (1999), and Myers and Williford (2000) for a summarization of bioremediation technologies and their application under site-specific conditions.

Chemical Treatment

Generally, chemical treatment refers to processes in which chemical reagents are added to the dredged or excavated material for the purpose of contaminant destruction. Contaminants may be destroyed completely, or may be altered to a less toxic form. Averett and colleagues (1990) reviewed several general categories of chemical treatment. Of the categories reviewed, treatments including chelation, dechlorination, and oxidation (of organic compounds) were considered most promising.

Extraction/Washing

Generally, the primary application of extraction processes is to remove organic and, in some cases, metal contaminants from the sediment particles. "Sediment washing" is another term used to describe extraction processes, primarily when water may be a component of the solvent. In the extraction process, dredged or excavated material is slurried with a chemical solvent and cycled through a separator unit. The separator divides the slurry into the three following fractions: 1) particulate solids; 2) water; and 3) concentrated organic contaminants. The concentrated organics are removed from the separator for post-process treatment. Extraction or washing may also generate large volumes of contaminated wastewater that generally must be treated prior to discharge.

Immobilization or Solidification/Stabilization

Generally, immobilization, commonly referred to as solidification/stabilization, alters the physical and/or chemical characteristics of the sediment through the addition of binders, including cements and pozzolans (U.S. EPA 1994d). Immobilization technologies primarily work by changing the properties of the sediment so contaminants are less prone to leaching. Alteration of the physical character of the sediment to form a solid material, such as a cement matrix, reduces the accessibility of the contaminants to water and entraps the contaminated solids in a stable matrix (Myers and Zappi 1989). Another form of immobilization, chemical stabilization, minimizes the solubility of metals primarily through the control of pH and alkalinity. Chemical stabilization of organic compounds may also be possible (Barth et al. 2001, Wiles and Barth 1992, Myers and Zappi 1989, Zimmerman et al. 2004).

Thermal Treatment

Generally, thermal technologies include incineration, pyrolysis, thermal desorption, sintering, and other processes that require heating the sediment to hundreds or thousands of degrees above ambient temperatures. Thermal destruction processes, such as incineration, are generally effective for destroying organic contaminants but are also expensive and have significant energy costs. Generally, thermal treatment does not destroy toxic metals.

Particle Size Separation

Generally, particle size separation involves separation of the fine material from the coarse material by physical screening. A site demonstration of the Bergman USA process resulted in the successful separation of less than 45 micron fines from washed coarse material and a humic fraction (U.S. EPA 1994f). As previously noted, particle size separation may serve as a pretreatment step prior to implementation of a treatment alternative. Many treatment processes require particle sizes of one centimeter or less for optimal operation.

Effluent Treatment/Residue Handling

Generally, treatment of process effluents means treatment of liquid, gas, or solid residues and is a major consideration during selection, design, and implementation of dredging or excavation. As shown in Highlight 6-1, dredging or excavation may require management of several types of residual wastes from the pretreatment and operational treatment processes that include liquid and/or air/gas effluents from dewatering or other pretreatment/treatment processes, residual solids, and runoff/discharges from active CDFs. Generally, these wastes can be handled through the use of conventional technologies for water, air, and solids treatment and disposal. However, the technical, cost, and regulatory requirements can be important considerations during the evaluation of dredging or excavation as a cleanup method.

Pilot and full-scale treatment processes have been conducted at a number of sites, although there is limited experience at Superfund sites. Where treatment has been used at Superfund sites, the most common treatment method is immobilization by solidification or stabilization. Additional information concerning treatment technologies for contaminated sediment may be found in U.S. EPA Office of Water's *Selecting Remediation Technologies for Contaminated Sediment* (U.S. EPA 1993d). Specific applications, limitations, specifications, and efficiencies of many sediment treatment processes are discussed in the ARCS program's *Remediation Guidance Document* (U.S. EPA 1994d). The NY/NJ

Harbor Project is an example of a large-scale demonstration of several dredged decontamination technologies (Highlight 6-9).

