TechData Sheet

Naval Facilities Engineering Command
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Contaminated Sediments at Navy Facilities: Cleanup Alternatives

Sediment contamination is recognized as a widespread and serious problem, and the management of contaminated sediments presents significant challenges. This TechData Sheet summarizes advances in sediment cleanup alternatives.

The U.S. EPA estimates that 5% of U.S. watersheds have health-threatening sediments, and 10% of marine or estuary sediments are potentially lethal to aquatic life. In 12 states, 100% of the rivers are under fish advisories, and 2,800 fish advisories are in force nationwide (U.S. EPA, 2001). Sediment contamination is also problematic for marine commerce. Of the 300 million cubic yards of sediments that are dredged annually for navigational purposes, 1% to 4% require treatment prior to disposal, increasing the cost of navigational dredging by a factor of 300 to 500.

Major sediment contaminants include: mercury, PCBs, dioxins, DDT, PAHs, and metals. These contaminants remain in the environment long after their sources have been removed. Contaminants enter sediments from spills, point sources such as industrial or municipal discharges, or nonpoint sources such as runoff; ship waste; or bilge waste.

The goals of sediment remediation are to remove contaminated sediments from the environment, obstruct contaminant migration into the environment, and/or minimize exposure of ecological or human receptors to sediment contaminants. Contaminated sediments can be either left in place or removed, and often several cleanup techniques are used in combination or in sequence. In some situations, the best solution is to allow natural burial and chemical weathering to permanently reduce risk. In other cases, sediments can be left in place with a low-permeability and erosion-resistant cap.

A variety of dredging techniques can be used when contaminated sediments must be removed from the aquatic environment. Once removed, the sediments may require dewatering and treatment prior to disposal. In situ and ex situ sediment cleanup alternatives are described.

MONITORED NATURAL RECOVERY

Description. Monitored natural recovery (MNR) relies on natural sediment burial and contaminant attenuation to permanently reduce risk. It is applicable to sites with relatively low risk to human and ecological receptors, where other alternatives are impractical, and where natural attenuative processes have been observed or are strongly expected. MNR can be implemented alone, in combination with other remedial strategies, or after an active remediation has been completed.

Advantages

- Takes advantage of natural processes.
- Natural burial reduces long term risk.
- Relatively low implementation cost.
- Minimizes short term disturbances due to remediation.
- Excavation, treatment, and disposal of sediments are not required.

Disadvantages

- Contaminated sediments remain in place.
- MNR is very slow (decades may be required for adequate recovery).
- No formal guidance for MNR in sediments is available.
- Long-term, extensive monitoring is required.
- Long-term monitoring costs can be high.

Design and Implementation Considerations. Prerequisites for MNR include source control and extensive site characterization, including detailed analysis of local hydrology and sediment chemistry. Evidence of contaminant weathering, in the form of biological transformation, chemical transformation, dissolution, volatilization, or sorption/sequestration is required. Long-term monitoring is often required to document progress toward remedial objectives.

Cost Considerations. Costs for MNR are not yet well established due to lack of experience and case studies and due to insufficient regulatory guidance.

IN SITU CAPPING

Description. In situ capping involves covering the contaminated sediment with clean material to physically isolate the contaminated sediment from the water column and the aquatic environment. The contaminated sediment can be capped in place, or consolidated in a confined aquatic disposal (CAD) facility (see Figure 1). Capping is appropriate for moderate to low risk sites that are in depositional, nonnavigational environments.

Advantages

- Reduces or eliminates the potential for sediment suspension and transport.
- Caps with low-permeability layers reduce or eliminate the advection or diffusion of contaminants to the water column.
- Eliminates direct contact between contaminated sediment and surface water.
- Recreates a healthy benthic environment.

Disadvantages

- Contaminated sediment remains in place.
- Long-term monitoring and maintenance may be required.
- More expensive than MNR.
- Permeable caps may allow release of contaminated porewater from the sediments to the surface water .

Configuration Options. A variety of cap configurations are available for use with contaminated sediments. They include sand-only, armored caps, geosynthetic caps, and Aquablok, a low-permeability cap made of bentonite bonded to gravel.

Placing a layer of imported, clean sand about 1 to 3 feet thick directly over the contaminated sediments creates sand-only caps. Sand-only caps reduce, but do not eliminate, suspension of contaminated sediment and contact between contaminated sediments and the water column.

Armored caps reduce contact between contaminated sediment and surface water, and they prevent suspension of contaminated sediment. In an armored cap, contaminated sediment is covered with a layer of imported clean sand, which then is covered by a layer of gravel or rock armoring.

A geosynthetic cap, a synthetic/geotextile membrane, is placed over the contaminated sediment, and then covered with a layer of imported clean sand or armoring. Geosynthetic caps prevent sediment suspension and hinder diffusion. Geosynthetic caps are appropriate for covering hot spots.

