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The groundwater treatment plant and storage tanks at the American Cyanamid Superfund site, constructed on elevated land outside the 500-year floodplain, avoided floodwaters in 2021. Photo Credit: Mark Schmidt.

Conducting Climate Vulnerability Assessments at Superfund Sites

Contents

The Technical Support Project Engineering Forum issue papers provide information on remediation technologies or technical issues of interest. The information is not guidance or policy.

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

— U.S. Environmental Protection Agency, 2021

https://semspub.epa.gov/work/HQ/100002993.pdf

1. Purpose

The U.S. Environmental Protection Agency (EPA) Office of Superfund Remediation and Technology Innovation (OSRTI), in collaboration with the Technical Support Project (TSP) Engineering Forum, developed this issue paper to document the lessons learned in conducting climate vulnerability assessments (CVAs) at sites on the National Priorities List (NPL). While developed for Superfund, this process is program neutral and may be used as a guide for performing CVAs at contaminated sites managed under other cleanup programs. Vulnerability assessments may be performed at all site types, by all site leads and at all stages of a cleanup. This issue paper may be used by all stakeholders wanting to replicate the CVA process applied in the Superfund Remedial Program.

2. Background

In June 2021, OSRTI issued a memorandum, *Consideration of Climate Resilience in the Superfund Cleanup Process for non-Federal NPL Sites* (EPA, 2021a). Consistent with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) and associated EPA Superfund guidance, the memo recommends the following approach for EPA regions to consider when evaluating climate resilience during the remedy selection and implementation process:

1. Assess the vulnerability of a remedial action's components and evaluate the impact of climate change on the long-term protectiveness of a selected remedy;
2. Identify and evaluate adaptation measures that increase the system's resilience; and
3. Implement adaptation measures necessary to ensure the long-term protectiveness of CERCLA remedial actions.

As described in the memo, and in response to requests from remedial project managers (RPMs) for assistance in determining site vulnerabilities to climate change, OSRTI offers climate vulnerability assessments as part of the Optimization Program. A climate vulnerability assessment includes conducting a detailed review of the site and remedy components, performing site-specific projections of climate conditions, and assessing how these changes may affect remedy protectiveness. The focus of the assessment is guided by current or planned site infrastructure, the extent to which site and remedy analyses incorporated forward-looking climate data, the type of contamination and structure of waste at the site, and the Superfund remedy phase.

3. Performing a Climate Screening

Before conducting a climate vulnerability assessment, a climate screening[1] may be performed to identify potential exposure to climate change. A screening is designed to identify *potential* future climate exposures at Superfund sites to help inform decision-making. If a significant change in climate is identified and the site includes remedies sensitive to the changes, a climate vulnerability assessment may be warranted.

A climate screening is a high-level assessment of climate exposure to changes in climate hazards such as:

- Extreme temperature
- Heavy precipitation
- Drought
- Inland flooding
- Sea level rise
- Storm surge
- Wildfire
- Landslides

Historic indicators of climate conditions provide a good understanding of what climate hazards are present at a site. However, the rapid rate of climate change requires that we project future conditions to better inform key remedy decisions such as selection, design, and operations, and to anticipate the impact on contaminant

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[1] A climate *screening* is typically limited to analyzing climate projections at a site using publicly available screening tools and considering at a high level potential remedy sensitivities. A climate vulnerability *assessment* includes a deeper analysis into remedy vulnerabilities and existing adaptation measures, including conversations between independent experts and the site team.

movement. Publicly available climate screening tools are available to identify changes in climate exposure for sites. A selection of commonly used climate exposure screening tools is listed in *Section 8. Selected Resources*. Two future timeframes are often available for review: mid-century and late century. The timeframe used for a climate screening is an important consideration—the timeframe should be associated with the anticipated lifespan of the remedial infrastructure or actions. For example*,* sites with technologies such as groundwater pump and treat may focus on mid-century projections, while those with engineered caps where waste is left in place may focus on late-century projections.

In combination with the identified climate exposure, site managers should consider other site-specific information, such as whether they are already taking action to reduce vulnerabilities at their site (e.g., a resilient remedy is already in place that reduces the impacts of a given climate hazard). Questions an RPM may consider when reviewing results of a screening are provided in *Appendix A. Determining if a Climate Vulnerability Assessment Is Needed at Your Site*. At many sites, a climate screening will provide all the necessary information for an RPM to determine if there are climate change concerns regarding remedy protectiveness. At sites where further information and analysis is required, RPMs may request a site-specific CVA. The following section is based on the lessons learned by the Superfund Remedial Program in piloting CVAs.