Highlight 6-9: NY/NJ Harbor - An Example of Treatment Technologies and Beneficial Use

The goal of the NY/NJ Harbor Sediment Decontamination Project is to assemble a complete decontamination system for cost effective transformation of dredged material (mostly from navigational dredging projects) into an environmentally safe material that can be used in the manufacturing of a variety of beneficial use products.

The following four treatment technologies are being used at the NY/NJ site: 1) sediment washing; 2) thermal treatment; 3) solidification; and 4) vitrification. Each technology has a sponsor from the private sector that will provide the capital needed for facility construction and operation.

Sediment washing (extraction) uses high-pressure water jets and proprietary chemical additives to extract both organic and inorganic contaminants from the sediment. The resulting materials can be used to produce manufactured soil for commercial, and in some cases, residential landscaping applications. Advantages to this treatment include modest capital costs and high throughput. The patented washing system has been demonstrated capable of decontaminating sediments containing high quantities of silt and clay.

A thermal treatment being used is a thermo-chemical manufacturing process that, at high temperatures, will destroy organic contaminants. The process will melt a mixture of sediment and modifiers, and the resulting product is a manufactured grade cement comparable to Portland Cement. This is a very effective treatment, but expensive.

A third process is a "treatment train" that includes dewatering, pelletizing, and transport to an existing light-weight aggregate facility. Pelletizing is a type of solidification treatment. After the sediment is dewatered, it is mixed with shale fines and extruded into pellets. The pellets are fed into a rotary kiln, and the organic matter explodes. The resulting material can be used as a structural component in concrete, insulation (pipeline) and for other geotechnical uses.

Finally, the process includes a high temperature vitrification, which uses an electrical current to heat (melt) and vitrify the soil in place. This process can destroy organic contaminants and incorporate metals into a glassy matrix that can be used to produce an architectural tile.

Source: Stern et al. 2000, Mulligan et al. 2001, Stern 2001, NRC 1997

Potential sediment treatment technologies will evolve as new technologies are developed and other technologies are improved. EPA has recognized the need for an up-to-date list of treatment alternatives and has developed the following databases:

- *EPA Remediation and Characterization Innovative Technologies (EPA REACH IT):* Provides information on more than 750 service providers that offer almost 1,300 remediation technologies and more than 150 characterization technologies (includes a variety of media, not just sediment). More information is available at http://www.epareachit.org/index3.html; and

- *EPA National Risk Management Research Laboratory (NRMRL) Treatability Database:* Provides results of published treatability studies that have passed the EPA quality assurance reviews, it is not specific to sediment, and is available on CD from the EPA's ORD National Risk Management Research Laboratory in Cincinnati, Ohio. Detailed contact information is available at http://www.epa.gov/ORD/NRMRL/treat.htm.

6.7.3 Beneficial Use

Although not normally considered a treatment option, beneficial use may be an appropriate management option for treated or untreated sediment resulting from environmental dredging projects. Significant cost savings may be realized if physical and chemical properties of the sediment allow for beneficial use, especially where disposal options are costly. For example, at Rouge River/Newburgh Lake, Michigan, a Great Lakes Area of Concern, significant cost savings were realized by using lightly contaminated dredged sediment as daily cover at a local sanitary landfill, where it did not pose risk within the landfill boundary. The Bark Camp Mine Reclamation Project in Pennsylvania provides another reuse example. Information is available through the Pennsylvania Department of Environmental Protection Web site at http://www.dep.state.pa.us/dep/DEPUTATE/MINRES/BAMR/bark_camp/barkhomepage.htm. However, beneficial use of dredged or excavated sediment has been only implemented infrequently for remedial projects, mainly due to lack of cost-effective uses in most instances. Where beneficial use is considered, the contaminant levels and environmental exposure, including considerations of future land use, should be assessed.

