EPA United States Environmental Protection Agency

Office of Superfund Remediation and Technology Innovation
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Climate Change Adaptation Technical Fact Sheet: Groundwater Remediation Systems

In February 2013, the U.S. Environmental Protection Agency (EPA) released the draft *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. To answer a related question, "*How is climate change likely to affect the ability of the Superfund Program to achieve its mission and strategic goals?*" EPA's Office of Superfund Remediation and Technology Innovation (OSRTI) conducted a screening analysis to identify climate change impacts most likely to affect remedies that are commonly used for contaminated groundwater, soil, or sediment; evaluate associated vulnerabilities of the remedies; and establish climate change adaptation strategies for new and existing remediation systems. Based on the findings, OSRTI developed a preliminary Superfund climate change adaptation action plan that is integral to a broader plan proposed in 2013 by EPA's Office of Solid Waste and Emergency Response.[2]

Existing processes for Superfund cleanup planning and implementation provide a robust structure that allows consideration of climate change impacts. Due to wide variation in the location and geophysical characteristics of contaminated sites, the nature of remedial actions at those sites, and local or regional climate and weather regimes, the process of considering climate change impacts and potential adaptation measures is most effective through use of a place-based strategy. Climate change vulnerability analyses and adaptation planning may be integrated throughout the Superfund process, including feasibility studies, remedial designs and remedy performance reviews.

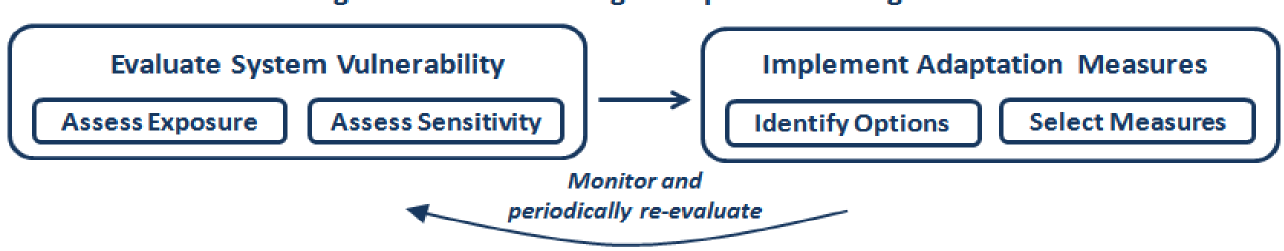
A key component of the preliminary Superfund climate change adaptation action plan involves developing tools that can help project managers and other cleanup stakeholders to identify, prioritize and implement site-specific measures for increasing remedy resilience to climate change impacts.

As the first in a series, this fact sheet addresses remedies involving groundwater remediation systems. 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. Concepts addressed in this tool may also apply to site cleanups conducted under other regulatory programs or through voluntary efforts. [a]

Groundwater remediation systems are a common element of contaminated site cleanup projects and may function *ex situ* and/or *in situ. Ex situ* processes often involve extracting contaminated groundwater from an aquifer and transferring it to an aboveground system where the water is treated; this approach is commonly known as "pump and treat" (P&T). In contrast, *in situ* processes typically involve injecting reagents directly into the subsurface to promote desired biological or chemical reactions in contaminated groundwater. *In situ* methods also may require construction and use of a well network and underground pumping systems. At some sites, vertical barriers or other engineered structures may be installed below ground surface to control groundwater flow or establish distinct reactive zones. Climate change adaptation for a groundwater treatment or containment system generally focuses on (1) evaluating the vulnerability and (2) implementing adaptation measures, when warranted, to ensure that the remedy continues to prevent human or environmental exposure to contaminants of concern (Figure 1).

> Effective mitigation of potential climate change impacts on a groundwater remediation system involves a site-specific analytical approach rather than a broad prescriptive plan.

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 Groundwater Remediation System Vulnerability

Evaluation of a groundwater treatment or containment system's vulnerability to climate change may involve:

- Identifying climate change hazards of concern
- Characterizing the system's exposure to those hazards of concern
- Characterizing the system's sensitivity to the hazards of concern
- Considering factors that may exacerbate the system's exposure and sensitivity, such as a long operating period.

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]

A **climate-change exposure assessment** identifies climate change hazards of concern for a treatment or containment system in light of potential climate/weather scenarios. Dynamic information relevant to specific locations is readily available from several federal agencies to help screen potential hazards and identify those of concern (Table 1). More information may be available from state agencies, regional or local sources such as watershed and forestry management authorities, non-profit groups, and academia. Exposure assessment may also include evaluating potential anthropogenic stressors; for example, future land development could remove natural protective barriers or cause infill subsidence in low-lying areas.