4. Assessing Vulnerability to Climate Change

Vulnerability is a function of **exposure**, **sensitivity**, and **adaptive capacity** (see Text Box 1 for definitions). In the context of climate change, a vulnerability assessment can help to identify and prioritize climate risks to contaminated sites.

Figure 1 shows how the climate vulnerability assessment process for Superfund sites or other contaminated sites incorporates these components. As illustrated, the process focuses on assessing change in climate **exposure** and remedy **sensitivity** to identify key climate vulnerabilities to climate changes at the site. The remedy **sensitivity** analysis documents the degree to which forward-looking climate data has already been considered and any measures for improving **adaptive capacity** that are already in place. **Vulnerabilities** are flagged and documented if there is an **exposure** and a potential **sensitivity** to the specific remedy (e.g., projected extreme heat and drought conditions may cause water stress for a vegetative cover, reducing the protectiveness of the remedy).

> **Text Box 1. Key Definitions**
>
> **Vulnerability**
>
> The degree to which a system or site is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes
>
> **Exposure**
>
> Whether a site could experience a climate hazard
>
> **Sensitivity**
>
> The degree to which a climate hazard impacts remedy protectiveness
>
> **Adaptive Capacity**
>
> The ability of a system to adjust to climate change (including climate variability and extremes), moderate potential damages, take advantage of opportunities, or cope with the consequences
>
> **Resilience**
>
> The capacity of a system to maintain function in the face of stresses imposed by climate change and to adapt the system to be better prepared for future climate impacts

The end goals of the vulnerability assessment are to:

- Assess future changes in climate conditions at a site so they may be factored into site decision-making;
- Determine whether the adoption of adaptation measures is necessary to improve remedy resilience (e.g., planting a drought-tolerant species for the vegetative cover); and
- Ensure remedy protectiveness is maintained under future changes in climate.

The purpose of this effort is to detail OSRTI's application of the vulnerability assessment process to Superfund sites at various stages of the remediation process. This tailored process draws on best practices, lessons learned (see Text Box 2), and the current state of the science.[2] Assessments may be performed at all site types and by all site leads (i.e., federal, state, or potentially responsible party). While developed for and applied to Superfund sites, the process is program neutral and could be modified for other types of contaminated sites.

