United States Environmental Protection Agency

Office of Superfund Remediation and Technology Innovation

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Climate Resilience Technical Fact Sheet: Groundwater Remediation Systems

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 involving groundwater remediation systems. It is intended to serve as a site-specific planning tool by (1) describing an approach to assessing potential vulnerability of a groundwater system, (2) providing examples of measures that may increase resilience of a groundwater system, and (3) outlining steps to assure adaptive capacity of a groundwater system 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.

Groundwater remediation systems are common elements of contaminated site cleanup projects and may function ex situ 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). The groundwater may be extracted though a single well or a network of wells equipped with pumps and interconnecting pipes. Treatment of the extracted groundwater commonly involves removing contaminants by way of activated carbon sorption, air stripping, filtration, ion exchange or metals precipitation.

In contrast, in situ processes often involve injecting reagents into the subsurface through one or more wells to promote desired biological or chemical reactions in contaminated groundwater. Another common process involves constructing one or more engineered subsurface cells that are made of reactive materials and strategically positioned to intercept and treat a plume of contaminated groundwater. Other in situ processes include air sparging, in-well air stripping and phytoremediation.

More than 80 percent of the Superfund site remedies selected since 1982 address contaminated groundwater. As of 2014, about 50% of the groundwater remedies involved in situ treatment.[2]

Climate resilience planning for a groundwater treatment system and associated hydraulic controls generally involves:

(1) Assessing vulnerability of the system's elements and associated site infrastructure.
(2) Evaluating measures potentially increasing the system's resilience to a changing climate.
(3) Assuring the system's capacity to adapt to a changing climate, which helps the cleanup 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]

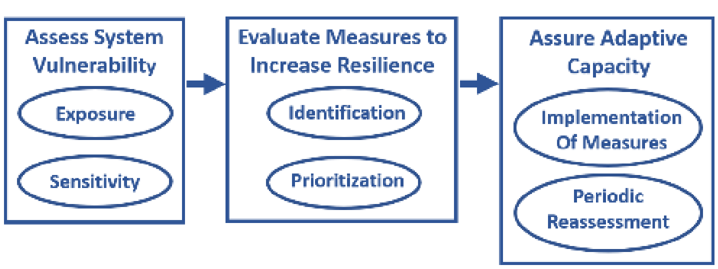

Figure 1. Climate Change Adaptation Management

Assessment of Groundwater Remediation System Vulnerability

Assessing a groundwater treatment system's vulnerability to the effects of climate change involves:

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

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 particular hazards of concern and characterizes exposure to those hazards in light of various climate and weather scenarios. Examples of potential hazards for a groundwater remediation system include altered directions of groundwater flow, higher influx of surface water and changes in the seasonal highs or lows of a water table.

The hazards may arise abruptly due to extreme weather events, which are expected to occur at increasing intensities, durations and frequencies as long-term climate conditions continue to change. Depending on a site's location and attributes, hazards associated with an extreme weather event may generate different outcomes and degrees of severity. For example, a given amount of coastal precipitation could result in tidal floodwater that infiltrates an existing stormwater management system at some sites, inundates ground surfaces at other sites or overcomes storm defenses at yet other sites.

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.

Vulnerability assessment may consider factors that potentially exacerbate the system's exposure and sensitivity, such as a long operating period. Many groundwater treatment systems are designed to operate for 30 years or longer. Another future vulnerability might concern the regional water infrastructure and water availability. For example, effluent from a P&T system may need to be used as onsite or offsite non-potable water instead of discharged to surface water if sustained reductions in regional precipitation are predicted. Other potential hazards may concern anthropogenic stressors, such as onsite or nearby construction of structures with impervious surfaces that hinder natural infiltration of precipitation and generate stormwater runoff.[5] In addition to posing greater stormwater management challenges at a site, such runoff adds a burden on a local publicly owed treatment works (POTW) that may already receive effluent from a P&T system.

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. Geological Survey (USGS) resources such as the *Groundwater Watch* database.
- National Oceanic and Atmospheric Administration (NOAA) information in the *National Integrated Drought Information System* portal, including downloadable LIDAR data.
- U.S. Army Corps of Engineers methods such as the *Climate Hydrology Assessment Tool*.

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

A **climate change sensitivity assessment** for a planned or operating groundwater remediation system evaluates the likelihood for the climate change hazards of concern to reduce the system's effectiveness. Potential direct effects of the hazards associated with an extreme weather event include power interruption, physical damage, water damage and reduced accessibility. Potential indirect effects include petroleum oil or chemical spills, accidental fire, explosions and ecosystem damage. System failures due to exposure to one or more hazards could result in:

- Inadequate capture of targeted groundwater due to unexpected alteration of groundwater flow or aquifer storage capacity, which may prompt a need to update the project's operating conceptual site model.