Climate Change Impacts

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

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

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

Wildfires:
- *Increased frequency & intensity*

Sea level rise

Office of Solid Waste and Emergency Response Climate Change Adaptation Plan (draft),[2] Appendix A (adaptation)

Table 1. Examples of Information Resources

Temperature	Precipitation	Wind	Sea Level Rise	Wildfires	Information Resources and Type of Information Available (►) for Applicable Impact (◆) *(Accessible via hyperlinks provided below and at* http://www.epa.gov/superfund/climatechange)
◆	◆		◆		EPA ***Climate Change Indicators in the United States*** website ► Information on "weather and climate" indicators relating to temperatures, precipitation and drought as well as extreme oceanic, snowfall and ice scenarios
	◆				Federal Emergency Management Agency (FEMA) ***Map Service Center*** website ► Floodplain maps
		◆		◆	National Interagency Coordination Center ***National Interagency Fire Center*** website ► Regional outlooks on wildlife activity and maps of current fire locations
	◆				National Integrated Drought Information System ***U.S. Drought Portal*** website ► Updates to the *U.S. Drought Monitor* map, drought impact summaries and forecasts
◆	◆				National Weather Service ***Climate Prediction Center*** website ► Data on soil moisture, evaporation, precipitation, runoff and temperature affecting drought conditions
		◆			National Weather Service ***National Hurricane Center*** website ► Wind speed maps
	◆	◆	◆		National Weather Service ***Probabilistic Hurricane Storm Surge*** website ► Projections on storm surges
	◆	◆	◆		National Oceanic and Atmospheric Administration Coastal Services ***Digital Coast*** website ► Data and tools for coastal hazards, including the *Sea Level Rise and Coastal Flooding Impacts Viewer*
◆	◆	◆			National Oceanic and Atmospheric Administration ***National Climatic Data Center*** website ► Historic *climate information*, *data access* capabilities and information on special topics such as *U.S. Tornado Climatology*

Climate Change Impacts					Information Resources and Type of Information Available (►) for Applicable Impact (◆) (*Accessible via hyperlinks provided below and at* http://www.epa.gov/superfund/climatechange)
Temperature	Precipitation	Wind	Sea Level Rise	Wildfires	
	◆	◆	◆		National Oceanic and Atmospheric Administration ***Tides and Currents*** website ► Information on local sea level trends
	◆				U.S. Geological Survey (USGS) ***Landslide Hazards Program*** website ► Information on landslide risks and a national landslide susceptibility map
	◆				U.S. Geological Survey ***Groundwater Watch*** website ►A searchable database containing groundwater records from about 850,000 wells in the United States

A **climate-change sensitivity assessment** evaluates the likelihood for the climate change hazards of concern to reduce effectiveness of a groundwater remediation system. Potential direct impacts of the hazards include power interruption, physical damage, water damage and reduced accessibility. Potential indirect impacts may include petroleum oil or chemical spills, accidental fire, explosions and ecosystem damage. Overall system failures might result in:

- Inadequate capture of targeted groundwater due to altered groundwater flow or aquifer storage capacity, which could in turn alter the project's conceptual site model
- Insufficient treatment of contaminated groundwater due to treatment system compromises (such as pressure loss) or catastrophic loss of the treatment system
- Operational downtime during or after extreme weather events
- Unexpected and additional project costs for repairing or replacing the remediation system and/or site infrastructure components such as power lines, maintenance corridors and buildings.

Points of potential vulnerability correspond to the system components, site operations and infrastructure (Table 2). Site operation vulnerability may include disruption of critical activities such as periodic injection of reactive reagents into the subsurface, delivery of fuels and other supplies, and scheduled sampling of groundwater. For new systems to be constructed, evaluation of the vulnerability and adaptation measures may be integrated into project designs.