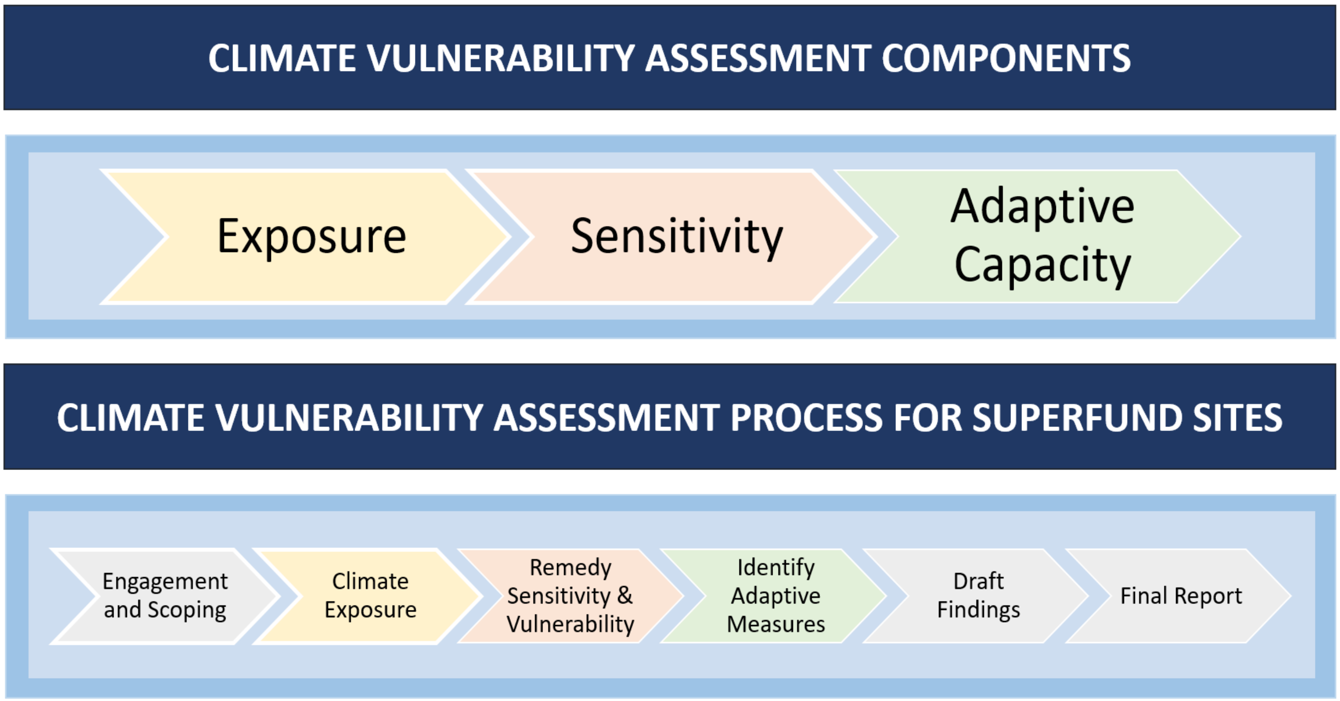

Figure 1. Comparison of the climate vulnerability assessment process components and the climate vulnerability assessment process implemented for Superfund sites.

Remedies at Superfund sites are already designed to maintain protectiveness under current climate conditions. Following the 2017 hurricane season in which three major hurricanes (Harvey, Irma, and Maria) made U.S. landfall, EPA evaluated information on the performance of remedies in areas recently impacted by the three hurricanes. The study, completed with input from the TSP Engineering Forum, concluded that damage was limited and adaptation measures to ensure remedy resilience are being implemented at Superfund NPL and Superfund Alternative Approach (SAA) sites where remedies are in place (EPA, 2018). Additional information on this study is summarized in *Appendix B. Previous Efforts Related to Climate Change and Adaptation*. Through the information developed from CVAs, the Superfund Remedial Program seeks to ensure continued protectiveness of remedies under future climate conditions.

The climate vulnerability assessment specifically evaluates the resilience of the remedy to the projected changes in future climate conditions. The CVA therefore identifies changing climate conditions, how these conditions may

[2] Many federal, state, and local agencies have also adapted the climate vulnerability assessment process to meet their specific interests and needs, including the Federal Highway Administration, the National Park Service, the U.S. Department of Agriculture, the U.S. General Services Administration, the U.S. Department of Housing and Urban Development, and the U.S. Forest Service. These agencies have served as benchmarks in piloting climate vulnerability assessments at Superfund sites and in drafting this issue paper.

affect remedy protectiveness, and what adaptation measures may be considered to ensure continued protectiveness under future climate conditions.

Text Box 2. Lessons Learned from Developing and Applying This Process

During the initial piloting of climate vulnerability assessments through Fiscal Year 2023, OSRTI supported climate vulnerability assessments at 26 sites, covering a variety of site types and EPA regions, under both the Superfund and Resource Conservation and Recovery Act cleanup programs. Lessons learned from the initial pilot assessments have informed the development of this formalized climate vulnerability assessment process, including:

- Determine a consistent list of relevant climate variables to include in each assessment
- Use the Representation Concentration Pathways (RCP) 8.5, 90th percentile values for the vulnerability assessment to screen for all potential risks, and provide RCP 4.5, 50th percentile data for select variables to capture a range of possible futures to consider when determining next steps and making future design decisions
- Leverage available local data and resources when possible, supplementing with national datasets as needed (see *Step 2. Climate Exposure* for more information on regional and national datasets)
- Increase the understanding of what remedy types are typically sensitive to certain climate hazards
- Assess the impact of climate change on contaminant movement and the conceptual site model
- Emphasize the importance of engaging RPMs throughout the process to better understand the local context
- Consult with subject matter experts on the planned or constructed remedy at the site to assess potential remedy sensitivities to the *delta*, or change, in future climate conditions
- Determine subject areas that require additional evaluation; these include assessing climate change effects on groundwater biogeochemistry relevant to groundwater contaminants, and how to incorporate climate change into Superfund site assessments
- Document previously performed climate change assessments and adaptation measures already in place

The following sections detail each step of the climate vulnerability assessment process as applied to Superfund sites. Minor modifications may be needed to apply the process to other types of contaminated sites.

Step 1. Engagement and Scoping

Do I need to complete a climate vulnerability assessment for my site?

The climate vulnerability assessment includes a review of site components and site-level climate impacts. Ideal candidates for an assessment include:

- Sites that have performed a climate screening and determined more information and analysis are needed
- Sites with remedies in a climatologically dynamic environment, such as coastal areas, those near waterways, or those subject to extreme temperature and drought conditions
- Sites that have or are currently experiencing damage or disruption from climate or severe weather-related hazards
- Sites that may not have incorporated future climate data into the remedial design
- Sites requiring documentation of remedy resilience to address community or other site stakeholder concerns
- Sites from which a potential release of contaminants caused by climate change would have a disproportionate impact

Additional questions and considerations an RPM may use in determining whether a climate vulnerability assessment is appropriate for their site can be found in Appendix A.