Dropping a layer of gravel/bentonite aggregate on the surface of the contaminated sediment creates Aquablok caps. As the bentonite hydrates, it swells to form a low-permeability clay barrier that isolates the contaminated sediment and porewater.

Data Needs and Design Considerations. Extensive site characterization, hydraulic analysis, and engineering design are required for capping remedies. Geotechnical issues include the sediment-bearing capacity, the cap-bearing capacity, slope stability, and the proposed cap geometry. Hydraulic issues include upward hydraulic gradients, water column impacts during construction, and the potential for cap erosion due to natural or ship-induced currents. Chemical issues include contaminant characteristics and migration potential, interaction between contaminants and sediment, and long-term fate of contaminants. Considerations of the benthic biota include bioturbation from burrowing animals and the potential impact on local ecology from cap construction. Considerations concerning site use include the minimum depth required for the intended use, boat impacts (wake erosion, anchors), human health protection, and the potential for future disturbances (e.g., land use changes).

Monitoring. Monitoring is an important component of cap placement, to confirm accurate placement and to identify maintenance needs. Caps may be monitored during and after placement using the following methods: sediment coring, bathymetric surveys, settling plates, sediment-profiling cameras, and "peeper" water profile meters.

Cost Considerations. Capping is generally less expensive than dredging. Major cost factors include: whether the sediment is consolidated, measures to protect the local environment during capping, the source and quantity of capping materials, the size of area to be capped, short-term and long-term monitoring, and cap maintenance.

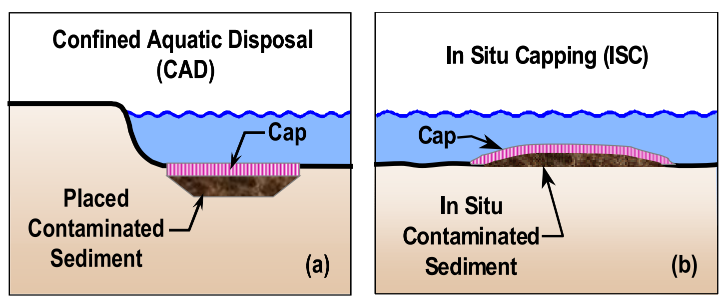


Figure 1. Common sediment caps; (a) capping over a confined aquatic disposal facility; (b) capping over contaminated surface sediments.

ENVIRONMENTAL DREDGING

Description. Dredging is a removal activity that is appropriate for high-risk sites where contaminated sediments must be removed for ex situ treatment and disposal. Dredged sediments can be collected on boats or barges, or piped directly to shore for dewatering, treatment, or disposal. Environmental dredges are classified as hydraulic or mechanical based on the method of sediment removal, but hybrid dredges and specialty dredges have been developed for environmental remediation.

Advantages

- Contaminated sediment is permanently removed from the aquatic environment.
- Wide range of commercially available equipment applicable to hard and soft sediment and varying depths.
- Relatively rapid remediation.
- Dredging alone has low to moderate cost.

Disadvantages

- Dredging can cause resuspension of contaminated sediments and significant turbidity.
- Dewatering, treatment, and disposal of dredged sediment increases cost substantially.
- Potential human exposure to contaminants during remediation .
- Difficulty achieving very low cleanup goals.
- Disruption of benthic and aquatic habitats.
- Negative public perception.
- Short-term increase in contaminant Bioavailability.
- Boulders and debris limit access and effectiveness.

Design and Implementation Considerations. The growing demand for removal of contaminated sediment has resulted in the development of a wide variety of specialized dredges suitable for use in environmental sediment removal projects. Factors that influence equipment selection include riverbed characteristics, water depth, sediment characteristics, volume of sediment being removed, the hydrodynamic environment, accessibility, availability of upland areas for sediment processing and storage, and ultimate disposal options. Dredging can be performed on dry sediments or on submerged sediments. For dry excavation, conventional excavation equipment or amphibious excavators with hydraulically actuated arms fitted with buckets or rakes can be used. Techniques for wet excavation are:

Mechanical dredges, such as buckets, clamshells, and backhoes, lift sediments to the surface and can operate from a barge or from shore. Some mechanical dredges are equipped with enclosed buckets to reduce sediment resuspension during removal. Mechanical dredges are effective for hot-spot and debris removal. The removed material has relatively low water content, but dewatering is still usually required prior to treatment or disposal. Disadvantages of mechanical dredging include significant turbidity, limited depth, relatively slow removal rates, and less uniform dredging than other dredging techniques.