Table 2. Considerations for Sensitivity Assessment of a Groundwater Remediation System

Examples of System Components		Potential Vulnerabilities			
		Power Interruption	Physical Damage	Water Damage	Reduced Access
Groundwater Extraction or Containment System	Wells		◆		◆
	Extraction or aeration pumps and aboveground controls	◆	◆	◆	◆
	Vertical barriers		◆		◆
	Pipe systems		◆	◆	◆
	Monitoring equipment	◆	◆	◆	◆
Aboveground Components of the Treatment System	Electrical controls	◆	◆	◆	◆
	Transfer pumps	◆	◆	◆	
	Pipe systems		◆		
	Equipment powered by electricity (such as air blowers), natural gas (such as heaters) and fossil fuel (such as diesel generators)	◆	◆	◆	
	Flow-through treatment units (such as granular activated carbon vessels, clarifiers, ion exchange units and tray strippers)	◆	◆	◆	
	Chemical storage containers		◆	◆	◆
	Treatment residuals disposal system		◆	◆	◆
	Treated water discharge system	◆	◆	◆	

Examples of System Components		Potential Vulnerabilities			
		Power Interruption	Physical Damage	Water Damage	Reduced Access
Site Operations and Infrastructure	Buildings, sheds, or housing	◆	◆	◆	◆
	Electricity and natural gas lines	◆	◆	◆	◆
	Liquid fuel storage and transfer	◆	◆	◆	◆
	Water supplies	◆	◆	◆	◆
	Exposed machinery and vehicles		◆	◆	◆
	Surface water drainage systems		◆	◆	◆

Results of exposure and sensitivity assessments may be integrated to evaluate the groundwater remediation system's overall vulnerability to climate change hazards. Detailed information about related concepts and tools is readily available in resources such as the:

- *Climate Change 2007: Impacts, Adaptation and Vulnerability* report from the Intergovernmental Panel on Climate Change (Working Group II), which includes a chapter (19) on assessing key vulnerabilities
- *Preparing for Climate Change: A Guidebook for Local, Regional and State Governments* guidance (as published in 2007 through a Local Governments for Sustainability partnership and funded by the National Oceanic and Atmospheric Administration [NOAA]) to provide local, regional or state governments with a detailed easy-to-understand process for climate change preparedness
- *Adapting to Climate Change: A Planning Guide for State Coastal Managers* report issued by NOAA in 2010, which includes a chapter (4) on vulnerability assessment.

Techniques for compiling information on exposure and sensitivity and for assessing overall vulnerability of a groundwater treatment or containment system may include:

- Collecting qualitative information, including photographs of system components and existing field conditions
- Extrapolating from quantitative data available in existing resources (including resources detailed in Table 1)
- Conducting quantitative modeling through use of conventional software or commercially available risk assessment software for engineered systems
- Developing summary maps, tables and matrices.

Implementation of Adaptation Measures

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

- Identifying measures that potentially apply to the scenarios
- Selecting and implementing priority adaptation measures for the given groundwater treatment or containment system.

Adaptation – "Adjustment or preparation of human systems to a new or changing environment which moderates harm or exploits beneficial opportunities."[3]

Identification of potential measures involves the screening of steps that may be taken to physically secure the system, provide additional barriers to protect the system, safeguard access to the system, and alert project personnel of system compromises (Table 3). Depending on the scenario, modifications can enable many measures to address more than one aspect of the overall groundwater remediation system. Some measures also may be scaled up to encompass multiple remediation systems and critical field activities. Yet others may provide a degree of desired redundancy; for example, access to an onsite or mobile renewable energy system could provide a redundant power source that enables continued treatment of groundwater despite disruptions to the local power grid.

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]

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 aboveground remedial components that are vulnerable could include, for example, structural reinforcement to protect buildings from high winds, secondary containment systems to capture hazardous liquids escaping from flood-damaged containers, and housing to protect monitoring equipment from high winds or flooding. Designs for vulnerable subsurface remedial components such as groundwater wells or containment barriers could include extra precautions for potential conditions such as surface mounding, desiccation or groundwater flow changes. Climate change considerations are particularly important in designs and associated modeling for groundwater treatment or containment systems anticipated to operate for 30 years or longer.

