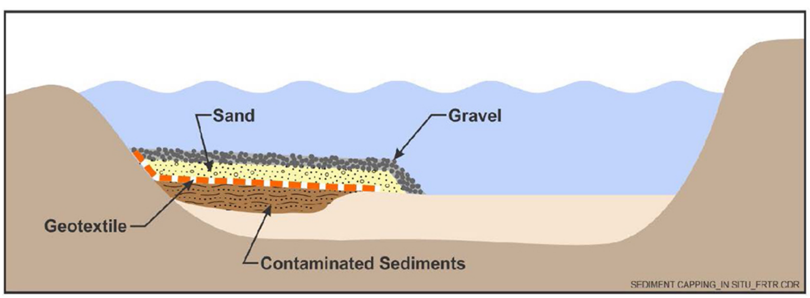
Sediment Capping

On this page:

Schematic



In Situ Capping of Contaminated Sediments Cross Section

Introduction

Sediment capping is a containment technology that involves isolating contaminated sediments from the surrounding aquatic environment using clean layers of geologic materials and/or synthetic liners. Conventional sediment capping is distinguished from capping with amendments in that the capping materials provide a *passive* barrier to sediment and porewater and prevent contaminant migration to the overlying aquatic environment (rivers, lakes, and maritime). The cap physically isolates and stabilizes the sediments and reduces contaminant flux to the overlying water column *without* promoting chemical reactions (e.g., adsorption, precipitation, oxidation/reduction). In contrast, sediment capping with amendments incorporates specialized materials that promote sequestration and/or biological degradation of the contaminants in the cap. Sediment capping should only be employed when the sources of contamination have been sufficiently reduced or eliminated so that the surface of the cap is not re-contaminated.

Other Technology Names

In situ sediment capping
Conventional capping
Isolation capping
Subaqueous capping

Description

Sediment capping involves the placement of clean material over contaminated sediments, which remain in place. Caps reduce ecological and human health risks from exposure to contaminated sediments by providing the following functions (EPA, 2005):

- **Physical isolation:** Prevents direct contact between sediment and aquatic biota
- **Stabilization:** Prevents resuspension and transport of sediment to other sites
- **Chemical isolation:** Reduces transport of dissolved contaminants from the sediment to the water column.

Conventional sediment caps typically are constructed of granular materials such as sand or gravel and can include geotextiles and other permeable or impermeable layers. Sediment from navigation dredging can also be used if the dredged material meets the sediment cap specifications. Although sediment capping is a passive remediation technique that does not reduce or eliminate contamination, it can be employed as either an interim or long-term remediation strategy under certain site-specific conditions. Capping can also be used in combination with other technologies such as dredging, monitored natural recovery, and/or enhanced monitored natural recover as part of an integrated/hybrid approach to sediment management.

Sediment capping involves the four steps described below:

1. **Site characterization.** Comprehensive site characterization must be completed to establish that site conditions are conducive to capping and to provide the data needed for cap design. Site characterization should focus on the conditions that have the greatest impact on the feasibility and effectiveness of the sediment cap, and the data needed to support cap design. These site characterization data needs include the following (EPA, 2005; ITRC, 2014):
   - **Delineation of the area to be capped:** The site should be adequately characterized with respect to the spatial extent of contamination (both areal and depth) and concentration of target contaminants. Determination of the area containing the bioavailable fraction of the contaminants (i.e., concentration of dissolved contaminants in porewater) may be more important than the concentration of contaminants sorbed onto sediment in identifying the sediments that pose the greatest risk.
   - **Sediment and water geochemistry:** The chemical nature of the sediments and overlying aqueous environment controls the chemical form of the contaminants and their transport behavior. Depending on the type of contaminant, parameters of interest may include (but are not limited to) organic carbon content, sulfide concentration, pH, dissolved oxygen, oxidation/reduction potential, ionic strength, and salinity. These parameters can be used to determine, for example, the potential for migration of metals through the capping layer, the specific form of inorganic contaminants (e.g., inorganic mercury versus methylmercury), or the potential for gas generation (i.e., ebullition) that could disrupt cap materials. These geochemical parameters can change rapidly through the sediment profile, especially oxidation/reduction parameters, and need to be profiled vertically from the surface into the underlying undisturbed sediments.
   - **Sediment physical characteristics:** Since the cap is placed in direct contact with the underlying contaminated sediment, physical characteristics of the sediment should be characterized to determine the ability of the sediment to support a cap and predict sediment behavior resulting from cap placement. Geotechnical characterization should include determination of particle size distribution, organic matter content, water content, plasticity (Atterberg limits), undrained shear strength, slope stability and bearing capacity. These parameters are

essential to determine the physical strength and stability of the sediment bed and potential for mixing and consolidation after the sediment cap has been placed.

