United States Environmental Protection Agency

Office of Superfund Remediation and Technology
EPA 542-F-14-001 May 2014

Climate Change Adaptation Technical Fact Sheet: Landfills and Containment as an Element of Site Remediation

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. Under the Agency's Superfund Program, existing processes for planning and implementing contaminated site cleanup provide a robust structure that allows consideration of climate change impacts. Climate change vulnerability analyses and adaptation planning leading to increased remedy resilience may be integrated throughout the Superfund process, including feasibility studies, remedial designs and remedy performance reviews or the equivalent in other cleanup programs. Due to wide variation in the location and hydrogeologic characteristics of contaminated sites, the nature of remedial actions at those sites, and local or regional climate and weather regimes, the process of considering climate change impacts and potential adaptation measures is most effective through use of a site-specific strategy.

This fact sheet addresses contaminated site remedies involving source containment 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. This tool was developed in context of the Superfund Program but its concepts may apply to site cleanups conducted under other regulatory programs or through voluntary efforts. [a]

The adaptation strategies for containment remedies build on concepts detailed in EPA's introductory ***Climate Change Adaptation Technical Fact Sheet: Groundwater Remediation Systems*** (EPA 542-F-13-004).[2] Supplemental information available online includes:

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

www.epa.gov/superfund/climatechange

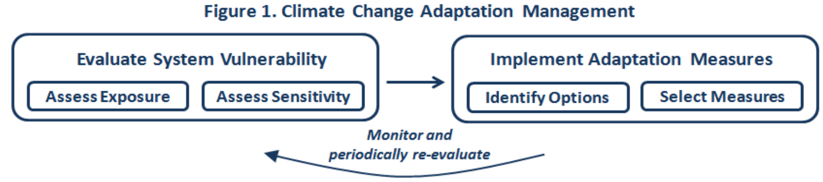
Materials acting as a source of environmental contamination often consist of contaminated soil or sediment. A source also could involve sludge, debris, solid waste, non aqueous-phase liquids, equipment, drums, or storage tanks.[3] Remediation of contaminated sites often involves containment systems to address the contaminant source(s). Containment systems may operate *ex situ* and/or *in situ*.

Ex situ processes may involve excavating contaminated source material and placing it in an engineered containment area (cell) that is lined, such as a landfill, or an area designated as a consolidation unit that is typically unlined. An *ex situ* source containment system often includes a cover (cap), which is required for a closed landfill. A hazardous waste landfill constructed under the Resource Conservation and Recovery Act also requires a leachate collection and removal system. In addition, some landfills have an active landfill gas collection and removal system, which may vary from simple flaring to recovery of the gas to produce electricity and/or useable heat. Other *ex situ* source containment remedies may involve subaqueous contaminated sediment or mining waste. At mining sites, contaminant sources such as waste rock, tailings, process areas, and heap and dump leach operations may be consolidated in open pits and capped in underground workings.

In contrast, *in situ* processes may involve placing a cover on contaminated material that is stabilized and left in place, such as an aged landfill. Other techniques may involve constructing vertical barriers (walls) made of clay (typically bentonite) and/or cement slurry poured into one or more subsurface trenches, synthetic materials such as geomembranes placed in trenches, or sheet piles driven into the subsurface. The barriers are designed to prevent movement of contaminants existing in a dissolved or free-phase form and often operate with a groundwater extraction and treatment system.

Climate change adaptation for an existing or planned containment system focuses on (1) evaluating the system's vulnerability to climate change and (2) implementing adaptation measures, when warranted, to ensure the remedy continues to prevent human or environmental exposure to contaminants of concern (Figure 1). The adaptation strategy should include monitoring of implemented measures, periodic re-evaluation of the system's vulnerability, and incorporating any needed changes.

Figure 1. Climate Change Adaptation Management



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

Evaluation of Containment System Vulnerability

Evaluation of a 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 system exposure and sensitivity, such as a long operating period; for example, *ex situ* containment systems typically operate as long as the material remains hazardous, which in some cases may exceed 100 years.