Table 3. Examples of Adaptation Measures

	Climate Change Impacts					
	Temperature	**Precipitation**	**Wind**	**Sea Level Rise**	**Wildfires**	**Potential Adaptation Measures for System Components**
Groundwater Extraction or Containment System		◆				**Dewatering well system** *Installing additional boreholes at critical locations and depths to maintain target groundwater levels in the extraction/containment zone and reduce groundwater upwelling while not compromising the remediation system*
	◆	◆	◆	◆	◆	**Remote access** *Integrating electronic devices that enable workers to suspend pumping during extreme weather events, periods of impeded access, or unexpected hydrologic conditions*
	◆	◆	◆			**Well-head housing** *Building insulated cover systems made of high density polyethylene or concrete for control devices and sensitive equipment situated aboveground for long periods*
Aboveground Components of the Treatment System	◆	◆	◆	◆	◆	**Alarm networks** *Integrating a series of sensors linked to electronic control devices that trigger shutdown of the system, or linked to audible/visual alarms that alert workers of the need to manually shut down the system, when specified operating or ambient parameters are exceeded*
		◆	◆	◆		**Coastal hardening** *Building "soft" seawalls (through techniques such as replenishing sand and/or vegetation), jetties or groins to stabilize and shield a shoreline from erosion; in some cases, "hard" seawalls (such as those made of reinforced concrete) may be warranted*
	◆	◆		◆		**Concrete pad fortification** *Repairing concrete cracks, replacing pads of insufficient size or with insufficient anchorage, or integrating retaining walls along the pad perimeter*
					◆	**Fire barriers** *Creating buffer areas (land free of dried vegetation and other flammable materials) around the treatment system and installing manufactured systems (such as radiant energy shields and raceway fire barriers) around heat-sensitive components*
		◆		◆		**Flood controls** *Building one or more structures to retain or divert floodwater, such as vegetated berms, drainage swales, levees, dams or retention ponds*
	◆	◆	◆	◆	◆	**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*
		◆	◆	◆		**Relocation** *Moving the system or its critical 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*)

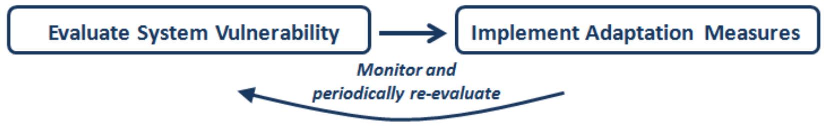
	Climate Change Impacts					
	Temperature	Precipitation	Wind	Sea Level Rise	Wildfires	Potential Adaptation Measures for System Components
Aboveground Components of the Treatment System		◆				**Riverbank armor** *Stabilizing banks of onsite segments of a river (or susceptible stream) through installation of "soft" armor (such as synthetic fabrics and/or deep-rooted vegetation) or "hard" armor (such as riprap, gabions and segmental retaining walls)*
		◆				**Slope fortification** *Anchoring a slope through placement of concrete or rock elements against a slope and installing anchors and cables to secure the elements, or containing a slope through placement of netting to hold back rock and 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*
Site Operations and Infrastructure	◆	◆			◆	**Building envelope upgrades** *Replacing highly flammable materials with (or adding) fire- and mold/mildew-resistant insulating materials in a building, shed or housing envelope*
		◆	◆	◆		**Hurricane straps** *Integrating or adding heavy metal brackets that reinforce physical connection between the roof and walls of a building, shed or housing unit*
		◆				**Pervious pavement** *Replacing impervious pavement that has deteriorated or impeded stormwater management with permeable pavement (in the form of porous asphalt, rubberized asphalt, pervious concrete or brick/block pavers) to filter pollutants, recharge aquifers and reduce stormwater volume entering the storm drain system*
	◆	◆	◆	◆	◆	**Plantings** *Installing drought-resistant grasses, shrubs, trees and other deep-rooted plants to provide shading, prevent erosion, provide wind breaks and reduce fire risk*
	◆	◆	◆	◆	◆	**Hazard alerts** *Using 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 potential measures and determining optimal measures** for a groundwater remediation system in a given scenario may consider:

- ✓ Complexity of the groundwater extraction/containment system
- ✓ Local or regional groundwater and surface water regimes and management plans
- ✓ Size and age of the system components and auxiliary equipment
- ✓ Anticipated duration of remedial system operations
- ✓ Status of infrastructure components such as roads, power and water supplies
- ✓ Existing and critical means of access
- ✓ Relevant aspects of future land use or development
- ✓ Anticipated effectiveness and longevity of the potential measures
- ✓ Capital cost and operations and maintenance (O&M) cost.

Selected measures may be integrated into primary or secondary documentation supporting existing groundwater remediation systems, such as monitoring plans, optimization evaluations, five-year reviews and close-out planning materials. The measures also may be integrated into the site's feasibility study and remedy design process.

The 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 reduce implementation costs in some cases. Adaptation also needs to be an iterative and flexible process that involves periodically re-evaluating the groundwater remediation system's vulnerability, monitoring the measures already taken, and incorporating newly identified options or information into the adaptation strategy. Periodic re-evaluations typically include verifying key data; for example, ongoing updates to FEMA floodplain maps may prompt implementation of flood-related measures that were previously considered unnecessary.



As an illustration, Figure 2 highlights results of a preliminary vulnerability evaluation for a groundwater remediation system currently deployed at a Superfund site. The illustration identifies potential disruptions to the system and provides a sample structure for documenting high-priority adaptation measures that could be implemented in the near term. Structures such as this also may be expanded for subsequent use in implementing additional adaptation measures and monitoring measures as well as tracking modifications over time.

