

Climate Resilience Technical Fact Sheet: Contaminated Sediment Sites

In June 2014, the U.S. Environmental Protection Agency (EPA) released the *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 Superfund Program, existing processes for planning and implementing site remedies provide a robust structure that allows consideration of climate change effects. Examination of the associated implications on site remedies is most effective through use of a place-based strategy due to wide variations in the hydrogeologic characteristics of sites, the nature of remediation systems operating at contaminated sites, and local or regional climate and weather regimes. Measures to increase resilience to a changing climate may be integrated throughout the Superfund process, including feasibility studies, remedy designs and remedy performance reviews.

As one in a series, this fact sheet addresses the climate resilience of Superfund remedies at sites with contaminated sediment. It is intended to serve as a site-specific planning tool by (1) describing an approach to assessing potential vulnerability of a sediment remedy, (2) providing examples of measures that may increase resilience of a sediment remedy, and (3) outlining steps to assure adaptive capacity of a sediment remedy as climate conditions continue to change. Concepts described in this tool may also apply to site cleanups conducted under other regulatory programs or through voluntary efforts.

Cleanup at many sites involves remediating contaminated aquatic sediment – the clay, silt, sand and organic matter at the bottom of or along the banks of rivers, lakes, estuaries, harbors or other surface water bodies. Common sediment remediation technologies are dredging or excavation with off-site treatment or disposal, capping to isolate contaminated sediment, and application of amendments that bind or destroy the contaminants.² Excavation is similar to dredging but includes partial dewatering of the sediment. Dewatering is accomplished by diverting water from the targeted area of a water body or constructing a coffer dam around the area, thereby allowing use of conventional construction equipment to remove the contaminated sediment.

In situ capping involves placing clean material on top of contaminated material remaining in place on a water body floor or at adjacent areas, which are often situated within the site’s floodplains. 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 an organoclay or activated carbon mat that binds or sequesters contaminants exiting the sediment pore water and thereby prevents contaminant release to surface water. Other in situ remedies involve monitored natural recovery (MNR) or enhanced MNR (EMNR). MNR relies on the site’s naturally occurring physical, chemical and biological processes to contain, destroy or otherwise reduce bioavailability or toxicity of contaminants in sediment. EMNR involves placing a thin layer of clean sediment or additives above contaminated sediment to accelerate contaminant transformation to less toxic or bioavailable compounds.

Climate resilience planning for a sediment remedy generally involves:

- (1) Assessing vulnerability of the remedy’s elements and site’s infrastructure.
- (2) Evaluating measures potentially increasing the remedy’s resilience to a changing climate.
- (3) Assuring the remedy’s capacity to adapt to a changing climate, which helps the remedy continue to be protective of human health and the environment (Figure 1).

Resilience: A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment.³



Figure 1. Climate Change Adaptation Management

Assessment of Sediment Remedy Vulnerability

Assessing a sediment remedy's vulnerability to the effects of climate change involves:

- Determining the remedy's exposure to climate or weather hazards.
- Determining the remedy's sensitivity to the hazards.

A **climate change exposure assessment** identifies particular hazards of concern and characterizes exposure to those hazards in light of various climate and weather scenarios. The hazards may arise abruptly due to extreme weather events, such as:

- Scour of a sediment cap or underlying sediment due to increased surface water flow velocity or turbulence caused by an intense storm.
- Influx of urban or agricultural stormwater runoff into the sediment containment or treatment zone due to prolonged or intense rainfall or rapid snowmelt.
- Entrance of additional waste or debris from upland or upstream sources due to flooding, intense wind or landslide.
- Increased water turbidity in a treatment zone due to high wind in shallow water or arrival of increased discharge to the watershed.
- Misinterpretation of sediment sampling conducted via passive devices, which might be affected by short-term events such as storms.⁵

Other climate-related hazards may arise gradually, such as:

- Desiccation of an unsubmerged sediment cap due to sustained drought conditions.
- Exposure of a riverine cap due to sustained decreases in channel flow.
- Scour of a sediment cap due to sustained freeze conditions.
- Increased interaction with groundwater due to more frequent heavy rainfalls generating more discharge.
- A sustained change in the freshwater-saltwater boundary at a coastal site due to a rising sea level.

