Climate Change Adaptation Technical Fact Sheet: Contaminated Sediment Remedies

In June 2014, the U.S. Environmental Protection Agency (EPA) released the final *U.S. Environmental Protection Agency Climate Change Adaptation Plan.*[1] The plan examines how EPA programs may be vulnerable to a changing climate and how the Agency can accordingly adapt in order to continue meeting its mission of protecting human health and the environment. Under the Agency's Superfund Program, existing processes for planning and implementing contaminated site cleanup provide a robust structure that allows consideration of climate change impacts. Climate change vulnerability analyses and adaptation planning leading to increased remedy resilience may be integrated throughout the Superfund process, including feasibility studies, remedial designs and remedy performance reviews or the equivalent in other cleanup programs. Due to wide variation in the location and hydrogeologic characteristics of contaminated sites, the nature of remedial actions at those sites, and local or regional climate and weather regimes, considering climate change impacts and potential adaptation measures is most effective through use of a site-specific strategy.

This fact sheet addresses remedies for contaminated sediment. It is intended to serve as an adaptation planning tool by (1) providing an overview of potential climate change vulnerabilities and (2) presenting possible adaptation measures that may be considered to increase a remedy's resilience to climate change impacts. This tool was developed in context of the Superfund Program but its concepts may apply to site cleanups conducted under other regulatory programs or through voluntary efforts. [a]

The adaptation strategies for sediment remedies build on concepts detailed in EPA's previously issued ***Climate Change Adaptation Technical Fact Sheet: Groundwater Remediation Systems*** (EPA 542-F-13-004)[2] and ***Climate Change Adaptation Technical Fact Sheet: Landfills and Containment as an Element of Site Remediation*** (EPA 542-F-14-001).[3] Supplemental information available online includes:

- Additional background information
- Definitions of key terms such as "vulnerability" and "resilience"
- Links to key sources of information.

www.epa.gov/superfund/climatechange

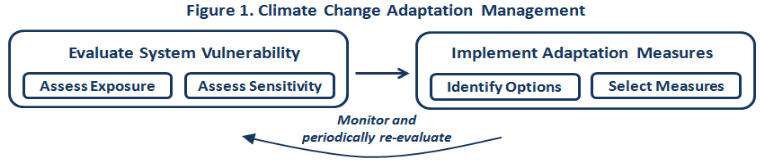
Cleanup at many sites involves remediation of contaminated aquatic sediment – the clay, silt, sand and organic matter along the bottom of rivers, lakes, ponds, estuaries and marine bays or harbors. Common sediment remediation technologies are dredging or excavation with off-site disposal, capping to isolate the contaminated sediment, and application of amendments that bind or destroy the contaminants. Dredging techniques frequently move the contaminated sediment directly to an onshore treatment or disposal area. Excavation is similar to dredging but includes partial dewatering of the sediment, by diverting surface water from the natural channel or by constructing a coffer dam around the sediment; the dewatering process allows target sediment to be removed through use of conventional construction equipment.

Capping (in situ capping) involves placing clean material on top of the contaminated material. A cap often consists of several layers of various materials, such as an isolation layer of sand and/or soil and an armor layer of gravel, cobbles, and/or large boulders. In some cases it includes a habitat layer designed to mimic the native sediment and promote recovery of benthic communities. In a reactive cap, the isolation layer includes an amendment (such as organoclay or activated carbon mats) that binds or sequesters contaminants exiting the sediment pore water, thereby preventing contaminant release to surface water.[4]

Other sediment remedies involve monitored natural recovery (MNR) or enhanced monitored natural recovery (EMNR), which entail burial of contaminated sediment with clean sediment. While MNR relies on the site's natural processes to reduce risks, EMNR uses engineered methods to speed the natural processes. Also, nearly two-thirds of recently selected sediment remedies include institutional controls to protect the remediation system or prevent consumption of contaminated fish and other wildlife.[5]

Climate change adaptation for a sediment remediation system generally focuses on: (1) evaluating the system's vulnerability to climate change and (2) implementing adaptation measures, when warranted, to ensure the remedy continues to prevent human or environmental exposure to contaminants of concern (Figure 1). An effective adaptation strategy includes monitoring implemented measures, periodically re-evaluating the system's vulnerability, and incorporating any needed changes.