Numerous resources to help understand climate change adaptation planning and implementation are available through online compendiums such as:

- EPA's *Adaptation Tools for Public Officials* website, which provides access to clearinghouses and sector- or region-specific tools and resources
- EPA's *Climate Impacts on Water Resources* website, which provides information pertaining to climate change impacts on water cycles, demands, supplies and quality
- The NOAA Coastal Services Center *Climate Change Adaptation* website, which provides access to numerous adaptation and action plans completed in jurisdictions throughout the United States, case studies, guidance and completed risk/vulnerability assessments
- The Local Governments for Sustainability-USA *Introduction to Climate and Energy Action* website, which provides access to case studies, fact sheets, studies, guidance and toolkits.

The general concepts, tools and examples provided in these resources may be used to tailor adaptation measures for a specific groundwater remediation system. Additionally, resources such as these may serve as a guide in assuring that the measures align with climate change actions taken by relevant state, regional or local agencies. Broader federal actions to enhance climate preparedness and resilience in the United States are outlined in the November 2013, Executive Order 13653, *Preparing the United States for the Impacts of Climate Change*.

References

[Web access date: December 2013]

[1] U.S. EPA; Climate Change Adaptation Plan (draft); June 2012; http://epa.gov/climatechange/pdfs/EPA-climate-change-adaptation-plan-final-for-public-comment-2-7-13.pdf

[2] U.S. EPA; Office of Solid Waste and Emergency Response Climate Change Adaptation Implementation Plan (draft); June 2013; http://epa.gov/climatechange/Downloads/impacts-adaptation/office-of-solid-waste-and-emergency-response-plan.pdf

[3] U.S. EPA; Glossary of Climate Change Terms; http://www.epa.gov/climatechange/glossary.html

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

Contacts

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

This sample cleanup scenario involves a large Superfund site located on the outskirts of a metropolitan area along the Atlantic coast, within a 1-meter sea-level rise zone. Contaminants remain from the site's past use for light manufacturing and processing of liquid industrial wastes received from other manufacturing and chemical firms. Remedial components include a subsurface containment wall (containing soil/bentonite slurry to a depth of 10 feet), a sheet-pile retaining wall along an onsite creek, and a groundwater P&T system with offsite discharge. The P&T system is situated in a downgradient portion of a 500-year floodplain that surrounds a 100-year floodplain, where some remedial and infrastructure components such as equipment/material storage sheds or containers and power lines exist.

Public information sources (including resources highlighted in Table 1) indicate potential hazards for this scenario include flooding, high wind, storm surge and sea level change. In combination with site-specific data existing in materials such as site investigation reports and the Superfund record of decision, professional judgment may be used to identify and prioritize adaptation measures for this remedy.

Potential Points of System Vulnerability		Potential System Disruption				Adaptation Measures for High-Priority Vulnerabilities
		Power Interruption	Physical Damage	Water Damage	Reduced Access	
Groundwater Extraction or Containment System	Wells		○		○	
	Extraction pumps and aboveground controls	●	●	●	●	Power from off-grid sources; Well-head housing
	Vertical barriers		○		○	
	Pipe system		○	○	○	
	Monitoring equipment	●	●	●	●	Power from off-grid sources; Remote access
Aboveground Components of the Treatment System	Electrical controls	●	●	●	●	Power from off-grid sources; Remote access
	Transfer pumps	◐	○	◐		
	Pipe system		◐			
	Electric equipment	●	○	●		Power from off-grid sources
	Natural gas-driven equipment	◐	○	◐		
	Ancillary equipment driven by fossil fuel	◐	○	◐		
	Flow-through units	◐	○	◐		
	Chemical storage containers		●	◐	●	Relocation; Tie down systems
	Treatment residuals disposal system		○	◐	◐	
	Treated water discharge system	◐	○	◐		
Site Operations and Infrastructure	Buildings, sheds, or housing	●	●	●	○	Power from off-grid sources; Hurricane straps
	Electricity and natural gas lines	●	◐	●	●	Relocation
	Liquid fuel storage and transfer	◐	◐	●	●	Concrete pad fortification; Tie down systems
	Water supplies	◐	◐	●	●	Coastal hardening
	Exposed machinery and vehicles		◐	●	●	Relocation
	Surface water drainage systems		◐	◐	◐	

● *high priority* ◐ *medium priority* ○ *low priority*