- Insufficient treatment of extracted groundwater due to compromises such as pressure loss or pump seizure.
- Undesired biological or chemical reactions due to increased interaction of groundwater and surface water, which could involve saltwater intrusion or pollutant-laden runoff.
- Suspended operation of an active treatment system over a long period.
- Unexpected and additional project costs for repairing or replacing the remediation system or site infrastructure components such as power lines, maintenance corridors and buildings.

Vulnerable points of a groundwater remediation system due to extreme weather events may physically exist below, at or above surface grades or involve the site's general operations and infrastructure (Table 1). For example, reduced access to a site due to road flooding could disrupt critical activities such as periodic injection of reactive reagents into the subsurface, delivery of fuels and other supplies and scheduled sampling of groundwater.

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

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

Techniques for assessing potential vulnerability of a groundwater remediation system may include:

- Collecting qualitative information such as photographs of system 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 summary site-specific maps, tables 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, and subsequently investigating the options and prioritizing, planning and taking specific actions to increase resilience.

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

- *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.

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 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 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 surrounding a 100-year floodplain where remediation equipment, material storage sheds and drums, and power lines exist.

Public information sources indicate that potential hazards for this scenario include flooding, high wind, storm surge and sea level rise. 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
		Power Interruption	Physical Damage	Water Damage	Reduced Access	
Groundwater Extraction or Containment System	Wells		○		○	
	Extraction pumps	●	●	●	●	Build well-head housing
	Vertical barriers		○		○	
	Monitoring equipment	●	●	●	●	Add a remote access system
Aboveground Components of the Treatment System	Electrical controls	●	●	●	●	Elevate above worst-case flooding
	Transfer pumps	◐	○	◐		
	Pipe system		◐			
	Electric equipment	●	○	●		Install a photovoltaic energy system for backup power
	Natural gas-driven equipment	◐	○	◐		
	Flow-through units	◐	○	◐		
	Chemical storage containers		●	◐	●	Relocate to higher ground Use tie down systems
	Residuals disposal system		○	◐	◐	
	Treated water discharge system	◐	○	◐		
Site Operations and Infrastructure	Buildings, sheds, or housing	●	●	●	○	Install hurricane straps
	Electricity lines	●	◐	●	●	Bury lines below ground surface
	Liquid fuel storage and transfer	◐	◐	●	●	Fortify concrete pads Install anchor systems
	Water supplies	◐	◐		●	
	Surface water drainage systems		●	◐	◐	Construct vegetated swales
● *high priority*		◐ *medium priority*			○ *low priority*	

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

Evaluation of Potential Climate Resilience Measures

Results of a vulnerability evaluation may be used to develop a strategy for increasing a groundwater remediation system'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 the given system.

Identification of potential resilience measures involves screening of steps that may be taken to physically secure the system, provide additional barriers to protect the system, safeguard access to the system or alert project personnel of system compromises (Table 2). Some of the measures may address more than one climate or weather scenario. For example, integrating electronic devices that provide remote access to a groundwater P&T system enables offsite workers to adjust or temporarily shut down operations during intense rainfall, high winds or a sudden wildfire.

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

Some measures also may be scaled up to increase the resilience of co-located remediation systems, such as a nearby soil vapor extraction operating in conjunction with a P&T system. Others may provide a degree of desired redundancy. For example, enclosure of electronic cables within raceway fire barriers could provide electronic equipment with additional heat- and fire-resistance in the event that an encroaching wildfire jumps an onsite building's fire buffer.

For a new remediation system, selecting optimal measures during the design phase may maximize the system's resilience to climate change implications throughout the project life and help avoid costly retrofits. Designs for a groundwater remediation system could include specifications to meet particular vulnerabilities. For example, the design could involve a deep well dewatering system to intermittently lower the groundwater table within an extraction zone and reduce upwelling; a secondary containment system to capture hazardous liquids escaping from flood-damaged treatment units; or structural reinforcement to protect buildings from high winds. Optimal design models use the latest climate predictions and a range of potential weather scenarios, in addition to historic climate and weather data.

> Descriptions of engineered structures commonly used in climate resilience measures are available online at **Superfund Climate Resilience: Resilience Measures**.

The process of identifying and prioritizing potential measures for a groundwater remediation system may consider:

- Size and age of the system components and auxiliary equipment.
- Complexity and anticipated duration of the groundwater remediation system.
- Local or regional groundwater and surface water regimes and management plans.
- 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 resilience measures.
- Capital cost and operations and maintenance (O&M) cost of the measures as well as costs associated with potential system repair or replacement due to climate-related damage in the future.