Figure 1. Climate Change Adaptation Management



[a] In manners consistent with existing regulations, including those under the Comprehensive Environmental Response, Compensation, and Liability Act; the National Oil and Hazardous Substances Pollution Contingency Plan; the Resource Conservation and Recovery Act; and the Small Business Liability Relief and Brownfields Revitalization Act.

Evaluation of Sediment Remedy System Vulnerability

Evaluation of a sediment remediation system's vulnerability to climate change may involve:

- Identifying potential hazards posed by climate change
- Characterizing the system's exposure to those hazards
- Characterizing the system's sensitivity to the hazards
- Considering factors that may exacerbate system exposure and sensitivity, such as the size of upstream water catchment, the size of adjacent floodplains, and land use in the floodplains.

Potential climate change hazards for a remediation system can be identified through a **climate-change exposure assessment** that reflects a range of possible climate and weather scenarios. A sediment remedy system may be particularly vulnerable to problems such as:

- Potential scour of a sediment cap or underlying sediment due to an increase in surface water flow velocity and/or turbulence associated with intense storms or sustained freeze conditions
- A significant increase in urban or agricultural runoff entering the sediment containment/treatment zone due to increased intensity, frequency and/or duration of storms
- Entrance of additional waste or debris from upland or upstream sources due to flooding, intense wind or landslide
- Increased discharge of groundwater to the associated water body due to increased intensity, frequency and/or duration of storms
- Increased turbidity of water in a treatment zone due to high wind in shallow surface water or arrival of floodwater or increased discharge
- Unexpected desiccation in the containment/treatment zone due to low precipitation.

Climate Change Impacts Potentially Affecting Remediation Vulnerability

Precipitation:
- *Increased heavy precipitation events*
- *Increased flood risk*
- *Decreased precipitation & increasing drought*
- *Increased landslides*

Temperature:
- *Increased occurrence of extreme temperatures*
- *Sustained changes in average temperatures*
- *Decreased permafrost*

Sea level rise

Wind:
- *Increased intensity of hurricanes*
- *Increased intensity of tornados*
- *Increased storm surge intensity*

Wildfires:
- *Increased frequency & intensity*

Office of Solid Waste and Emergency Response
Climate Change Adaptation Implementation Plan,[6] Appendix A (adaptation)

Consideration of the materials deposited in floodplains, whether called sediment or soil, is critical to reducing risk in aquatic environments. Effective control of the upland sediment/soil and other upland source materials is also critical. Accordingly, many measures to increase resilience of an aquatic sediment remediation system concern the adjoining upland environment.

Sediment and surface water systems are dynamic. As a result, development of a robust conceptual site model (CSM) during remedial investigation and frequent CSM updating during the feasibility study and remedial design are critical in planning climate change adaptation for sediment cleanups. At most Superfund sites involving contaminated sediment, completing a sediment erodibility and deposition assessment (SEDA) will be an important part of developing or refining the CSM; the U.S. Army Corps of Engineers (USACE) recently published detailed technical guidelines for conducting a SEDA.[8]

Information to help develop and maintain a robust CSM is available in *Environmental Cleanup Best Management Practices: Effective Use of the Project Life Cycle Conceptual Site Model*.[7]

The process of incorporating potential climate change scenarios and impacts into a site's CSM may involve using predictions or other information previously compiled through one or more climate change models. The information may consist of data that could be integrated into other tools such as groundwater models or of qualitative information that could be used to generally inform CSM decision-making.