- **Sediment biological characteristics:** Sediment-dwelling organisms move and mix sediment and contaminants during burrowing and feeding activities, commonly referred to as bioturbation. The thickness of a sediment cap must be greater than the thickness of the biologically active zone with a sufficient factor of safety to allow for localized surficial sediment migration, to ensure that the capped sediments remain isolated from aquatic biota.
- **Physical environment:** General characteristics of the site (e.g., presence of infrastructure, utilities, in-water structures, and debris) should be documented to ensure that capping is feasible. In addition, information about water depth and bathymetry is needed to establish baseline conditions and estimate the impacts of the cap on the water body (e.g., changes in hydrodynamic conditions, flooding potential, and habitat). Tides, currents, waves, ice scour, and propeller scour should be fully characterized across the entire area to be capped to ensure that the sediment cap is designed to withstand disruptive forces. In some cases, it may be necessary to protect the cap with coarse rock or rip-rap which performs as an armor layer to protect the cap from erosion. The groundwater upwelling rate should be assessed because it can facilitate contaminant migration from the subsurface and compromise cap integrity.
- **Waterway uses:** Site characterization should also include establishing the current and future uses of the waterway in which the cap is to be placed. Uses that should be considered include navigation, maritime industry, flood control, recreation, water supply and storm water and effluent discharges. These waterway uses have the potential to compromise the sediment cap after placement.

2. **Cap Design.** The next phase of a sediment capping remediation project is cap design, including selection of appropriate capping materials and determining the cap thickness needed to achieve project objectives. In general, the capping materials represent the largest single cost of a sediment capping project as large amounts of each material are needed. For example, a sediment cap covering 1 acre to a depth of 1 foot requires over 1,600 cubic yards of capping material. For this reason, it is desirable to select low-cost materials that can be easily procured in large amounts close to the remediation site. Clean sediment dredged from a nearby location or upstream of the contamination source may be a feasible option. Utilizing clean sediment from a nearby channel deepening

project can result in cost reductions for both projects since transportation, procurement and disposal costs can be minimized. Other common capping materials include clean sand and gravel or a combination of sand, gravel and/or clean sediment. Another option is the use of manufactured geotextiles which can provide physical separation between the contaminated sediment and capping material. However, it is important that the material chosen for the cap displays physical and chemical stability under the current *and future* conditions identified during site characterization. The thickness of the sediment cap must be sufficient to account for the various processes that could adversely affect performance and cap integrity (e.g., erosion, bioturbation, advection, and diffusion). A safety factor also should be incorporated into the design to account for mixing of contaminated sediments into the cap and uncertainties during cap placement. The cap design should also consider the potential effects of climate change on site conditions (EPA, 2015). Cap design also must address anticipated water current forces to ensure currents do not cause cap material to be displaced downstream and to ensure cap material gradations are maintained during placement.

3. **Cap placement.** After the site has been characterized to determine the areal extent and thickness of the proposed cap and the capping materials have been selected, the cap must be placed. The sediment cap can be placed directly over the contaminated sediments or the contaminated sediments can be placed into a depression formed by dredging clean sediments and the cap placed over top (contained aquatic disposal [CAD]). The major concerns while placing the capping material are accurate placement, cap density after placement, the rate of application of the capping material, and maintaining water quality (i.e., turbidity, total dissolved solids, dissolved oxygen). The cap should be placed so that it covers the entire contaminated area footprint under conditions that maintain general water quality criteria. The cap density refers to the weight per unit volume of material after the cap has been placed, which will gradually increase as settling occurs and pore water is expressed. Placing a sediment cap with a greater thickness than designed can lead to over-consolidation of the underlying sediment and a short-term release of contaminated pore water. However, the cap density will increase, effective porosity will be reduced, helping to minimize leaching and diffusion of contaminants through the sediment. The rate of application of the material should be controlled to minimize mixing of contaminated sediments and the sediment cap. Excessive application rates can also lead to displacement of fine contaminated sediments, which can lead to contamination of adjacent areas. Options for placement of a sediment cap include (but are not limited to) the following (USACE ERDC, 2005):