The hazards also may concern potential resuspension and transport of contaminated sediments during construction of a remedy or its long-term operation. In near-shore lake and marine settings, sediment transport may be particularly affected by wave energy flux, tidal energy flux, wind forced currents, and subsurface currents as well as the topography of a water body floor.² Other hazards may concern onsite or offsite anthropogenic stressors, such as land development that removes vegetated windbreaks and other natural protective barriers or causes infill subsidence in low-lying areas. Unchecked stormwater runoff in highly developed areas has the potential to increase pollutant loads as well as enable sediment recontamination at a site. Evaluation of stormwater runoff volumes and pollutant loadings in developed areas need to consider a wide range of rain conditions rather than only large storms.⁷

Dynamic information about climate and weather variabilities and trends across the United States is available from several federal agencies to help screen potential hazards in a given spatial area and identify those of concern. Web-based platforms and tools include:

- U.S. Army Corps of Engineers (USACE) methods such as the *Climate Hydrology Assessment Tool*.
- U.S. Geological Survey (USGS) resources such as *StreamStats*.
- National Oceanic and Atmospheric Administration (NOAA) resources such as *Digital Coast*, *Sea Level Trends and Sea, Lake and Overland Surges from Hurricanes (SLOSH)*.

Information also may be available from state agencies, regional or local sources such as watershed and forestry management authorities, non-profit groups and academia.

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed; its sensitivity; and its adaptive capacity.³

Changing climate conditions include sustained changes in average temperatures, increased heavy precipitation events, increased coastal flooding, increased intensity of storm surge, sea level rise and increased wildfire severity.⁴ A vulnerability assessment helps project decision makers:

- Understand which conditions may change at a site.
- Understand how altered conditions may affect the site remedy.

About one-half of recently selected sediment remedies involve treatment via physical separation processes. Of these, dewatering accounts for about one-half and oil/water separation and mechanical sorting account for the remainder.⁶

A climate change sensitivity assessment for a sediment remedy evaluates the likelihood for the climate change hazards of concern to reduce the remedy’s effectiveness. Potential direct effects of hazards associated with an extreme weather event include power interruption, physical damage, water damage and reduced accessibility. The indirect effects include hazardous incidents such as a chemical spill or explosion as well as altered site conditions such as denuded vegetation.

Repeated exposure to extreme weather events or gradual changes in the site’s climate regime may affect the remedy or site in additional ways. For example, sites subject to sustained sea level rise may experience slumping of banks, increased sediment deposition in floodplains and littoral zones, and greater saltwater intrusion. Over time, a site may experience other related changes such as a modification in its allowable use or an alteration of its ecosystem services.

Depending on the site and the implemented remedial technology, overall failures of the remedy components may result in:

- Recontamination of sediment due to escape of capped material.
- Contamination of surface water due to incomplete binding or sequestering of contaminants within a reactive cap’s isolation layer.
- Migration of contaminants from sediment to groundwater via sediment pore water.
- Transport of resuspended/contaminated sediment to downstream or inland areas that were previously uncontaminated.
- Contamination of upland sediment or soil due to escape of excavated sediment from holding areas or engineered treatment cells.
- Delayed recovery of benthic communities.
- Loss of wetland or riparian vegetation used for treatment or local buffering.
- Incomplete or excess dredging of sediment.
- Unexpected and additional costs for repairing or amending sediment caps, performing additional dredging or excavation/dewatering, or upgrading onsite infrastructure elements such as transportation corridors or equipment storage areas.