Options for beneficial use may include the following:

- Construction fill;
- Sanitary landfill cover as in the above example;
- Mined lands restoration;
- Subgrade cap material or subgrade in a restoration fill project (topped with clean sediment or other fill);
- Building materials (e.g., architectural tile; see Highlight 6-9); and
- Beach nourishment (for a clean sand fraction).

A series of technical notes on beneficial uses of contaminated material has been developed by the USACE (Lee 2000), and the USACE maintains a Web site of beneficial use case studies currently available at http://el.erdc.usace.army.mil/dots/budm/budm.html. Use of contaminated materials from CDFs (to include treated material) is a major thrust of the USACE Dredging Operations and Environmental Research (DOER) program (http://el.erdc.usace.army.mil/dots/doer). In addition, Barth and associates evaluated beneficial reuse using an effectiveness protocol (Barth et al. 2001).

In some cases, a CDF (see description in Section 6.8.2) can be integrated with site reuse plans to both reduce environmental risk and simultaneously foster redevelopment in urban areas and brownfields sites. For example, at the Sitcum Waterway cleanup project in Tacoma, Washington, contaminated sediment was placed in a near shore fill in the Milwaukee Waterway, which was then developed into a container terminal. Also, there may be innovative and environmentally protective ways to reuse dredged contaminated sediments in habitat restoration projects (e.g., placement of lightly contaminated material over highly contaminated materials to build up elevations necessary for eventual creation of clean emergent marshlands).

6.8 SEDIMENT DISPOSAL

For purposes of this guidance the term "disposal" refers to the placement of dredged or excavated material and process wastes into a temporary or permanent structure, site, or facility. The goal of disposal is generally to manage sediment and/or residual wastes to prevent contaminants associated with them from impacting human health and the environment. Disposal is typically a major cost and logistical component of any dredging or excavation alternative. The identification of disposal locations can often be the most controversial component of planning and implementing a dredging remedy and, therefore, should be considered very early in the feasibility study.

Historically, contaminated sediment from Superfund sites has been typically managed in upland sanitary landfills, or hazardous or chemical waste landfills, and less frequently, in CDFs. Contaminated sediment has also been managed by the USACE in contained aquatic disposals (CADs). Also, the material may have a beneficial use in an environment other than the aquatic ecosystem from which it was removed (e.g., foundation material beneath a newly constructed brownfields site), especially if the sediment has undergone treatment. As noted below, all disposal options have the potential to create some risk. These risks may result from routine practices (i.e., worker exposure and physical risks and volatilization), while other risks may result from unintended events, such as transportation accidents and contaminant losses at the disposal site. All potential risks should be considered when comparing alternatives. The ARCS program's *Remediation Guidance Document* (U.S. EPA 1994d) provides a discussion of the available disposal technologies for sediment, including an in-depth discussion of costs, design considerations, and selection factors associated with each technology. Averett and colleagues (1990), EPA (1991b), and Palermo and Averett (2000) provide additional discussion of disposal options and considerations.

6.8.1 Sanitary/Hazardous Waste Landfills

Existing commercial, municipal, or hazardous waste landfills are the most widely used option for disposal of dredged or excavated sediment and pretreatment/treatment residuals from environmental dredging and excavation. Landfills also are sometimes constructed onsite for a specific dredging or excavation project. Landfills can be categorized by the types of wastes they accept and the laws regulating their operation. Most solid waste landfills accept all types of waste (including hazardous substances) not regulated as Resource Conservation and Recovery Act (RCRA) hazardous waste or Toxic Substances Control Act (TSCA) toxic materials. Due to typical restrictions on liquids in landfills, most sediment should be dewatered and/or stabilized/solidified before disposal in a landfill. Temporary placement in a CDF or pretreatment using mechanical equipment may therefore be necessary (Palermo 1995).

