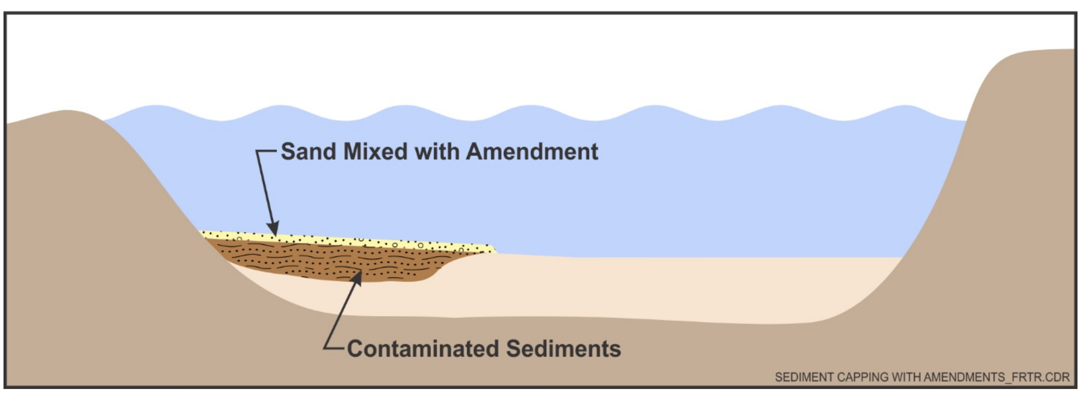
Sediment Capping with Amendments

On this page:

Schematic



Cross Section of Sediment Capping with Amendments

Introduction

Sediment capping with amendments involves covering contaminated sediments with a single- or multi-layered cap that includes a layer of adsorptive, low permeability, or reactive material (i.e., an amendment), or a layer of granular material such as sand mixed with an amendment. The amendments are used to improve the overall effectiveness of the cap by sequestering or degrading contaminants and preventing them from migrating into the overlying aquatic environment. Amendments also can be mechanically mixed into surface sediments, or placed on the sediment surface and mixed into the sediment by natural processes such as burrowing of organisms (i.e., bioturbation).

Amended caps are an innovative approach used in situations where a conventional isolation cap is not feasible or is unlikely to be effective. Amended caps often can be thinner than conventional sediment caps and can be designed to resist erosion and reduce contaminant transport from groundwater upwelling, gas migration (i.e., ebullition), or non-aqueous phase liquid (NAPL).

Amendments are used to treat or contain contaminant(s) through adsorption, containment, or chemical degradation/transformation. Examples of amendments that can be used in sediment caps include carbon-based products such as activated carbon or coke breeze; organoclays; apatite, zeolites, and bauxite; and zero-valent iron. Sediment capping with amendments can be used alone or in combination with other remedial technologies such as dredging and monitored natural recovery as part of an integrated approach to sediment site management.

Other Technology Names

Active caps
Innovative caps
Sediment reactive barriers
Reactive caps or mats
Thin layer caps

Description

Conventional [sediment capping](https://frtr.gov/matrix/Sediment-Capping/) consists of single or multiple layers of granular material, such as clean sediment, sand, or gravel. Sediment 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 the transport of dissolved contaminants from the sediment to the water column.

Various sediment amendments have been developed in recent years to enhance cap performance. Some of these amendments have been tested at laboratory- or pilot-scale only. The addition of amendments to a cap can increase the cap's effectiveness by one to two orders of magnitude (EPA, 2013). Amendments are designed to treat contaminant(s) in three ways:

1. **Adsorption**: by adsorbing dissolved-phase contaminants or NAPL moving upward into the cap, thereby inhibiting contaminant migration into the overlying water column;
2. **Containment**: by providing a low-permeability physical barrier that limits the mobility of the sediment-associated contaminants; and
3. **Chemical degradation or transformation**: by enhancing contaminant degradation or transformation processes such as biodegradation of organic contaminants or precipitation of inorganic contaminants.