Of the remedies selected for sediment sites in fiscal years 2012 through 2014, about 44 percent address polycyclic aromatic hydrocarbons, 44 percent address polychlorinated biphenyls, and more than 75 percent address metals.⁶

Dredging or excavation of sediment is involved at more than 80% of the large sediment sites known as “Tier 1” sites, where remedial actions are addressing more than 10,000 cubic yards or five acres of contaminated sediment.⁶

A temporary armored cap was installed at the **San Jacinto Waste Pits** National Priorities List (NPL) site outside Houston, Texas, in 2011 to cover waste containing dioxins and furans. This coastal site near Galveston Bay receives an average of 54 inches of rain annually and is vulnerable to tides, winds, waves and currents resulting from extreme weather conditions such as strong storms, flooding, tornadoes and hurricanes. About 50 percent of the cap is submerged in the San Jacinto River.

In 2017, the site experienced 500-year flood conditions due to Hurricane Harvey. Post-hurricane assessment indicated damage to submerged as well as above-water portions of the cap, including its geotextile layer and rock armor. About 1,000 tons of rock was placed in 36 damaged areas to temporarily armor the cap.

The remedy selected later in 2017 involves removal and offsite disposal of material in the existing waste impoundments and MNR in an area with low levels of contamination. Selection of the remedy considered Galveston Bay’s predicted 2.1 feet rise in sea level by 2100 as well as USACE hydrodynamic models of the site during past storm and hurricane conditions. Modeling of remedial alternatives involving waste caps projected significant erosion of cap armor under combined hurricane and flood conditions.



Repair of the San Jacinto Waste Pits cap armor following Hurricane Harvey.

Vulnerable points of a sediment remedy due to extreme weather events may concern the remedy’s submerged components, its upland components, or site infrastructure critical to the remedy’s construction, monitoring and operation (Table 1). For example, reduced access to a site due to flooding of access roads could delay critical post-storm inspection of a sediment cap.

Table 1. Considerations for Sensitivity Assessment of a Sediment Remedy

Examples of Remedy Components		Potential Vulnerabilities Due to Extreme Weather			
		Physical Damage	Water Damage	Power Interruption	Reduced Access
Submerged Components	Geotextile layer(s) and armor of an in situ cap	◆			◆
	Activated carbon in the insulation layer of a reactive cap	◆			
	Clean sediment layer overlaying contaminated sediment for EMNR	◆			
Upland Components	Dikes enclosing an engineered unit that stores dredged or excavated material	◆			◆
	Bank or slope stabilization structures such as riprap revetment, steel nets or terrace stoplogs	◆	◆		◆
	Subsurface barriers made of cement slurry or sheet piles	◆	◆		◆
Site Operations and Infrastructure	Temporary piers or water containment booms	◆			
	Barges and tugs used to dredge contaminated sediment	◆	◆		◆
	Exposed construction machinery and vehicles	◆	◆		◆
	Monitoring equipment	◆	◆	◆	◆
	Sediment dewatering and treatment facilities	◆	◆	◆	◆
	Fencing and signs for controlling access or use	◆			
	Access roads	◆			◆
	Buildings, sheds or housing	◆	◆	◆	◆
	Liquid fuel storage units	◆	◆		◆
	Water supplies	◆	◆	◆	◆

Techniques for assessing potential vulnerability of a sediment remedy may include:

- Collecting qualitative information such as photographs of submerged or upland components and current field conditions.
- Extrapolating quantitative data documented in resources such as NOAA or USGS mapping systems.
- Modeling that uses predictive weather and climate data, through use of conventional software or commercially available risk assessment software for engineered systems.
- Developing site-specific maps and matrices that can aid decision-making.

Detailed information about climate-related vulnerability assessment and access to associated tools is provided in resources such as the:

- *U.S. Climate Resilience Toolkit* for exploring hazards and assessing vulnerability and risks.
- *Climate Change 2014: Impacts, Adaptation and Vulnerability* report from the Intergovernmental Panel on Climate Change, which includes a chapter (19) on assessing emergent risks and key vulnerabilities.