A **climate-change exposure assessment** identifies climate change hazards of concern for a remediation system in light of a range of potential climate and weather scenarios. One climate change hazard that is relatively unique to landfill/containment systems involves precipitation changes that could degrade the covers. These systems also may be adversely affected by land-cover changes associated with climate impacts, such as increased sinkholes.[4] At some sites, other hazards may relate to the system's original siting or to potential lapses in the system's long-term stewardship. Landfills at or near sea level in coastal areas, for example, might be subject to saltwater intrusion and increased groundwater salinity, which may increase permeability of a clay liner and consequently decrease its performance.

Climate Change Impacts

Temperature:
- *Increased occurrence of 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),[5] Appendix A (adaptation)

Exposure assessment should include evaluating potential anthropogenic stressors, such as future land development that could remove natural protective barriers or cause infill subsidence in low-lying areas. Exposure assessment should also recognize near-term use of a covered landfill/containment area; for example, EPA and other federal agencies are evaluating opportunities to install renewable energy facilities on current or formerly contaminated lands, landfills and mine sites.[6] Site managers are encouraged to work closely with future-use planning entities when assessing site-specific exposure to climate change hazards.

Dynamic information concerning specific locations is readily available from several federal agencies to help screen potential hazards and identify those of concern. More information may be available from state agencies, regional or local sources such as watershed and forestry management authorities, non-profit groups and academia. At some sites, installation of a meteorological station may be warranted to monitor the need for response measures and to aid predictive modeling for targeted vulnerabilities.

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

www.epa.gov/superfund/climatechange/resources

A **climate-change sensitivity assessment** evaluates the likelihood for the climate change hazards of concern to reduce effectiveness of a landfill/containment 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. Depending on the type and size of a system, overall system failures may result in:

- Damage to liner or cover materials and potential washout of contaminated contents
- Damage to or loss of a leachate collection/removal system
- Damage to or loss of a landfill gas (LFG) management system, which may involve one or more flares to destroy excess gas or a facility to recover and convert the gas to useable energy

- Loss of subaqueous cover integrity due to increased erosion associated with intense water currents and waves
- Loss of surface grade integrity and potential spread of contaminants
- Unexpected and additional costs for repairing or replacing a cover system, a leachate or LFG management system, or infrastructure components such as power lines, maintenance corridors and buildings.

Points of potential vulnerability correspond to the landfill/containment system components (including any leachate and/or LFG management systems), site operations and infrastructure (Table 1). Site operation vulnerability may include disruption of critical activities such as scheduled inspections of a landfill cover or sampling of LFG.

Table 1. Considerations for Sensitivity Assessment of a Source Containment System

Examples of System Components		Potential Vulnerabilities			
		Power Interruption	**Physical Damage**	**Water Damage**	**Reduced Access**
Underground and At-Grade Components	Synthetic materials such as geomembrane in a composite liner or cover system, geonet for drainage, and/or geotextile for leachate filtration		◆	◆	
	Bottom layer of unlined waste			◆	
	Vegetative layer integral to an evapotranspiration cover or overlaying a conventional cover		◆	◆	
	Vertical and horizontal wells for LFG extraction		◆		◆
	Pipe networks for leachate and/or LFG collection		◆	◆	◆
	Wells for monitoring groundwater or LFG		◆		◆
	Vertical barriers		◆		◆
Aboveground Components	Electrical controls for leachate and LFG management systems	◆	◆	◆	◆
	Pipe systems for leachate treatment and disposal and for LFG collection and transfer		◆		
	Transfer pumps for leachate and LFG	◆	◆	◆	
	Flow-through leachate treatment units for coagulation/flocculation, aerobic treatment, chemical precipitation, ozonation, or reactive carbon absorption	◆	◆	◆	
	Leachate treatment pond		◆		◆
	LFG pre-treatment equipment such as blowers, coolers and condensers	◆	◆	◆	
	LFG flares	◆	◆	◆	◆
	LFG-to-energy turbines	◆	◆	◆	
	Chemical storage containers		◆	◆	◆
	Treatment residuals disposal system		◆	◆	◆
	Treated leachate discharge system	◆	◆	◆	
	Auxiliary equipment powered by electricity, natural gas or fossil fuel	◆	◆	◆	
	Monitoring equipment	◆	◆	◆	◆
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		◆	◆	◆
	Fencing for access control and litter prevention		◆		