Some of the materials that have been used or investigated as capping amendments include the following (EPA, 2013; ITRC, 2014; NAVFAC, 2016):

- **Carbon amendments**, including activated carbon, coke breeze, and coal. Carbon amendments adsorb dissolved-phase organic contaminants, reducing contaminant bioavailability and inhibiting contaminant transport through the cap to the overlying aquatic environment. Carbon amendments have been used at multiple sites in pilot- and full-scale applications.
- **Clay aggregate composite materials**. that reduce permeability and prevent contaminant transport through the cap. These types of impermeable caps can include "funnel and gate" systems that direct upwelling groundwater into channels or chambers filled with adsorptive or reactive materials. These materials have been used in pilot- and full-scale applications.
- **Organophilic clays** that adsorb organic contaminants, metals, and NAPL. Organophilic clays have been used as a capping amendment at multiple sites in pilot- and full-sale applications.

- **Phosphate additives (apatite) or zeolites** that immobilize heavy metals through adsorption, ion exchange, and other processes. These materials have been used in laboratory- and pilot-scale studies.
- **Bauxite**, which sequesters many heavy metals including mercury, arsenic, chromium, cadmium, lead, zinc, and nickel. Bauxite has been tested in laboratory- and pilot-scale studies.
- **Zero-valent iron**, which promotes the chemical degradation of chlorinated hydrocarbons such as polychlorinated biphenyls (PCBs) and chlorinated pesticides. Zero-valent iron has been tested at the laboratory scale.
- **Biopolymers**, which are naturally occurring materials that can bind metals and organic compounds. Biopolymers have been tested at the laboratory scale.

Because capping amendments are relatively new, their longevity and long-term effectiveness are not well understood. Additional field applications and evaluation of long-term monitoring data will increase the understanding of these technologies and the key factors that affect their long-term effectiveness (EPA, 2013).

Depending on the type of amendment and the cap design, amendments can be placed as a single layer, as one layer in a multi-layer cap, or can be mixed and placed with granular material such as sand or clean sediment. Amended caps can be placed using conventional methods such as surface release from a barge or sub-subsurface tremie placement (NAVFAC, 2016). Several amendments utilize innovative delivery mechanisms such as use of agglomerate binders (EPA, 2013). Some amendments, such as activated carbon, have poor settling characteristics and must be pre-wetted or placed close to the sediment surface to prevent amendment loss (ITRC, 2014). Another placement approach utilizes engineered synthetic materials, such as reactive mats, where the amendment is sandwiched between two thin non-woven fabric (geotextile) mats.

General site conditions that are suitable for capping with amendments are the same as those for conventional sediment capping. For design of an effective reactive sediment cap, the reactive material should be compatible with the physical/hydrologic environment of the contaminated site and the chemical nature of the contaminant.

In all cases where capping is chosen as part of a remedy, ongoing sources of contamination should be reduced or eliminated prior to construction to prevent recontamination of the cap surface. Furthermore, capping can be used in combination with other technologies such as dredging, monitored natural recovery, and enhanced monitored natural recovery as part of an integrated approach to sediment management.

Development Status and Availability

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

☒ At the laboratory/bench scale and shows promise

☒ In pilot studies

☒ At full scale

☐ To remediate an entire site (source in vadose zone)

☒ 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 with amendments 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 with Amendments

(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	I/D	I/D

Sediment capping with amendments can be applied to sediments containing halogenated or nonhalogenated volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs), PCBs, polycyclic aromatic hydrocarbons (PAHs), chlorinated pesticides, metals/metalloids (e.g., arsenic, chromium, lead, mercury, etc.), and light non-aqueous phase liquids such as petroleum fuels. In principle, sediment capping with amendments also could be used to isolate and treat radionuclides, munitions, and emerging contaminants, although few case studies have been documented.