- **Direct mechanical placement:** This method entails the use of backhoes and end dumping trucks and must carefully consider the available access of the mechanical equipment to the contaminated site.
- **Surface discharge:** This method includes the discharge of the capping material using conventional dredging equipment such as barges or hopper dredges.
- **Barge movement:** In this method, an opening of a split-hull barge for controlled periods of time ensures that capping material is accurately placed over contaminated sediments with a controlled rate of application. Movement of the barge can be accomplished under its own power, or, in the case of lateral cap placement in a river, with the use of tug boats.
- **Hydraulic washing:** In this method, capping material is transported by a barge and washed overboard using hoses. This method is especially suitable to shallow environments (<10 feet) and allows for the gradual buildup of capping materials to ensure that the cap is applied at a controlled rate and the appropriate thickness.
- **Pipeline application:** This method is used in conjunction with a baffle plate or sandbox. The baffle plate or sandbox not only distributes the capping material evenly over the contaminated sediment but also provides energy dissipation to the capping slurry which minimizes mixing of the contaminated sediment with the capping material and re-suspension of the contaminated sediment.

Site-specific conditions, remedial goals, and specific regulatory requirements must be considered when selecting an appropriate method. Equipment and placement techniques that cause the capping material to displace or mix with the contaminated sediment should not be used (EPA Clu-In Sediment Remediation website).

4. **Monitoring.** The final component of a sediment capping project is the design and execution of a long-term monitoring plan. Long-term monitoring is needed to ensure that the sediment cap is functioning as designed and that recontamination has not occurred. In the case of sediment capping, long-term monitoring is particularly important because contaminants remain in the sediment below the cap and have the potential to be released into the aquatic environment. A detailed analysis of the contaminant profile under the cap must be well understood so that if the cap is recontaminated, as determined by the long-term monitoring program, sufficient data are available to determine whether contamination can be attributed to cap failure or to previously

unidentified sources. Furthermore, a detailed analysis of the capped profile (bathymetric survey) must be developed shortly after installing the cap, which will serve as a benchmark for future surveys to gauge cap stability, and perform maintenance (i.e. add additional material) if necessary. Long-term monitoring should confirm the integrity of the cap, including that 1) the contamination remains contained; 2) the capping material remains at the appropriate location and has the appropriate thickness; 3) biota have reestablished on and around the cap, if appropriate; and 5) all institutional controls are maintained (ASTSWMO, 2009).

In general, the success of a sediment capping project depends on the following:

- Appropriate site characterization.
- Selection of appropriate capping materials and determination of the thickness required to isolate the underlying contaminated sediments.
- Cost-effective transportation of capping material to the site.
- Careful selection and operation of the capping equipment.
- Appropriate placement techniques (accuracy of placement) for site-specific conditions.
- Effective monitoring of the cap to ensure that its integrity has not been compromised.

Development and Implementation Status

The following checklist provides a summary of the development and implementation status of sediment capping:

☐ At the laboratory/bench scale and shows promise

☐ In pilot studies

☒ At full scale

☐ To remediate an entire site (source and plume)

☒ To remediate a source only

☒ As part of a technology train

☒ As the final remedy at multiple sites

☒ To successfully attain cleanup goals in multiple sites

Sediment capping is available through the following vendors:

☒ Commercially available nationwide

☐ Commercially available through limited vendors because of licensing or specialized equipment

☐ Research organizations and academia

Applicability

Contaminant Class Applicability Rating for Sediment Capping

(Rating codes: ● Demonstrated Effectiveness, ◐ Limited Effectiveness, ○ No Demonstrated Effectiveness, I/D Insufficient Data, N/A Not Applicable)

Nonhalogenated VOC	Halogenated VOC	Nonhalogenated SVOC	Halogenated SVOC	Fuels	Inorganics	Radionuclides	Munitions	Emerging Contaminants
◐	◐	●	●	◐	●	●	●	I/D

Full-scale application of sediment capping is commonly applied to sediments containing recalcitrant organic and inorganic contaminants including pesticides, polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), and heavy metals and metalloids, munitions constituents and radionuclides. However, because sediment caps are designed to create a physical barrier between the contaminated sediment and the overlying surface water, they are able to effectively treat most contaminants.