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

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

Ex situ soil/waste containment systems rely on effective control of water entering or exiting the system. As a result, these systems are commonly vulnerable to flooding that could cause cover material erosion, side slope failure or contaminant washout. Damaging floods from extreme precipitation events may be exacerbated if preceded by severe heat and drought. Source containment systems in coastal areas also are particularly vulnerable to saltwater intrusion caused by sea level rise and associated flooding.

Adaptation measures are underway at the American Cyanamid Superfund site along the Raritan River in Bridgewater, New Jersey, which experienced significant flooding in 2011 due to Hurricane Irene. Measures have already been implemented for general site operations, such as installing submersible pumps in bedrock wells to maintain hydraulic control during future flood events and elevating critical onsite electrical infrastructure (shown above on left). A remedy selected in 2012, which calls for treatment and capping of contaminated wastes, will also incorporate a number of flood adaptation measures, such as designing engineered covers to withstand a 500-year flood event. The berms (shown above at right) surrounding two highly contaminated waste impoundments have been reinforced to increase their strength and prevent scouring until a remedy for the impoundments can be developed and implemented.

Implementation of Adaptation Measures

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

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

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 to system compromises (Table 2). Depending on the scenario, modifications may enable many measures to address more than one aspect of an overall containment 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 leachate and/or LFG despite disruptions to the local power grid.

For new containment systems to be constructed, evaluation of the vulnerability and adaptation measures may be integrated into project designs. For systems already operating, subsidence and slope instability may signal the need to closely examine subsurface components of the system and re-evaluate their vulnerabilities.

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 closed or elevated housing to protect leachate pumps or monitoring equipment from high winds or flooding. Designs for vulnerable subsurface remedial components such as leachate/LFG pipe networks or *in situ* 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 containment systems anticipated to operate for 30 years or longer. If an area is predicted to experience increasingly frequent flooding or storm surge activity or be subject to rising sea levels, disposal of contaminated soil offsite in an area not subject to these problems may be an option.

Resilience of a covered landfill at the Davisville Naval Construction Battalion Center Superfund site, which is located along the Narragansett Bay in Rhode Island, is strengthened by an armored base to prevent erosion. Intertidal wetlands and a seawall work together below the base to reduce wave energy during storm surge from the adjacent Allen Harbor. Prior to installation of the landfill cover, the wetlands were reconstructed by replacing the adjacent polluted mudflat with a layer of rocks topped by dredge spoils (from the harbor entrance channel) and planting deep-rooted cordgrass (*Spartina*) on the modified surface.

Table 2. Examples of Adaptation Measures

	Climate Change Impacts					**Potential Adaptation Measures for System Components** *Brief descriptions of engineered structures integral to many of the measures are available on the Superfund* ***Climate Change Adaptation*** *website.*
	Temperature	Precipitation	Wind	Sea Level Rise	Wildfires	
Underground and At-Grade Components of the Containment System		◆				**Construction at grade** *Designing a new containment system to be built at rather than below ground surface, in order to minimize potential contact between groundwater and targeted waste (or an engineered liner) due to consistent rising of the water table*
		◆				**Dewatering well system** *Installing extraction wells at critical locations and depths to prevent or minimize groundwater upwelling into the waste zone of an aged landfill, waste consolidation unit, or lined engineered landfill*
		◆		◆		**Leachate extraction upgrades** *Installation of additional wells (and aboveground pumps) for leachate extraction in vulnerable areas*
	◆	◆		◆		**Liner system reinforcement** *Selection of geomembranes with a maximum feasible thickness for new liner systems, use of a secondary liner or geotextile, or extension of geosynthetic materials to vulnerable sides of a waste cell*
		◆	◆			**Pipe burial** *Installation of pipes below rather than above ground surface where feasible, particularly for LFG transfer*
		◆				**Run-on controls** *Building one or more earthen structures (such as vegetated berms, vegetated swales, or stormwater ponds) or installing fabricated drainage structures (such as culverts or French drains) at vulnerable locations to prevent stormwater accumulating at higher elevations from reaching a landfill/containment system*