Cost

Costs for sediment capping with amendments can vary widely and depend on a number of site-specific parameters. The most important factors are: 1) the areal extent over which the amended cap must be placed, which impacts the quantity of cap materials and the time required to complete installation; and 2) the type of amendment to be used in the cap. Although less material is required for a reactive cap compared to a conventional sediment cap, reactive cap materials are generally more expensive than conventional material, and therefore the total cost of the materials may be similar. Nonetheless, the reduced volume of reactive cap material can minimize placement time and associated cost. Many of the cost considerations are similar to those for conventional sediment capping. Major cost drivers include:

Upfront Costs

- Site surveys including profiling sediment surface elevations (i.e., bathymetry), water quality, and collection of characterization data for cap design.
- The type of traditional capping material, if used, with the amendment.
- The type of amendment.
- 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.
- Contaminant type and hydrodynamic conditions, which influence cap design and types and quantities of amendments required.
- Availability and required volume of the selected cap amendment.
- Method of emplacement (conventional or specialized methods, or use of geotextile mats).
- Need for dredging. Dredging may be required to remove a portion of the sediment either because of the presence of mobile contamination (e.g., NAPL) or to achieve a specific cap design depth to allow navigation of the waterbody, 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, surface water quality, and sediment coring or sediment profile imaging to verify amended cap thicknesses.
- 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 duration for amended caps is likely to be extended by several weeks to several months beyond the 1 to 4 months expected for conventional sediment capping depending on the type of amendment used and method of deployment. Inspections should be conducted frequently in the first 6 months of post-cap placement, since problems related to cap settling and architecture would most likely appear during this period. In particular, if reactive mats are used, they may be more prone to minor displacement or lifting due to tides, waves, or currents.

Long-term monitoring must be performed to evaluate the cap's integrity and functionality at a frequency that is appropriate for the site-specific conditions. For example, integrity monitoring should generally be performed more frequently if the cap is placed in a more hydrodynamically energetic system. The cap should be designed to inhibit contaminant flux to the overlying waterbody for as long as the contaminated sediment requires management. The time requiring active monitoring and maintenance will be site-specific, but is likely to be at least 20 years or longer.

Implementability Considerations

Potential implementability considerations for sediment capping with amendments include the following:

- The contaminated sediments remain in place. Although contaminants are physically and chemically separated from the overlying aquatic environment, the possibility of future exposure remains a concern should the structural integrity of the cap be compromised. Hence, long-term monitoring and maintenance is a necessity and must be factored into the design.
- The surfaces of the amendments available for chemical adsorption/transformation/degradation may become saturated and/or passivated over time, reducing the ability of the cap to prevent contaminant transport to the overlying aquatic environment.
- Some types of amendments are difficult to place in hydrodynamically active settings because of poor settling characteristics.
- Amended caps are a relatively novel and innovative technology, and little long-term monitoring data are available to assess long-term effectiveness. Thus, the effective life span and long-term stability of amended caps have not been established.
- Placement of capping and/or amendment material can resuspend contaminated sediment in the water column. Sediment entrainment and contaminant release, as well as general water quality parameters, e.g. total dissolved solids (TDS) and turbidity, should be monitored during the placement of capping material.
- Capping materials generally elevate the sediment bed, resulting in a bathymetric change that could reduce available vessel draft for a navigable

waterway. Vessel propeller scour should also be considered in amended cap design and placement.

- The cap design must consider erosion by tides and waves, flooding, ice scouring, storms, and other physical forces that could disrupt the cap.
- The influence of benthic activity on cap performance needs to be considered with respect to the degree of the bioturbation/burrowing depth and the re-colonization of indigenous habitat species. Gas ebullition from organic matter biodegradation because of methanogenic activity in the underlying sediment should be evaluated since it could compromise the integrity of the cap with a contaminant migration and/or release.

Resources

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

ASTSWMO. Sediment Remedy Effectiveness and Recontamination: Selected Case Studies (2013)
This document presents 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. Contaminated Sediments Web Page
This Web page contains links to sediment guidance documents, fact sheets and policies and other documents relevant to contaminated sediments.

EPA. CLU-IN Sediment Remediation — Capping Web Page
This Web page provides an overview of sediment capping and links to references and case studies.