More examples of relevant tools and other resources are described online at **Superfund Climate Resilience: Vulnerability Assessment**.

As an illustration, Figure 2 highlights results of a preliminary vulnerability assessment for a sediment remedy currently in place at a Superfund site. The illustration identifies potential disruptions to the remedy components due to extreme weather events and provides a sample structure for documenting high-priority resilience measures that could be implemented in the near term. Planning tools such as this also may be used to build additional adaptive capacity over time.

This sample cleanup scenario involves a 50-acre Superfund site in an industrial area situated on a Mid-Atlantic shoreline. Contaminants remain from past onsite disposal of industrial waste, including contaminated sludge that was disposed of in an estuarine wetland. The soil, sediment and groundwater contaminants include metals, polynuclear aromatic hydrocarbons, dioxins and pentachlorophenol and associated dense non-aqueous phase liquid (DNAPL).

The remedy involves MNR in a portion of the wetland, sludge removal from other parts of the wetland via dredging, a gravel cover for contaminated soil in the former disposal area, in situ solidification/stabilization of DNAPL-contaminated soil, and a groundwater collection system with supporting storm sewer upgrades. Following onshore solidification via cement mixing, a portion of the dredged sediment will be used to cover a highly contaminated area of the river.

The majority of the site is within a 100-year floodplain and its elevation currently ranges from sea level to 9.5 feet above mean sea level. Public information sources indicate that potential hazards for this scenario include flooding due to storm surge and high tides, partial inundation due to sea level rise, and high winds associated with hurricanes. For example, predictions of sea level rise in the area estimate a rise of 3.9 to 8.9 feet by the year 2100. In combination with site-specific data existing in materials such as site investigation reports and the Superfund record of decision, professional judgment is used to identify and prioritize resilience measures for this remedy.

Potential Points of System Vulnerability		Potential System Disruption Due to Extreme Weather				Resilience Measures for High-Priority Vulnerabilities
		Physical Damage	Water Damage	Power Interruption	Reduced Access	
Submerged or Subsurface Components	Solidified sediment layer of cap placed within the river	●				Use predictive storm surge data to model potential wave- and tide-related scour
	Wells for groundwater collection or monitoring	○			○	
	Sheet-pile vertical barrier for groundwater control	○				
Aboveground Components	Layer of gravel covering contaminated soil	●				Maximize thickness of the gravel layer to prevent water-related erosion
	Leachate collection system for soil cover	●				Size the leachate evaporation pond to hold increasing generation of leachate
	Containment area storing dredged sediment	●				Enclose the area with an earthen berm to protect it from stormwater runoff
	In situ soil/cement mixing area	●				Construct a bulkhead to protect the area from storm surge
Site Operations and Infrastructure	Water containment booms	◐			○	
	Barge used for sediment dredging	◐			◐	
	Sediment dewatering equipment	●			◐	Construct wind- and water-resistant housing for the equipment
	Machinery and trucks used to transfer material offsite	○			○	
	Liquid fuel storage units	●			◐	Relocate and anchor the units on higher ground
	Connection to municipal sewage system	◐			○	
		● <i>high priority</i>	◐ <i>medium priority</i>	○ <i>low priority</i>		

Figure 2. Illustrative Superfund Site Scenario: Vulnerability Assessment Results and Prioritized Adaptation Measures

Evaluation of Potential Climate Resilience Measures

Results of a vulnerability assessment may be used to develop a strategy for increasing a contaminated sediment remedy's resilience to a changing climate and extreme weather events. Development of the strategy entails:

- Identifying resilience measures potentially applying to the hazards of concern under various climate and weather scenarios.
- Prioritizing resilience measures for specific components of the remedy.

Effective mitigation of climate change hazards for a sediment remedy involves a site-specific analytical approach rather than a broad prescriptive plan.