	Climate Change Impacts					Potential Adaptation Measures for System Components
	Temperature	Precipitation	Wind	Sea Level Rise	Wildfires	
Aboveground Components of the Containment System		◆				**Armor** *Fixed structures placed on or along the shoreline of flowing inland water or ocean water to mitigate effects of erosion and protect site infrastructure; "soft" armor may comprise synthetic fabrics and/or deep-rooted vegetation while "hard" armor may consist of riprap, gabions and segmental retaining walls*
		◆	◆	◆		**Coastal hardening** *Installation of structures to stabilize a shoreline and shield it from erosion, through "soft" techniques (such as replenishing sand and/or vegetation) or "hard" techniques (such as building a seawall or installing riprap)*
	◆	◆		◆		**Concrete pad fortification** *Repairing cracked pads or replacing inadequate pads (of insufficient size or with insufficient anchorage), particularly those used for monitoring purposes, and integrating retaining walls along a concrete pad perimeter where feasible*
		◆	◆			**Containment fortification** *Placement of riprap adjacent to a subsurface containment barrier located along moving surface water, to minimize bank scouring that could negatively affect barrier integrity; for soil/waste capping systems vulnerable to storm surge, installation of a protective vertical wall or armored base to absorb energy of the surge and prevent cap erosion or destruction*
		◆	◆		◆	**Entombment** *Enclosure of vulnerable equipment or control devices in a concrete structure*
		◆				**Evapotranspiration cover modification** *Replacement of existing vegetation with a plant mix more tolerant of long-term changes in precipitation or temperature, and/or soil addition to increase water storage capacity*
					◆	**Fire barriers** *Creating buffer areas (land free of dried vegetation and other flammable materials) around vulnerable remediation/monitoring components and installing manufactured systems (such as radiant energy shields and electrical raceway fire barriers) around heat-sensitive components*
		◆	◆		◆	**Flare enclosure** *Industrial-strength protective material that surrounds equipment used to ignite and combust excess LFG*
		◆				**Ground anchorage** *One or more steel bars installed in cement-grouted boreholes (and in some cases accompanied by cables) to secure an apparatus on a ground surface or to reinforce a retaining wall against an earthen slope*
		◆	◆	◆		**Relocation** *Moving selected system components to positions more distant or protected from potential hazards; for flooding threats, this may involve elevations higher than specified in the community's flood insurance study*
		◆			◆	**Retaining wall** *A structure (commonly of concrete, steel sheet piles or timber) built to support earth masses having a vertical or near-vertical slope and consequently hold back loose soil, rocks or debris*
		◆	◆			**Tie down systems** *Installing permanent mounts that allow rapid deployment of a cable system extending from the top of a unit to ground surface*
	◆	◆	◆			**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*