6.8.2 Confined Disposal Facilities (CDFs)

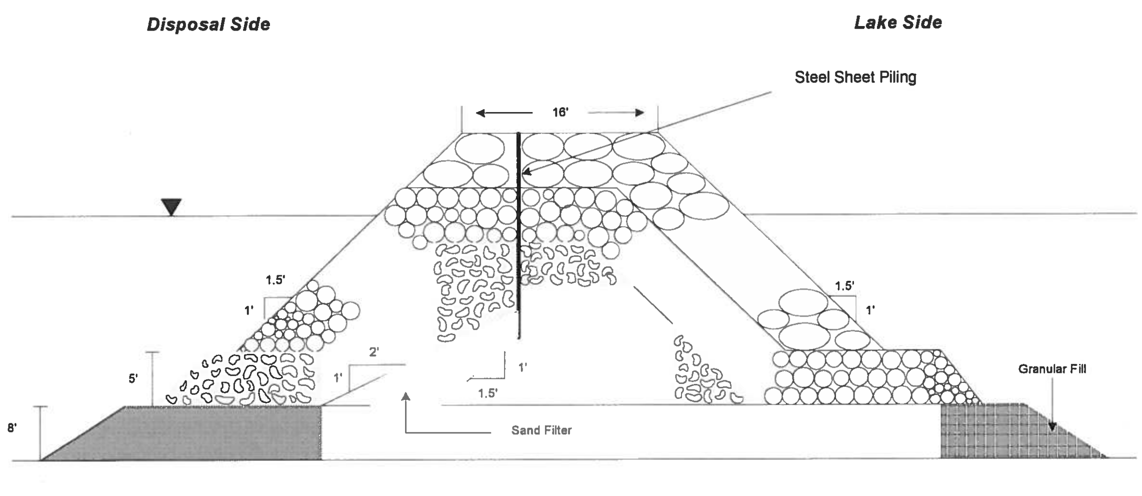
CDFs are engineered structures enclosed by dikes and specifically designed to contain sediment. CDFs have been widely used for navigational dredging projects and some combined navigational/environmental dredging projects but are less common for environmental dredging sites, due in part to siting considerations. However, they have been used to meet the needs of specific sites, as have other innovative in-water fill disposal options, for example, the filling of a previously used navigational waterway or slip to create new container terminal space (e.g., Hylebos Waterway cleanup and Sitcum

Waterway cleanup in Tacoma, Washington). In some cases, new nearshore habitat has also been created as mitigation for the fill.

Under normal operations of a CDF, water is discharged over a weir structure or allowed to migrate through the dike walls while solids are retained within the CDF. Typically effluent guidelines or discharge permits govern the monitoring requirements of the return water. Details regarding the use and engineering design of CDFs are available in the USACE Engineer Manual, *Confined Disposal of Dredged Material* (USACE 1987) and the USACE *Testing Manual* (USACE 2003).

A cross-sectional view of a typical nearshore CDF dike design is shown in Highlight 6-10. CDFs may be located either upland (above the water table), near-shore (partially in the water), or completely in the water (island CDFs). There are several documents available containing thorough descriptions, technical considerations, and costs associated with CDFs (U.S. EPA 1996e, U.S. EPA 1994d, U.S. EPA 1991c, and Averett et al. 1990). Additionally, USACE and EPA (2003) describes a history and evaluation of the design and performance of CDFs used for navigational dredging projects in the Great Lakes Basin, including a review and discussion of relevant contaminant loss and contaminant uptake studies.

Highlight 6-10: Cross Section of a Typical Confined Disposal Facility Dike with a Filter Layer



Note: 1ft. = 0.3m

Note: Adapted from US. EPA 1998d

6.8.3 Contained Aquatic Disposal (CAD)

For purposes of this guidance, contained aquatic disposal is a type of subaqueous capping in which the dredged sediment is placed into a natural or excavated depression elsewhere in the water body. A related form of disposal, known as level bottom capping, places the dredged sediment on a level bottom elsewhere in the water body, where it is capped. CAD has been used for navigational dredging projects (e.g., Boston Harbor, Providence River), but has been rarely considered for environmental dredging projects. However, there may be instances when neither dredging with land disposal nor capping contaminated sediment in-situ is feasible, and it may be appropriate to evaluate CADs. The depression used in the case of a CAD should provide lateral containment of the contaminated material, and also should have the advantage of requiring less maintenance and being more resistant to erosion than level-bottom capping. The depression for the CAD cell may be excavated using conventional dredging equipment or natural or historically dredged depressions may be used. Uncontaminated material excavated from the depression may be subsequently used for the cap (U.S. EPA 1994d).