Identification of potential resilience measures involves screening of steps that may be taken to physically secure remediation components, provide additional barriers to protect the components, safeguard access to the components or alert project personnel of remedy compromises (Table 2).

Some of the measures may address more than one climate or weather scenario. For example, installing tie-down systems for metal sheds that house remediation equipment would reduce likelihood for the structures to be turned over or carried away by moving floodwater or intense wind. Other measures could address multiple components of a remedy. Constructing vegetated berms outside the perimeter of a sediment cap, for example, could protect the cap from stormwater crossing the site while protecting an adjoining wetland from airborne debris carried by intense wind. Yet other measures could be scaled up to address multiple hazards. One example is the rock layer typically used to armor a sediment cap from adjacent surface water; extending the armor length to the cap's full perimeter would protect the cap from upland stormwater runoff as well as storm surge.

In most cases, 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 remedy's exposure.

Measures to prevent erosion on the banks of surface water bodies due to intense rainfall, rapid snowmelt, or intense wind may involve installing "hard" armor such as stone riprap, "soft" armor such as plants, or a combination of hard and soft armor.⁸ The U.S. Federal Emergency Management Agency (FEMA) *Engineering with Nature: Alternative Techniques to Riprap Bank Stabilization* describes a range of alternatives to riprap, such as constructing engineered logjams, structural earth walls and brush mattresses.⁹ Construction or expansion of an onsite wetland is another important option. In addition to minimizing erosion along shores or banks, wetlands can buffer the impacts of extreme wind, serve as floodwater storage areas, and filter nonpoint source pollutants and sediment from stormwater runoff.¹⁰

Descriptions of engineered structures commonly used in climate resilience measures are available online at [Superfund Climate Resilience: Resilience Measures](#).

For a newly identified remedy, selecting optimal measures during the design phase may maximize the remedy's resilience to climate change hazards throughout the project life and help avoid costly retrofits. For example, designs for an aquatic sediment cap may need to consider greater seasonal variation or sustained changes in conditions of the given environment, such as water temperatures, depths or salinity. Environmental conditions such as these directly affect the specific zone of bioturbation where significant physical mixing of sediment takes place; this biologically active layer of surface sediment often drives the level of exposure to contaminants. Other design considerations include assessing aquatic sediment movement due to future changes in tides, flooding, ice-related scour, oscillation of lake elevation caused by sustained winds, storm-generated waves and currents, seismic-generated waves, and earthquakes and associated landslides.

EPA's *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* recommends that contaminated sediment site evaluations 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). It is important to consider whether the future 100-year flood is expected to differ from the historical 100-year flood. Updated floodplain maps are available online from FEMA.¹¹