	Climate Change Impacts					Potential Adaptation Measures for System Components
	Temperature	Precipitation	Wind	Sea Level Rise	Wildfires	
Site Operations and Infrastructure	◆	◆	◆	◆	◆	**Alarm networks** *Integrating a series of sensors linked to electronic control devices that trigger shutdown of selected remediation/monitoring components, or linked to audible/visual alarms that alert workers of the need to manually shut down the components, 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*
		◆		◆		**Flood controls** *Building one or more earthen structures (such as vegetated berms, vegetated swales, stormwater ponds, levees, or dams) or installing fabricated drainage structures (such as culverts or French drains) to retain or divert floodwater spreading from adjacent surface water or land surface depressions*
		◆	◆	◆		**Hurricane straps** *Integrating or adding heavy metal brackets that reinforce physical connection between the roof and walls of a building, shed or housing unit, including structures used for leachate and LFG management*
		◆				**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*
	◆	◆	◆	◆	◆	**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*
	◆	◆	◆	◆	◆	**Remote access** *Integrating electronic devices that enable workers to suspend pumping or selected activities during extreme weather events, periods of impeded access, or unexpected hydrologic conditions*
	◆	◆	◆	◆		**Renewable energy system safeguards** *Extended concrete footing for ground-mounted photovoltaic (PV) systems, additional bracing for roof-top PV or solar thermal systems, and additional masts for small wind turbines or windmills; for utility-scale systems, safeguards to address climate change vulnerabilities may be addressed in the site-specific renewable energy feasibility study*
	◆	◆	◆		◆	**Utility line burial** *Relocating electricity and communication lines from overhead to underground positions, to prevent power outages during and often after extreme weather events*
	◆	◆	◆	◆	◆	**Weather alerts** *Electronic systems that actively inform subscribers of extreme weather events or provide Internet postings on local/regional weather and related conditions*

The process of **selecting potential measures and determining optimal measures** for a landfill/containment system in a given scenario may consider:

- ✓ Size and age of aboveground components of the system and auxiliary equipment
- ✓ Complexity of any associated leachate and/or LFG management systems
- ✓ Anticipated duration of remedial system operations
- ✓ Existing infrastructure components such as roads, power and water supplies
- ✓ Primary and back-up means of access

- ✓ Project aspects affecting future land use or development
- ✓ Anticipated effectiveness and longevity of the potential measures
- ✓ Capital cost and operations and maintenance (O&M) cost.

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

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

To be most effective, adaptation should be an iterative and flexible process that involves periodically re-evaluating the source containment system's vulnerability, monitoring the measures already taken, and incorporating newly identified options or information into the adaptation strategy. Periodic re-evaluations should include verifying key data; for example, predictions for increased frequency of intense inland surface water currents and tides may prompt upgrades to subaqueous soil/sediment capping systems, as could the changing patterns of ice versus non-ice conditions. As another example, updated floodplain mapping could lead to installation of engineered structures to protect a landfill in an area previously considered a 500-year floodplain but now classified as a 100-year floodplain.

Effective adaptation planning also considers how climate change may affect short- and long-term availability of clean water and ecosystem services that may be critical to maintenance of a source containment system as well as future land use.[7] Information about related data and government and/or private sector partnerships is available to the site cleanup community, local or regional planners, and the general public through the recently launched U.S. Climate Data Initiative.[8]

References

[Web access date: May 2014]

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; Climate Change Adaptation Technical Fact Sheet: Groundwater Remediation Systems; EPA 542-F-13-004; December 2013; http://www.epa.gov/superfund/climatechange/cca-tech-fact-sheet-gw-remediation-systems.pdf

3 U.S. EPA; Superfund Remedy Report; Fourteenth Edition; EPA 542-R-13-016; November 2013; http://www.clu-in.org/asr/

4 U.S. Geologic Survey; The Science of Sinkholes; http://www.usgs.gov/blogs/features/usgs_top_story/the-science-of-sinkholes/

5 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

6 The White House; Presidential Memorandum – Federal Leadership on Energy Management; December 5, 2013; http://www.whitehouse.gov/the-press-office/2013/12/05/presidential-memorandum-federal-leadership-energy-management

7 U.S. EPA; Climate Impacts on Water Resources; http://www.epa.gov/climatechange/impacts-adaptation/water.html

8 The White House; The President's Climate Data Initiative: Empowering America's Communities to Prepare for the Effects of Climate Change; March 19, 2014; http://www.whitehouse.gov/the-press-office/2014/03/19/fact-sheet-president-s-climate-data-initiative-empowering-america-s-comm

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

Questions about climate change adaptation in EPA's Superfund Program may be forwarded to:
Carlos Pachon (pachon.carlos@epa.gov), Anne Dailey (dailey.anne@epa.gov) or Ellen Treimel (treimel.ellen@epa.gov