6.8.4 Losses from Disposal Facilities

Evaluation of a new on-site disposal facility for placement of contaminated sediment should include an assessment of contaminant migration pathways and should incorporate management controls in the facility design as needed. Landfill disposal options may have short-term releases, which include spillages during transport and volatilization to the atmosphere as the sediment is drying. As for any disposal option, longer-term releases depend in large part on the characteristics of the contaminants and the design and maintenance of the disposal facility.

For CDFs, contaminants may be lost via effluent during filling operations, surface runoff due to precipitation, seepage through the bottom and the dike wall, volatilization to the air, and uptake by plants and animals. The USACE has developed a suite of testing protocols for evaluating each of these pathways (U.S. EPA and USACE 1992), and these procedures are included in the ARCS program's *Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments* (U.S. EPA 1996e). The USACE has also developed the *Testing Manual* (USACE 2003), which describes contaminant pathway testing. Depending on the likelihood of contaminants leaching from the confined sediment, a variety of dike and bottom linings and cap materials may be used to minimize contaminant loss (U.S. EPA 1991c, U.S. EPA 1994d, Palermo and Averett 2000). Depending on contaminant characteristics, CDFs for sediment remediation projects may need control measures such as bottom or sidewall liners or low permeability dike cores. Project managers should also be aware that permeability across these barriers can decline significantly with time due to the consolidation process and blockage of pore spaces with fine materials. Therefore, site-specific evaluation is important.

Contaminants may be released as a mud wave outside of the boundaries of the CAD, or to the water column or air during placement of the contaminated sediment. Seepage of pore water may also occur during the initial consolidation of the sediment following placement. Other releases common to in-situ caps, such as through erosion of the cap or movement of contaminants through the cap (see Chapter 5, In-Situ Capping) may also occur. Whatever disposal options are evaluated, the rate and potential effects of contaminant losses during construction and in the long term should be considered.

Highlight 6-11 presents some general points to remember from this chapter.

Highlight 6-11: Some Key Points to Remember When Considering Dredging and Excavation

- Source control should be generally implemented to prevent recontamination
- A dredging or excavation alternative should include details concerning all phases of the project, including sediment removal, staging, dewatering, water treatment, sediment transport, and sediment treatment, reuse, or disposal
- Transport and disposal options may be complex and controversial; options should be investigated early and discussed with stakeholders
- In predicting risk reduction effects of dredging or excavation of deeply buried contaminants, exposure and risk are related to contaminants that are accessible to biota. Contaminants that are deeply buried have no significant migration pathway to the surface, and are unlikely to be exposed in the future may not need removal
- Environmental dredging should take advantage of methods of operation, and in some cases specialized equipment, that minimize resuspension of sediment and transport of contaminants. The use of experienced operators and oversight personnel is very important to an effective cleanup
- A site-specific assessment or pilot study of anticipated sediment resuspension, contaminant release and transport, and its potential ecological impacts should be conducted prior to full scale dredging
- Realistic, site-specific predictions should be made of residual contamination based on pilot studies or data from comparable sites. Where residuals are a concern, thin layer placement/backfilling, MNR, or capping may also be needed
- Excavation (conducted after water diversion) often leads to lower levels of residual contamination than dredging (conducted under standing water)
- A dredging or excavation project should be monitored during implementation to assess resuspension and transport of contaminants, immediately after implementation to assess residuals, and after implementation to measure long-term recovery of biota and to test for recontamination