Dynamic information concerning climate change predictions and related impacts derived through existing climate change models is readily available from several federal agencies to help screen potential hazards. More information may be available from state or municipal agencies, regional or local sources such as watershed and forestry management authorities, non-profit groups and academia. Geographic scales of available information vary, ranging from specific regions of the United States or individual states to smaller jurisdictions such as counties or cities and in some cases neighborhoods (based on latitude/longitude). Projections derived through tools employing a general circulation model may benefit from down-scaling in order to achieve the optimal spatial resolution for a given site.[9]

Online Tools for Vulnerability Evaluation

Federal agencies such as EPA, the National Oceanic and Atmospheric Administration (NOAA) and the Federal Emergency Management Agency (FEMA) offer dynamic online information that is frequently updated to help evaluate vulnerability to climate change impacts; links for key information resources are available at:

www.epa.gov/superfund/climatechange/resources

The likelihood for potential climate change hazards to reduce effectiveness of a sediment remedy system can be evaluated through a **climate-change sensitivity assessment**. Potential direct impacts of the hazards include interruption of power for ongoing activities, physical or water damage to remedial components (including machinery and equipment) and reduced access to the site or remediation system. Direct impacts also may concern relatively long-term changes in site conditions. For example, sites subject to sustained sea level rise may experience slumping of banks and increased sediment deposition in floodplains and littoral zones. Potential indirect impacts of the hazards may include land use shifts and ecosystem damage.

Points of potential vulnerability may concern underwater components of the remediation system; upland components of the remediation system; and the system's construction, monitoring and operation in context of the site infrastructure (Table 1).

Table 1. Considerations for Sensitivity Assessment of a Sediment Remediation System

Examples of System Components		Potential Vulnerabilities			
		Power Interruption	Physical Damage	Water Damage	Reduced Access
Underwater Components	Habitat layer, armor layer, amendment, geotextile or isolation layer in an in situ cap		◆		◆
	Amendment for binding or degrading contaminants		◆		◆
	Clean sediment layer overlaying contaminated sediment, as part of MNR or EMNR		◆		◆
Upland Components	Bank stabilization structures		◆	◆	◆
	Floodplain cap(s)		◆	◆	◆
Remedy Construction, Operation and Maintenance	Exposed in-place vessels such as barges or tugs and equipment used to dredge or place caps and amendments	◆	◆	◆	◆
	Monitoring equipment	◆	◆	◆	◆
	Exposed machinery and vehicles		◆	◆	◆
	Sediment processing, treatment or dewatering facilities	◆	◆	◆	◆
	Fencing for access control and litter prevention		◆		
	Access roads		◆		◆
	Buildings, sheds, or housing	◆	◆	◆	◆
	Electricity and natural gas lines		◆	◆	◆
	Liquid fuel storage and transfer	◆	◆	◆	◆
	Water supplies	◆	◆	◆	◆

Depending on the site and the implemented remedial technology, overall system failures may result in:

- Loss of subaqueous cap integrity due to increased erosion associated with intense water currents and waves
- Potential damage to the sorbent layer in a reactive cap due to increasing desiccation in a shallow environment.
- Ineffective dewatering of excavated sediment

- Alteration or loss of wetland or riparian vegetation used for treatment or local buffering
- Changes to the bathymetry and patterns of erosion and sediment deposition.

Remediation of contaminated sediment at Terminal 4 (T-4) in Portland Harbor, a National Priorities List site in Oregon, has included dredging and transporting approximately 14,000 cubic yards of contaminated sediment to an offsite disposal facility and isolating contaminated sediment in a target area through installation of an organoclay-sand cap. The Port of Portland also stabilized banks along the adjoining Williamette River by installing rock armor and planting native vegetation to minimize erosion and improve stability during extreme weather conditions.

Techniques for compiling information on exposure and sensitivity and assessing overall vulnerability of a sediment remediation system may include:

- Collecting qualitative information, including photographs of system components and existing field conditions
- Extrapolating quantitative information from data in existing resources
- Conducting quantitative modeling through use of conventional software or commercially available risk assessment software for engineered systems
- Developing summary maps, tables and matrices.