Table 2. Examples of Climate Resilience Measures

	Climate Change Effects					Potential Climate Resilience Measures for a Contaminated Sediment Remedy
	Temperature	Precipitation	Wind	Sea Level Rise	Wildfires	
Submerged or Subsurface Components	◆	◆	◆	◆		Armor enhancement for in situ cap <i>Replacing additional stone and gravel above a sand base layer to withstand scouring forces of more intense waves and currents or more frequent development of ice jams</i>
	◆	◆	◆			Amendment scheduling optimization <i>Applying materials intended for long-term contaminant binding or destruction far in advance of (or after) seasons that typically bring low temperatures, high winds or high precipitation, to maximize the time available for amendment-sediment mixing without interference from conditions such as more intense tidal action or ice scour</i>
		◆		◆		Deposition controls <i>Building engineered structures such as dams to control the flow of flood-related deposition in settings where increased underwater deposition enhances remedy performance</i>
	◆	◆	◆	◆		Modeling expansion for MNR and EMNR <i>Incorporating additional subsurface parameters and sampling devices in monitoring plans to gauge the potential for resuspension of contaminated sediment under more extreme weather and changing climate scenarios</i>
Upland Components		◆	◆	◆		Armor on banks and floodplains <i>Installing fixed structures 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 deep-rooted vegetation, while hard armor may consist of riprap, gabions and segmental retaining walls</i>
		◆	◆	◆		Coastal hardening <i>Installing structures to stabilize a shoreline and shield it from erosion through soft techniques such as replenishing sand and vegetation or hard techniques such as building a seawall or installing riprap</i>
		◆	◆	◆		Constructed wetlands <i>Creating swamps, marshes, bogs or other areas vegetated with plants that are adapted for life in saturated soils and therefore capable of reducing the height and speed of floodwaters and providing buffer from wind or wave action and storm surge</i>
		◆	◆			Containment fortification <i>Placing riprap adjacent to a subsurface containment barrier located along moving surface water, to minimize bank scouring that could negatively affect barrier integrity; for a sediment cap vulnerable to storm surge, installing a protective vertical wall or armored base to absorb energy of surges and prevent cap erosion or destruction</i>
		◆				Ground anchorage <i>Installing one or more steel bars 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</i>
		◆	◆	◆		Relocation <i>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</i>
		◆			◆	Retaining wall <i>Constructing a structure (commonly of concrete, steel sheet piles or timber) that can support earth masses having a vertical or near-vertical slope and consequently hold back loose soil, rocks or debris</i>
		◆	◆			Tie down systems <i>Installing permanent mounts that allow rapid deployment of a cable system extending from the top of a unit to ground surface</i>

	Climate Change Effects					Potential Climate Resilience Measures for a Contaminated Sediment Remedy
	Temperature	Precipitation	Wind	Sea Level Rise	Wildfires	
Remedy Construction, Operation and Maintenance		◆		◆		Flood controls <i>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</i>
		◆	◆	◆		Hurricane straps <i>Integrating heavy metal brackets that reinforce physical connection between the roof and walls of a building, shed or housing unit</i>
	◆	◆	◆	◆	◆	Plantings <i>Selecting native grasses, shrubs or trees that are tolerant of future weather and climate scenarios where vegetation is needed for groundcover, shading, erosion control or wind breaks</i>
	◆	◆	◆	◆	◆	Power from off-grid sources <i>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</i>
	◆	◆	◆	◆		Renewable energy system safeguards <i>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</i>
	◆	◆	◆		◆	Utility line burial <i>Relocating electricity and communication lines from overhead to underground positions, to prevent power outages during and often after extreme weather events</i>
	◆	◆	◆	◆	◆	Weather alerts <i>Using electronic systems that actively inform subscribers of extreme weather events or provide updated Internet postings on local/regional weather and related conditions</i>

The process of identifying and prioritizing potential measures for a sediment remedy at any phase of its implementation may consider:

- Unique topography of the site.
- Age of any remedy components already in place.
- Climate adaptation plans of local or regional agencies.
- Existing infrastructure components such as navigation channels, access roads, and power and water supplies.
- Current and future use or development of the site as well as adjacent properties.
- Anticipated longevity of the potential measures.
- Capital cost and operations and maintenance cost, as well as costs associated with potential repair or replacement of remedy components due to weather- or climate-related damage in the future.

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.

Prioritization of resilience measures may necessitate professional judgements regarding other aspects such as:

- Critical versus non- or marginally-critical equipment, activities or infrastructure.
- Minimum performance thresholds for remedial or site operations.
- Levels of tolerance for operational disruptions.

The **Atlantic Wood Industries Superfund Site** of Portsmouth, Virginia, is located in and along the Southern Branch of the Elizabeth River tidal estuary. Onsite contamination resulted from past use of the site for commercial wood-treating and U.S. Navy waste disposal. Remediation of the contaminated sediment involves dredging and excavation, with onsite capping of dredged material that is consolidated behind two offshore pile walls.