Hydraulic dredges, such as cutterheads and hopper/dragheads, use centrifugal pumps to collect sediment slurries. A rotating cutting head allows the removal of consolidated or unconsolidated sediments. The sediment/water slurry is held on a vessel or pumped to shore for treatment. Hydraulic dredges remove large volumes of sediment quickly and accurately. They are excellent for navigational dredging and environmental dredging. Disadvantages of hydraulic dredges include the high water content of the removed material, a minimum of 2-3 feet water depth for cutterheads and more for hopper operation, and the inability to remove debris.

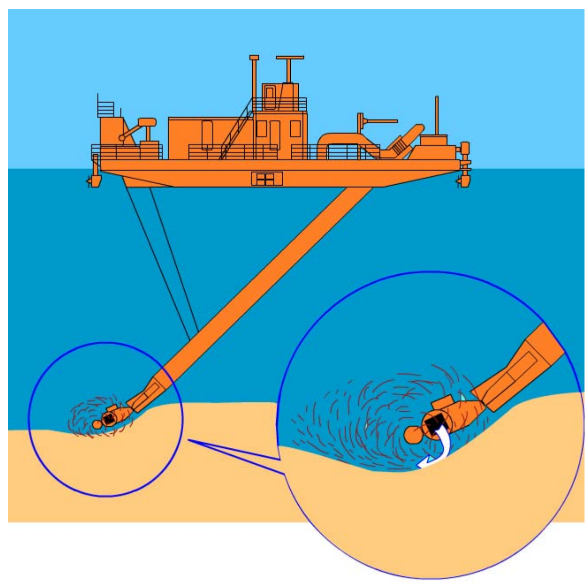


Figure 2. Water-injection vessel Jetsed.* *(©Ifremer Environnement; http://www.ifremer.fr)

Pneumatic dredges use compressed air and hydrostatic pressure differential to remove a sediment slurry. A chamber filled with compressed air is placed on the sediment surface. The compressed air is released and a gate on the bottom is opened, causing the chamber to fill with sediment. The bottom gate then is closed and compressed air is added to the chamber, causing the sediment to exit the chamber through a tube leading to the surface. Pneumatic dredges are not suitable for shallow excavations.

TREATMENT OF DREDGED SEDIMENTS

Prior to disposal, the dredged sediment often requires pretreatment and treatment. Pretreatment can involve debris removal, particle size separation, dewatering, and wastewater treatment.

Options for sediment treatment are listed below, with the treatment outcome listed in parentheses. Separation technologies physically separate the contaminant from the sediment, resulting in a smaller volume of contaminated material for disposal. Destructive technologies permanently destroy the contaminant. Immobilization technologies prevent the contaminants from migrating. A treatment option that is rapidly gaining popularity is "beneficial use," where treatment converts sediment to construction-grade cement, aggregate, architectural glass tile, or other usable materials.

Thermal Methods

- Thermal desorption (separation)
- Incineration (destruction)
- Vitrification (destruction/immobilization)

Chemical Methods

- Solidification/stabilization (immobilization)
- Sediment washing (separation)
- Solvent extraction (separation)
- Chemical oxidation (destruction)
- Base-catalyzed decomposition (destruction)
- Electrokinetics (destruction)

Biological Methods

- Biopile/composting (destruction)
- Slurry-phase bioreactors (destruction)
- Phytoremediation (destruction/separation)

Beneficial Use

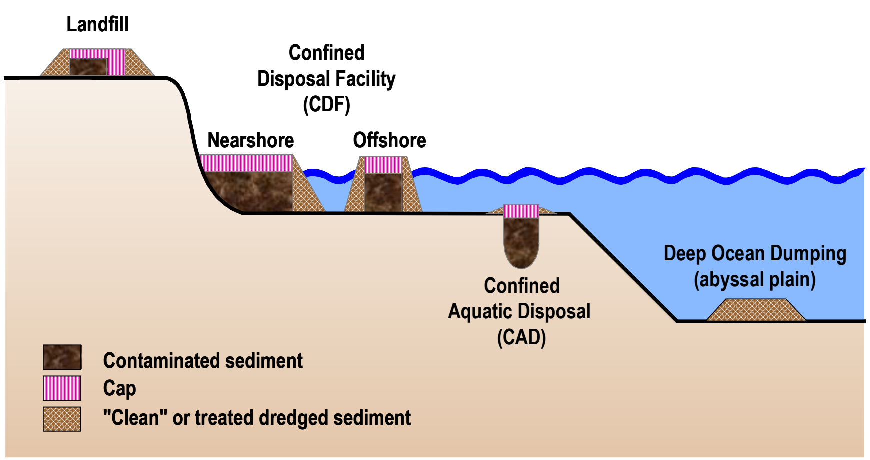
- Manufactured soil/fill (separation)
- Cement (destruction)
- Aggregate (destruction)
- Glass tile (destruction/immobilization)

DISPOSAL OF DREDGED SEDIMENTS

Numerous options exist for the permanent disposal of dredged sediments. The most common disposal option is a commercial landfill, also referred to as upland disposal. Engineered landfills reduce the potential for contaminant migration and can be cost-effective. Pretreatment costs, transportation, long-term monitoring costs, and limited availability of landfill sites increase the cost of this disposal option. Although solidification/stabilization is often required prior to landfilling, treatment generally does not occur inside the landfill.