Conventional sediment caps are less effective at containing non-aqueous phase liquids (e.g., fuels) and contaminants that are relatively mobile in the environment (e.g., volatile organic compounds [VOCs]). However, caps can be designed with high levels of organic matter or use sediment capping with amendments to facilitate retention or destruction of these compounds.

Site conditions that are conducive to sediment capping include:

- The contaminants are strongly sorbed to the sediment particles (i.e., immobile).
- The anticipated future use of the water body and the infrastructure needs are compatible with a cap.
- The water depth is sufficient to accommodate a cap.

  Hydrodynamic forces (e.g., currents, waves, ice) are not likely to disrupt a cap or can be accounted for in the design.
- Groundwater upwelling rates and gas ebullition are low or are unlikely to result in unacceptable contaminant releases (ITRC, 2014).
- The contaminated sediments have sufficient strength to support a cap.

As with any sediment remediation approach, it is important to establish that any ongoing sources of contamination to the water body have been sufficiently reduced or eliminated so that the surface of the cap is not re-contaminated.

Cost

Costs for conventional sediment capping can vary widely and depend on a number of site-specific parameters. The most important factor is the areal extent over which the cap must be placed, which impacts the quantity of cap materials and the time required to complete installation. Other major cost drivers include:

Upfront Costs

- Site surveys including bathymetry, water quality, and collection of characterization data for cap design.
- The type of capping material. The costs may be less if capping material is available as a byproduct of other operations, e.g. sediment available for beneficial reuse from navigation dredging.
- Location of the contaminated sediment within the waterbody. Sediment along a shoreline can be less costly to cap than contamination extending across large

bodies of water.

- Location of source of capping materials in relation to the site. Large quantities of materials must be procured and delivered to the site, which can be timely and costly if the source is located far from the site.
- Contaminant type and hydrodynamic conditions, which influence cap design and types and quantities of materials required.
- Method of emplacement (mechanical or hydraulic).
- Need for dredging. Dredging may be required to remove a portion of the sediment either because of the presence of mobile contamination (e.g., light non-aqueous phase liquid) or to achieve a specific cap design depth to allow navigation of the water body, prevent erosion, etc. Cost for removal, treatment and/or disposal of the sediment can be substantial.

Operation and Maintenance Costs

- Monitoring requirements for process control during installation, including but not limited to bathymetry and surface water quality.
- Long-term monitoring requirements including, but not limited to bathymetry, periodic cap and sediment sampling, porewater sampling, and surface water sampling.
- Utilities, including diesel for boats, yellow iron, generators and other equipment.

Duration

Installation of a conventional sediment cap may range from 1 to 4 months, but can take much longer depending on the location, areal extent, types and volumes of materials needed, and application method. Inspections should be conducted frequently in the first 6 months of post-cap placement, since problems related to cap settling and architecture would be most likely to appear during this period. The cap should be designed to provide containment and prevent contaminant flux to the overlying water body for as long as the contaminated sediment requires management. The cap should be monitored periodically after 6 months to verify cap integrity, particularly if there is a reason to believe that the cap has been compromised (e.g., major storm event). Monitoring can be performed more frequently if the cap is in a more dynamic system. In general, the time requiring active monitoring and maintenance will be site-specific, but is expected to be 20 years or longer.

Implementability Considerations

Potential implementability considerations for sediment capping include the following:

- The objective of capping is to eliminate the exposure pathway; however, it does not eliminate the source of risk.
- The cap must withstand erosion over time, although some erosion is permissible if it does not significantly compromise the function of the cap.
- Caps require long-term monitoring and maintenance to ensure that the contaminants are not migrating and that the integrity of the cap has not been compromised. The actual operating life of a conventional cap is uncertain and must be monitored until a time at which underlying sediment is determined to not present a risk to human health or the environment.
- Maintenance may require emplacement of additional materials if significant erosion has occurred.
- Placing the first layer of capping material can resuspend contaminated sediment in the water column. Sediment entrainment and contaminant release should be carefully monitored during emplacement. General water quality parameters, e.g. total dissolved solids (TDS) and turbidity, should also be monitored during the placement of this and other layers of capping material.
- Capping materials raise the existing sediment surface elevation, potentially changing the habitat type or reducing available clearance for water traffic.
- The preferred habitat may not be provided by surficial cap materials.
- Although it may be technically feasible to cap contaminated sediments in place at their original location, at times the use of the waterway may conflict with a reduction in available draft caused by the cap and therefore may indicate that the contaminated sediments should be removed.
- Strong currents may displace cap materials.