EPA. Innovative Capping Technology to Prevent the Migration of Toxic Chemicals from Contaminated Sediments (2011)
This publication summarizes collaborative efforts of EPA and other government and business partners in evaluating new innovative capping materials.

EPA. Use of Amendments for In Situ Remediation at Superfund Sediment Sites (2013)

This document introduces the most promising amendments for in situ remediation of sediments and summarizes some of the information on contaminated sediment sites that have already employed these amendments.

EPA Great Lakes National Program Office. Evaluation of Sorbents (Organoclay and Activated Carbon) as Active Cap Materials to Remediate Contaminated Sediment Sites (2014)
This publication provides information on "active" materials that can be used to minimize transport of contaminants in porewater to the bioactive zone and water column.

EPA. Climate Change Adaptation Technical Fact Sheet: Contaminated Sediment Remedies (2015)
This fact sheet explains how to evaluate sediment remedy system vulnerability and develop strategies for increasing a sediment remediation system's resilience to climate change.

Ghosh, U., R.G. Luthy, G. Cornellisen, D. Werner, and C.A. Menzie. In-situ Sorbent Amendments: A New Direction in Contaminated Sediment Management (2011) Environmental Science and Technology 45(4): 1163-1168
This paper summarizes research by several groups that involves introducing sorbent amendments into contaminated sediments that alter sediment geochemistry, increase contaminant binding, and reduce contaminant exposure risks to people and the environment. The paper describes laboratory studies and presents a brief outline of ongoing pilot-scale trials, field challenges, regulatory issues, and further research needs.

Interstate Technology and Regulatory Council (ITRC). Contaminated Sediments Remediation: Remedy Selection for Contaminated Sediments (2014)
This Web page 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 sediment management including Navy and EPA guidance documents, relevant agency Web sites, sediment-related conference and workshop information and other publications.

NAVFAC. Reactive Capping Mat Development and Evaluation for Sequestering Contaminants in Sediment (2011)
The project consisted of developing a reactive geotextile mat system to serve as a chemically effective, mechanically stable, and cost efficient technology for reducing ecological risks by sequestering contaminants in sediment. The project area was Cottonwood Bay, Grand Prairie, Texas.

NAVFAC. Sustainable Sediment Remediation (2015)
This Web page 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™ which has been developed to integrate sediment-specific remedial activities.

NAVFAC. Reactive Capping Fact Sheet (2016)
This fact sheet provides an overview of state-of-the-art practices for designing and applying reactive cap remedies at sediment sites.

Remediation Innovative Technology Seminar (RITS). Sediments Part 1: Managing Sediment Sites Using Navy Policy and Guidance (2010)
This document 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)
Challenges associated with establishing sediment cleanup goals are addressed, and guidance and available tools for development cleanup goals are provided, and case studies presented.

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

RITS. Innovations in in Situ Sediment Remediation (2017)
Addresses current in situ sediment remediation technologies such as reactive capping, carbon amendments, and in situ treatment with bioaugmentation.

Strategic Environmental Research and Development Program (SERDP)/Environmental Security Technology Certification Program (ESTCP). 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.

SERDP/ESTCP. Activated Biochars with Iron for In-situ Sequestration of Organics, Metals, and Carbon (2012)
This project tested a range of biochars and especially formulated biochars that can reduce the bioavailability and leaching of toxic chemicals like PAHs, PCBs, DDTs, mercury, and methylmercury in sediments.

SERDP/ESTCP. A Permeable Active Amendment Concrete (PAAC) for Contaminant Remediation and Erosion Control (2013)
This project developed a permeable active amendment concrete (PAAC) consisting of apatite, limestone, organoclays, zeolite, sand, and cement. PAAC has the potential to produce a barrier that combines high structural integrity with the ability to stabilize a variety of contaminants.

SERDP/ESTCP. Demonstration of In Situ Treatment with Reactive Amendments for Contaminated Sediments in Active DoD Harbors (2017)
The objective of this project was to demonstrate and validate the placement, stability, and performance of reactive amendments for the treatment of contaminated sediments in active Department of Defense (DoD) harbor settings.