What should be the focus of a climate vulnerability assessment at my site?

The focus of the assessment is guided by current or planned remedy infrastructure, the extent to which site and remedy analyses incorporated forward-looking climate data, the type of contamination and structure of waste at the site, the Superfund remedy phase, and the magnitude of the projected changes in climate. Example support provided by the remedy phase includes:

- Up through remedial investigation (RI): integration of current and projected climate impacts into risk assessments and the conceptual site model (CSM); considerations for potential remedy alternatives
- Feasibility study: analysis of adaptation measures for each remedial alternative based on projected climate impacts
- Remedial design: incorporation of engineered adaptation measures to the remedy design
- Remedial action (RA), long-term response action (LTRA), operation and maintenance (O&M): evaluation of remedy performance under current and future climate and any necessary modifications

Who should be engaged throughout the vulnerability assessment?

As the characteristics of every site are unique, this process requires a collaborative effort with EPA, subject matter experts, site managers, and other relevant staff to understand site specifics and ensure the results will be useful to decision-making. The key engagement points with the site team are during the initial scoping and during the presentation of preliminary vulnerability assessment findings.

The scoping call provides an opportunity for the site manager, regional technical staff, and climate, remediation, and GIS technical experts to discuss and identify site needs related to climate impacts. The site manager typically provides a site overview and identifies the primary climate concerns for current or planned remedies or community concerns. A discussion regarding specific aspects of the site that may be vulnerable to changes in climate leads to the identification of specific site documents requested of the RPM that the experts will review as part of the remedy sensitivity analysis.

Step 2. Climate Exposure

The climate exposure analysis **identifies the projected changes in climate conditions that the site is likely to experience for the appropriate future timeframe.** Understanding the magnitude of expected changes from the baseline to a future time period is an essential input for reflecting on remedy sensitivity and vulnerability. The climate exposure analysis uses the best available site-level climate projections and local data sources. The parameters of the climate exposure analysis are detailed below, including timeframe, climate projection scenarios, data sources, and climate hazard variables.

Timeframe for the Exposure Analysis

Climate projections are typically **provided for a mid-century and late-century 30-year timeframe and compared to a historical baseline.** Climate projections are traditionally presented as a 30-year range to minimize year-to-year natural fluctuations and capture long-term trends. Projections beyond late-century are increasingly uncertain, typically providing diminishing value in informing site decisions.

Choosing an appropriate timeframe for climate projections depends on many factors such as specific conditions and remedies at the site and decision-making needs. Consider the following factors to determine an appropriate timeframe to use:

- **Remedy lifespan** – Certain remedies or infrastructure types are expected to last a certain number of years before needing to be replaced and redesigned. The useful life of a given asset can help determine an appropriate timeframe. For example, if the useful life is 30 years, mid-century projections would be appropriate to use for informing decision-making.
- **Criticality** – Assets that provide critical services or protection from severe consequences should be built to last as long as necessary. Thus, both mid-century and late-century projections would be appropriate to consider.

Climate Projection Scenarios Used for the Exposure Analysis

Climate projections are inherently uncertain and as a result **a range of emission scenarios are available to use**. These scenarios represent different potential futures, depending on factors like the adoption of major policies to reduce global greenhouse gas emissions.

The Superfund climate risk assessments use projections for the 90th percentile of the high emissions scenario to better understand the "worst case" scenario. If a CVA analysis indicates a remedy (as designed or built) continues to be protective under the worst-case future climate scenario, the site team will have greater certainty regarding its continued protectiveness.

While the worst-case scenario is useful for screening purposes, additional climate data may be needed when making design and adaptation measure decisions as it may not always be feasible or effective to build to those projections. To help inform future decision-making, projections for the 50th percentile of the intermediate-low scenario, which assumes significant reductions in greenhouse gas emissions by mid-century, are included in the appendix of each climate vulnerability assessment report for select variables.[3] Using a range of projections and considering risk tolerance allows for the fine-tuning of adaptation measures. **Risk tolerance** is the willingness to accept potential climate impacts to a project or remedy. For example, designing to a higher emissions scenario may lead to a more costly project. Risk tolerance is influenced by factors such as asset criticality. If damage or failure to a remedy would have major health or environmental consequences, risk tolerance is low, and it may be worth building to the more conservative projections. If there are backup measures in place that would limit the severity of consequences, risk tolerance is higher, and it may be

Text Box 3. Climate Scenarios

Climate projection scenarios are updated periodically based on the latest science. The Superfund climate risk assessments originally used Coupled Model Intercomparison Project Phase 5 (CMIP5) scenarios until the release of CMIP6.