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

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

Table 2. Examples of Climate Resilience Measures

	Climate Change Effects					Potential Climate Resilience Measures for System Components
	Temperature	Precipitation	Wind	Sea Level Rise	Wildfires	
Groundwater Extraction and Control 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 without compromising the remediation system*
	◆	◆	◆	◆	◆	**Remote access** *Integrating electronic devices that enable workers to remotely 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*
	◆	◆			◆	**Building envelope upgrades** *Replacing highly flammable materials with (or adding) fire- and mold/mildew-resistant insulating materials in a building, shed or housing envelope*
	◆	◆		◆		**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*
	◆	◆	◆	◆	◆	**Hazard alerts** *Using electronic systems that actively inform subscribers of extreme weather events or provide updated Internet postings on local/regional weather and related conditions*
		◆	◆	◆		**Hurricane straps** *Integrating or adding heavy metal brackets that reinforce physical connection between the roof and walls of a building, shed or housing unit*
	◆	◆	◆	◆	◆	**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*
		◆	◆			**Tie down systems** *Installing permanent mounts that allow rapid deployment of a cable system extending from the top of a unit to ground surface*
		◆				**Treatment water reuse** *Reclaiming treated groundwater for the purpose of recharging the aquifer or meeting onsite water needs such as irrigation, heating or cooling, wetlands replenishment or wildlife/habitat support*

	Climate Change Effects					Potential Climate Resilience Measures for System Components
	Temperature	Precipitation	Wind	Sea Level Rise	Wildfires	
Site Operations and Infrastructure		◆	◆	◆		**Constructed wetlands** *Creation of 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 a buffer from wind or wave action and storm surge*
		◆				**Pervious pavement** *Replacing impervious pavement that impedes stormwater management with permeable pavement in forms such as rubberized asphalt and brick pavers*
	◆	◆	◆	◆	◆	**Plantings** *Installing drought-resistant grasses, shrubs, trees and other deep-rooted plants to provide shading, prevent erosion, provide wind breaks and reduce fire risk*
		◆				**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*

Assurance of Adaptive Capacity

Assuring the adaptive capacity of a groundwater remediation system involves:

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

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]

Climate resilience measures selected for implementation may be integrated into primary or secondary documentation supporting existing groundwater remediation systems. Key documentation includes monitoring plans, optimization evaluations, five-year reviews and close-out planning materials. For new projects, the measures also may be integrated into the site's feasibility study and remedy design process. Remedy 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 selected measures to benefit the site's anticipated reuse. For example, armoring of an onsite riverbank could shield a groundwater treatment plant from flooding hazards throughout its operating period while beginning to stabilize the site for future industrial use.

Assurance of sufficient 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, ongoing updates to Federal Emergency Management Agency (FEMA) floodplain maps may prompt implementation of flood-related measures that were previously considered unnecessary. Established plans for the timing of vulnerability reassessment may use triggers such as an extreme weather event or involve a predetermined schedule.

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 provide climate and weather data and periodically updated maps on economic impacts of weather disasters.
- EPA's *Addressing Climate Change in the Water Sector* website, which provides information pertaining to climate change impacts on water cycles, demands, supplies and quality.

More examples of tools to help assure adaptive capacity of a site remedy are described online at **Superfund Climate Resilience: Adaptive Capacity**.

The concepts, tools and examples in such resources may be used to tailor climate resilience planning for a specific groundwater remediation system. Such resources also may serve as a guide in assuring that the measures align with climate adaptation actions taken by relevant federal, state, regional or local agencies, such as EPA's water reuse action plan to ensure water availability and mitigate risks posed by droughts.[6]

Cleanup at the 1,400-acre **Summitville Mine** National Priorities List site in Colorado has involved constructing a water treatment plant, a dam impoundment storing mine-influenced water prior to its treatment, groundwater interceptor trenches and a sludge disposal repository. Past mining operations at this remote high-altitude site led to large-scale erosion and metals mobilization that contaminate the Alamosa River.

The climate hazards include rapid snowmelts each spring and early summer, intense rainfall events, cold temperatures and landslides. Resilience measures have involved:

- Constructing the water treatment plant at a position outside the 500-year floodplain.
- Elevating the spillway channel of the dam impoundment by three feet to increase the dam's storage capacity by 16 percent.
- Upgrading surface water culverts and conveyances to withstand a 100-year snowmelt or 500-year, 24-hour rainfall event.
- Removing standing dead wood to create a defensible fire space.

Dam impoundment and upgradient water treatment plant at the Summitville Mine site in the San Juan Mountains of Colorado.

References

[Web access date: October 2019]

1. U.S. EPA; Climate Change Adaptation Plan; June 2014; https://www.epa.gov/greeningepa/climate-change-adaptation-plans
2. U.S. EPA; Superfund Remedy Report; Fifteenth Edition; EPA-542-R-17-01; July 2017; https://www.epa.gov/remedytech/superfund-remedy-report
3. U.S. EPA; Vocabulary Catalog; Topics: Climate Change Terms; https://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/glossariesandkeywordlists/search.do
4. U.S. EPA; Climate Change Indicators in the United States 2016; Fourth Edition; EPA 430-R-16-004; https://www.epa.gov/climate-indicators
5. U.S. EPA; Green Infrastructure; https://www.epa.gov/green-infrastructure/green-infrastructure-climate-resiliency
6. U.S. EPA; Water Reuse Action Plan; https://www.epa.gov/waterreuse/water-reuse-action-plan

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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