Cleanup at the Pine Street Canal NPL site in Burlington, Vermont, involves an eight-acre sediment cap made of a reactive core mat and sand, habitat restoration and long-term monitoring. This 38-acres site lays along the eastern shore of Lake Champlain (aerial view at left). Output from the Storm Surge Inundation and Hurricane Strike Frequency Map[10] illustrates the site's position in a 100-year floodplain (contour at right). A weir at the onsite canal's outlet to Lake Champlain maintains a minimum water depth that protects the cap from scour and erosion during annual spring flooding, winter ice buildup and storms.

Implementation of Adaptation Measures

Results of a vulnerability evaluation may be used to develop a strategy for increasing a sediment remediation system's resilience to climate change. This involves:

- Identifying measures that potentially apply to the vulnerabilities in a range of weather/climate scenarios
- Selecting and implementing priority adaptation measures for the given sediment remediation system.

Identification of potential measures involves the screening of steps that may be taken to physically secure the system, provide additional actions or barriers to protect the system, safeguard access to the system, and alert project personnel to system compromises (Table 2). Depending on the scenario, modifications may enable many measures to address more than one aspect of an overall remediation system. Some measures also may be scaled up to encompass multiple remediation systems and critical field activities. Others may provide a desired degree of redundancy or additional safety factors incorporated into the remedial design. For the purpose of event-driven preparedness, an independent contract may be secured for accelerated access to an outboard motor-equipped boat that may be used to assess surface water conditions above a sediment treatment/capping area.

In early 2003, a severe ice jam formed upstream of a 7-acre cap that had been installed two years earlier on a pilot-scale basis in the lower Grasse River in Massena, New York. Later monitoring indicated that high-velocity and turbulent water flow created underneath the ice jam toe had scoured part of the cap and some native sediment beneath it. Although sediment transport due to severe ice jam events was not previously known for this site, subsequent studies found that ice jam events capable of scouring and redistributing contaminants (polychlorinated biphenyls [PCBs]) buried in the river sediment have occurred about once every 10 years in the upper 1.8-mile stretch of the site. Due to these findings, mechanical ice breaking along approximately seven miles of the river was conducted as an interim measure during the next significant ice jam, which occurred in 2007. Additionally, the full-scale cap design and construction specifications for the upper 2-mile stretch (encompassing 59 acres) includes a six-inch layer of sand/top soil, six-inch layer of gravel and 13-inch layer of stone that armors the subaqueous sand/topsoil cap to be placed throughout the 7-mile main channel area where PCB concentrations equal or exceed 1 milligram/kilogram.

For a new remediation system, selecting optimal measures during the design phase may maximize the system's resilience to climate change impacts throughout the project life and help avoid costly retrofits. Designs for subaqueous remedial components that are vulnerable could include, for example, adding a thicker layer of sand or clean soil in the lower isolation layer of an in situ cap in shallow water if allowed under state and local environmental programs. The design of a sediment remediation system's armor (or buffer strip) provides another example. In some states, such as New York, Maryland and Washington, vegetation replenishment or other "soft" armoring methods along shorelines are preferred over "hard" armoring methods such as riprap emplacement.[11] Measures to increase vegetation resilience may involve designing vegetated areas that are large enough to accommodate future changes in precipitation or sea level rise or adding a mix of other soft materials such as logs or root wads.

For new remedial systems to be constructed, evaluation of the vulnerability and adaptation measures may be integrated into project designs. For systems already operating, increases in erosion may signal the need to closely examine components of the sediment remediation system and re-evaluate vulnerabilities.