With capping, contaminants remain in place at the site, requiring long-term monitoring and maintenance to ensure that contaminants are not migrating. The integrity of the cap should be investigated regularly. The cap should be designed to provide containment for as long as the contaminated sediment requires management.

Resources

Association of State and Territorial Solid Waste Management Officials (ASTSWMO). Framework for Long-Term Monitoring of Hazardous Substances at Sediment Sites (2009)
Discusses long-term monitoring considerations for a range of sediment remediation approaches.

ASTSWMO. Sediment Remedy Effectiveness and Recontamination: Selected Case Studies (2013)
Discusses causes and issues related to recontamination. Topics include recontamination of sediment sites from both known sources and newly identified sources and case studies of sites where inadequate source control and/or recontamination have been documented.

EPA. CLU-IN Sediment Remediation – Capping Web Page
Provides an overview of sediment capping and links to references and case studies.

EPA. Assessment and Remediation of Contaminated Sediments (ARCS) Program (1998)
This document provides technical guidance for subaqueous, in situ capping as a remediation technique for contaminated sediments.

EPA. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (2005)
This document provides an overview of remedy investigation considerations, feasibility study considerations, and a summary of monitored natural recovery, in situ capping, dredging, and remedy selection and monitoring issues.

EPA. Climate Change Adaptation Technical Fact Sheet: Contaminated Sediment Remedies (2015)
Explains how to evaluate sediment remedy system vulnerability and develop strategies for increasing a sediment remediation systemâ€™s resilience to climate change.

International Joint Commission (U.S. and Canada). Status of Restoration Activities in Great Lakes Areas of Concern – A Special Report, Chapter 3: Progress Toward Restoration, Contaminated Sediment (2003)
Discusses potential sediment remediation alternatives and provides a cost estimate for thick capping.

Interstate Technology and Regulatory Council (ITRC). Contaminated Sediments Remediation: Remedy Selection for Contaminated Sediments (2014)

Provides a remedy selection framework to help project managers evaluate remedial technologies and develop remedial alternatives (often composed of multiple technologies) based on site-specific data.

NAVFAC. Contaminated Sediment Web Portal
This Web portal provides an interactive tool (Contaminated Sediment Overview) and a variety of links to resources for contaminated sediments management including Navy and EPA guidance documents, relevant agency Web sites, sediment-related conference and workshop information and other publications.

NAVFAC. Sediment Remedy Effectiveness Web Tool
This interactive Web tool provides an overview and case studies of three sediment remedies (environmental dredging, in situ capping, and monitored natural recovery) and information on selection criteria for each type of remedy.

NAVFAC. Sustainable Sediment Remediation (2015)
Provides a connection between existing Department of Navy (DON) optimization and green and sustainable remediation guidance and DON guidance pertaining to sediment sites. The document introduces a new version of SiteWise™ that has been developed to integrate sediment-specific remedial activities.

Remediation Innovative Technology Seminar (RITS). Sediments Part 1: Managing Sediment Sites Using Navy Policy and Guidance (2010)
Reviews key Navy policies and guidance for contaminated sediment sites and provides case studies that demonstrate policy implementation.

RITS. Sediments Part 2: Establishing SMART Sediment Cleanup Goals (2010)
Addresses challenges associated with establishing sediment cleanup goals, provides guidance and available tools for development cleanup goals, and presents case studies.

RITS. Advances in Sediment Characterization and Remediation (2013)
Topics include sediment characterization and assessment tools and selection of applicable remedial technologies.

SPAWAR. Implementation Guide for Assessing and Managing Contaminated Sediment at Navy Facilities (2005)
This document presents guidelines for conducting sediment site assessments and remedial alternative evaluations within the Navyâ€™s Environmental Restoration program. It is intended for use by Remedial Project Managers

(RPMs) and their technical support staff as stepwise guidance that will apply to most Navy sediment investigations.

USACE Engineer Research and Development Center (ERDC). Equipment and Placement Techniques for Subaqueous Capping (2005)
Describes equipment and placement techniques for subaqueous capping projects.