Measures to reduce the remedy's vulnerability to sea level rise and storm surge-related flooding include:

- Increasing design height of the offshore pile wall to 12.5 feet above mean sea level, rather than the 10- to 12-foot height traditionally used in the area.
- Constructing grassed swales on upland sides of the offshore pile walls to collect and convey stormwater runoff.
- Designing the sediment cap to withstand continuing sea level rise; NOAA-funded modeling conducted for the City of Portsmouth in 2013 predicts a rise of 1.0-1.7 feet by 2050 and 2.5-6.3 feet by 2100.



One of two berms confining dredged sediment at the Atlantic Wood Industries Superfund Site in Portsmouth, Virginia.

Adaptive Capacity: The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.³

Assurance of Adaptive Capacity

Assuring the adaptive capacity of a contaminated sediment remedy involves:

- Implementing new or modified measures to increase climate resilience of the system or site operations and infrastructure, as needed.
- Establishing plans for periodically reassessing the system and site vulnerabilities, to determine if additional capacity is needed as cleanup progresses and climate conditions change.

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 thereafter are critical in assuring a remedy's adaptive capacity. At most Superfund sites involving contaminated sediment, completing a sediment erodibility and deposition assessment (SEDA) is an important part of developing or refining the CSM; the USACE offers detailed technical guidelines for conducting a SEDA.¹²

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.¹³

Climate resilience measures that are selected for implementation may be integrated into primary or secondary documentation supporting existing containment systems. Key documentation includes monitoring plans, optimization evaluations, five-year reviews and close-out planning materials. Resilience planning also may involve incorporating specific requirements to be met in cleanup service contracts. In general, implementation of climate resilience measures during early, rather than late, stages of the cleanup process might expand the universe of feasible options, maximize integrity of certain measures and reduce implementation costs. Upfront planning also could enable the measures to benefit the site's anticipated reuse. For example, climate-resistant plantings at an urban riverfront property undergoing cleanup may be integrated into master plans for future redevelopment of the site for retail or residential use.

Assurance of sufficient adaptive capacity is an iterative and flexible process. It involves periodically reassessing the system's vulnerability, monitoring the measures already taken and incorporating newly identified options or information. Periodic reassessments typically include verifying key data. For example, predictions of colder winter temperatures and associated ice jams in channels connected to the Great Lakes could prompt upgrades to the armor of an existing subaqueous cap. Established plans for the timing of vulnerability reassessment may involve a predetermined schedule or use triggers such as an extreme weather event.

For systems already operating, increases in erosion may signal the need to closely examine components of the sediment remedy and reevaluate vulnerabilities.

Resources to help understand climate resilience planning and implementation are available through online compendiums such as:

- ▶ *ARC-X* (EPA's Climate Change Adaptation Resource Center), which provides online access to tools that help communities anticipate, plan for and adapt to the changing climate.
- ▶ The NOAA *National Centers for Environmental Information*, which provides multiple climate and weather datasets and monthly summaries of U.S. temperatures and precipitation.
- ▶ EPA's *Addressing Climate Change in the Water Sector* website, which provides information pertaining to climate change impacts on water cycles and access to the State Water Agency Practices for Climate Adaptation Database.

The concepts, tools and examples provided in such compendiums may be used to tailor climate resilience planning for a specific waste containment remediation system. Resources such as these also may serve as a guide in assuring that the measures align with climate adaptation actions taken by relevant state, regional or local agencies. The Port Authority of New York and New Jersey, for example, established a methodology for factoring projected future sea level rise into its project design criteria.¹⁴ Over recent years, coastal communities also have collaborated in using the Sea Level Affecting Marshes Model (SLAMM) to develop specific plans for responding to the issue of sea level rise.¹⁵

More examples of tools to help assure adaptive capacity of a site remedy are described online at [Superfund Climate Resilience: Adaptive Capacity](#).

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[Web access date: October 2019]

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

www.epa.gov/superfund/superfund-climate-resilience

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