The second disposal option is the use of a confined disposal facility (CDF), a partially submerged permanent disposal facility located nearshore or offshore. The contaminated sediments are consolidated into underwater storage cells constructed from clean-fill or clean-dredged material, and covered with a low-permeability cap. CDFs are less expensive than landfills, and proximity to the site limits transportation costs. CDFs also can provide beneficial future use as wetlands or brownfields. In addition, treatment of sediments within CDFs is possible. Disadvantages to CDFs are that contaminants are not destroyed, there is a potential for contaminant leaching into the aquatic environment, long-term monitoring is required, regulations are increasingly stringent, and new CDFs are difficult to site. CDFs increasingly require pretreatment and/or solidification/stabilization, particularly for contaminated sediments.

Confined aquatic disposal cells (CADs) are submerged disposal cells strategically sited within natural or excavated depressions. Pretreatment and treatment is usually not performed prior to disposal. Capping minimizes future releases of contaminants. Disadvantages to CADs are that new CADs are difficult to site, and regulations are increasingly stringent. Contaminants are not treated and releases can occur during placement. The risk of cap breach by storm events or benthic activity must be considered, and long-term monitoring is required.



COST CONSIDERATIONS

The cost considerations for dredging are summarized in Table 1 for each component of environmental dredging, including excavation, pretreatment, treatment, and disposal.

IN SITU TREATMENT

Description. In response to the technical challenges and high cost of environmental dredging, several in situ treatment options are under development. Two emerging in situ treatment technologies have been successfully used to date, focusing on reducing or eliminating high sediment organic loads. Limnofix™ (Golder Associates, Niagra Falls, NY) uses nitrate addition to stimulate nitrate-reduction of easily degraded organic contaminants. In the Hamilton Harbor (Ontario, Canada) pilot study, Limnofix™ reduced PAHs by 64% and TPH by 57% after 2 years. InStreem™ (Battelle, Daytona Beach, Florida) involves aquatic sediment aeration using surface-water aerators for recovery of aquatic environments impacted by high organic loads, and is more innovative for surface sediment recovery. Other in situ treatment technologies that are in the conceptual design phase include the use of aquatic plants to oxygenate and stabilize surface sediments, and the application of sediment reactive/binding materials to stabilize sediment contaminants and reduce bioavailable concentrations in sediment porewater and surface water. Cost considerations are not yet available for in situ treatment options**.**

SUMMARY

The goals of sediment remediation are to remove contaminated sediments from the environment, obstruct contaminant migration into the environment, and/or minimize exposure of ecological or human receptors to sediment contaminants. Contaminated sediments can be either left in place or removed, and often several cleanup techniques are used in combination or in sequence. In some situations, the best solution may be to allow natural burial and chemical weathering to permanently reduce risk. In other cases, sediments can be left in place with a low-permeability and erosion-resistant cap. In cases of relatively high risk of leaving sediments in place, dredging may be required to remove sediments from their existing environment. Once removed, the sediments may require dewatering or treatment prior to disposal, and may be disposed in upland disposal sites, in subaqueous CADs or CDFs. Innovative in situ treatment technologies are under development, some of which may provide beneficial use of the contaminated sediments as feed stock for the manufacture of Portland cement, light-weight aggregate, architectural tiles, or for low-contaminated sediments compost.

Table 1. Cost Considerations for Dredging

Activity	Cost Estimates (dollars per cubic yard)
Dredging	• Dredging alone (no treatment), under $10 • Environmental dredging costs 300 to 500 times more than navigational dredging, when treatment and transportation costs are included • New technologies focus on reducing the cost of environmental dredging
Pretreatment [1]	• Air drying (passive), $4 to $7 • Filtration, $8 • Centrifuge, less than $8 • Gravity thickening, less than $8 • Size separation, dewatering and wastewater treatment, $15 to $75
Treatment [2]	• Thermal desorption, incineration, vitrification, $110 to $1,350 • Sediment washing, $81 to $330 • Solidification/stabilization, $81 to $392 • Biopile/composting, phytoremediation, $20 to $270
Disposal [3]	• Commercial landfill, $30 to $300 • On-site landfill, $3 to $20 • CDF, $15 to $50 • CAD, more than $50

[1] Feyerherm and Wardlaw, 2001.
[2] Mulligan, 2001.
[3] NRC, 1997.

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