EPA's *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* recommends that evaluation of contaminated sediment sites should include assessing the potential impacts on sediment and contaminant movement caused by a 100-year flood and other events or forces with a similar probability of occurrence (0.01 chance of occurring in a year).[4] In considering the impacts of climate change, it is important to consider whether the future 100-year flood is expected to differ from the historical 100-year flood. Designs for vulnerable construction-phase remedial components such as emplaced sheet pile walls, for example, could include use of anchoring cables mounted on underlying bedrock. Updated floodplain maps are available online from the Federal Emergency Management Agency[12] and information on similar scenarios such as predicted sea-level changes is available from other agencies such as the USACE .[13]

In most cases, activities such as sediment dredging or excavation have a relatively short duration. Scheduling of these activities during times that are least likely to experience extreme weather events may significantly reduce a sediment remediation system's exposure.

Climate change considerations are particularly important in designs and associated modeling for in situ capping, MNR, and EMNR remedies anticipated to operate for 30 years or longer. If an area is predicted to experience increasingly frequent flooding or storm surge activity or be subject to rising sea levels, disposal of contaminated sediment offsite in an area not subject to these problems may be an option.

Table 2. Examples of Adaptation Measures

	Climate Change Impacts					**Potential Adaptation Measures for System Components** *Brief descriptions of engineered structures integral to many of the measures are available on the Superfund* ***Climate Change Adaptation*** *website.*
	Temperature	**Precipitation**	**Wind**	**Sea Level Rise**	**Wildfires**	
Underwater Components	◆	◆				**Armor enhancement for in situ cap** *Additional or deeper layers of stone and/or gravel above a sand base layer to withstand scouring forces of ice jams*
		◆	◆	◆		**Amendment settling enhancement** *In situ placement of amendments through techniques such as broadcasting the material in a pelletized form or using a thicker layer of cover sand to accelerate material settling*
		◆		◆		**Deposition controls** *Engineered structures such as dams to control the flow of flood-related deposition in settings where increased underwater deposition enhances remedy performance*
	◆	◆	◆	◆		**Modeling expansion for MNA** *Incorporation of additional subsurface parameters and sampling devices in monitoring plans to gauge the potential for re-suspension of contaminated sediment under more extreme weather/climate scenarios*
Upland Components		◆				**Armor on banks and floodplains** *Fixed structures placed on or along the shoreline of flowing inland water or ocean water to mitigate effects of erosion and protect site infrastructure; "soft" armor may comprise synthetic fabrics and/or deep-rooted vegetation while "hard" armor may consist of riprap, gabions and segmental retaining walls*
		◆	◆	◆		**Coastal hardening** *Installation of structures to stabilize a shoreline and shield it from erosion, through "soft" techniques (such as replenishing sand and/or vegetation) or "hard" techniques (such as building a seawall or installing riprap)*
		◆	◆			**Containment fortification** *Placement of riprap adjacent to a subsurface containment barrier located along moving surface water, to minimize bank scouring that could negatively affect barrier integrity; for soil/waste capping systems vulnerable to storm surge, installation of a protective vertical wall or armored base to absorb energy of the surge and prevent cap erosion or destruction*
		◆				**Ground anchorage** *One or more steel bars installed in cement-grouted boreholes (and in some cases accompanied by cables) to secure an apparatus on a ground surface or to reinforce a retaining wall against an earthen slope*
		◆	◆	◆		**Relocation** *Moving selected system components to positions more distant or protected from potential hazards; for flooding threats, this may involve elevations higher than specified in the community's flood insurance study*
		◆			◆	**Retaining wall** *A structure (commonly of concrete, steel sheet piles or timber) built to support earth masses having a vertical or near-vertical slope and consequently hold back loose soil, rocks or debris*
		◆	◆			**Tie down systems** *Installing permanent mounts that allow rapid deployment of a cable system extending from the top of a unit to ground surface*

	Climate Change Impacts					Potential Adaptation Measures for System Components *Brief descriptions of engineered structures integral to many of the measures are available on the Superfund **Climate Change Adaptation** website.*
	Temperature	Precipitation	Wind	Sea Level Rise	Wildfires	
Remedy Construction, Operation and Maintenance		◆		◆		**Flood controls** *Building one or more earthen structures (such as vegetated berms, vegetated swales, stormwater ponds, levees, or dams) or installing fabricated drainage structures (such as culverts or French drains) to retain or divert floodwater spreading from adjacent surface water or land surface depressions*
		◆	◆	◆		**Hurricane straps** *Integrating or adding heavy metal brackets that reinforce physical connection between the roof and walls of a building, shed or housing unit, including structures used for leachate and LFG management*
	◆	◆	◆	◆	◆	**Plantings** *Selecting native grasses, shrubs, trees and other deep-rooted plants that are resistant to drought or increased temperatures where vegetation is used for shading, erosion control or wind breaks or for treatment or local buffering in wetland or riparian settings*
	◆	◆	◆	◆	◆	**Power from off-grid sources** *Constructing a permanent system or using portable equipment that provides power generated from onsite renewable resources, as a primary or redundant power supply that can operate independent of the utility grid when needed*
	◆	◆	◆	◆		**Renewable energy system safeguards** *Extended concrete footing for ground-mounted photovoltaic (PV) systems, additional bracing for roof-top PV or solar thermal systems, and additional masts for small wind turbines or windmills; for utility-scale systems, safeguards to address climate change vulnerabilities may be addressed in the site-specific renewable energy feasibility study*
	◆	◆	◆		◆	**Utility line burial** *Relocating electricity and communication lines from overhead to underground positions, to prevent power outages during and often after extreme weather events*
	◆	◆	◆	◆	◆	**Weather alerts** *Electronic systems that actively inform subscribers of extreme weather events or provide Internet postings on local/regional weather and related conditions*

The process of **selecting optimal measures** for a sediment remediation system may consider remedial aspects such as:

- ✓ Complexity and scale of the project
- ✓ Complexity of erosion controls or adjacent drainage areas
- ✓ Complexity of in-place monitoring systems
- ✓ Anticipated duration of remedial system operations
- ✓ Existing infrastructure components such as roads, power and water supplies
- ✓ Primary and back-up means of access
- ✓ Project aspects affecting future land use or development
- ✓ Anticipated effectiveness and longevity of the potential measures
- ✓ Capital cost and operation and maintenance (O&M) cost.

Selected measures may be integrated into primary or secondary documents supporting existing remediation systems, such as monitoring plans, optimization evaluations, five-year reviews and close-out planning materials. For new systems to be constructed, the measures also may be integrated into the site's feasibility study and remedy design process. Significant or fundamental changes may need formalization through a decision document (such as a record of decision amendment) or a permit modification. In general, implementation of adaptation measures during early rather than late stages of the cleanup process may expand the universe of feasible options, maximize integrity of certain measures, and in some cases reduce implementation costs.

To be most effective, adaptation should be an iterative and flexible process that involves periodically re-evaluating the sediment remediation system's vulnerability, monitoring the measures already taken, and incorporating newly identified options or information into the adaptation strategy. Periodic re-evaluations should include verifying key data; for example, predictions for increased frequency of intense inland surface water currents and tides may prompt upgrades to subaqueous capping armor, as could the changing patterns of ice versus non-ice conditions.

A sample structure for documenting evaluation of site-specific vulnerabilities, prioritizing potential adaptation measures, and monitoring implemented measures is available in ***Climate Change Adaptation Technical Fact Sheet: Groundwater Remediation Systems*** (EPA 542-F-13-004).[2]

Effective adaptation planning also considers how climate change may affect short- and long-term availability of clean water and ecosystem services as well as land uses that may be critical aspects of the maintenance of a sediment remediation system.[14] Information about related data and government and/or private sector partnerships is available to the site cleanup community, local or regional planners, and the general public through the recently launched U.S. Climate Data Initiative.[15]

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[Web access date: April 2015]

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To learn more about climate change adaptation at Superfund sites and access new information and decision-making tools as they become available, visit:

www.epa.gov/superfund/climatechange

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