CVAs incorporate climate projections under a worst-case scenario to conservatively screen for all potential climate risks at a site, accomplished by using the **90th percentile of a high emissions climate scenario**.

For CMIP5, RCP 8.5 assumes greenhouse gas concentrations continue to rise through 2100 and represented the worst-case emissions scenario.

CMIP6 defines emission scenarios differently through Shared Socioeconomic Pathways (SSPs). These scenarios are future narratives that reflect different socio-economic development strategies, climate policies that may be undertaken by society, and radiative forcing levels. SSP5-8.5 is considered the worst-case scenario in the new CMIP6 climate models and represents an "unabated" future in which society is still heavily reliant on fossil fuel and CO_2 emissions continue to increase until late into the 21st century.

[3] Additional information on Representation Concentration Pathways can be found on EPA's EnviroAtlas website: https://www.epa.gov/enviroatlas/changes-over-time.

worth the cost savings to build to the lower scenario. Discussion of risk tolerance helps to improve the transparency and credibility of any subsequent decisions.

Data Sources Used for the Exposure Analysis

While there are a variety of climate data sources available, the Superfund Remedial Program used best-available data from an ensemble of statistically downscaled global climate models (see Table 2 for specific sources) when conducting pilot CVAs. This approach better accounts for uncertainty by including a range of global climate models and it produces climate projections at a finer spatial resolution, which is important for a site-specific assessment.

Superfund climate vulnerability assessments use the latest versions of LOCA (Localized Constructed Analogs) data and CMIP (Coupled Model Intercomparison Project) for generating temperature and precipitation projections.[4] LOCA consists of an ensemble of 32 statistically downscaled CMIP Global Climate Models (GCMs) at 6 × 6 km spatial resolution and daily temporal resolution. The Fourth National Climate Assessment and other peer-reviewed publications leverage LOCA downscaled climate projections over other datasets because of the robust downscaling methodology, spatial and temporal completeness across the continental U.S., and larger model ensemble. A larger model ensemble of climate projections creates a more comprehensive set of plausible future climate change outcomes and associated impacts.[5] From this ensemble, the high end of projections represents a more extreme climate future and allows sites to take a risk-averse position when incorporating climate data.

For climate hazards and variables beyond temperature and precipitation derived from LOCA, the next best available national or local-/state-level data sources are used (see Table 2 for specific sources). For example, California has the Cal-Adapt platform, which provides publicly available climate change data and climate projections for the state, including LOCA-derived average annual temperature and precipitation, but also additional variables such as area burned by wildfire, snowpack, extreme precipitation events, and sea level rise inundation. Furthermore, EPA Shared Enterprise Geodata & Services (SEGS) hosts a curated collection of climate change data (EPA SEGS, 2023). Specific geospatial resources include current climate observations, future climate scenario projections, including LOCA data for a select group of climate hazards, and associated guidance on using climate change data.

Climate Hazards and Variables

To determine a list of climate hazards and variables to include in a climate vulnerability assessment, consider the following questions:

- What climate hazards have affected the site in the past?
- What climate hazards may be of concern under future climate conditions?
- Are there any data limitations on including a particular climate hazard or variable?

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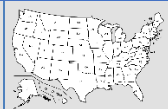
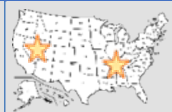
[4] LOCA version 2 was released in 2023 to downscale CMIP6 data. More information on the change from LOCA version 1 to version 2 can be found on the LOCA Statistical Downscaling website: https://loca.ucsd.edu/loca-version-1-vs-loca-version-2/.

[5] Taking the average of many (>20) GCMs reduces uncertainty inherent in model projections by creating a probable range of future climate rather than any one model value. Raw model outputs from GCMs have coarse resolutions and contain biases (e.g., some models trend hotter or wetter than others, some models perform better in certain regions than in others), so using LOCA downscaled data provides these assessments with finer resolution (~6 × 6 km, or 3.7 × 3.7 mi grid cells) and more meteorologically accurate data.

Table 1 summarizes the climate hazards included in the Superfund assessments as appropriate. This list builds on conversations between site managers and technical experts to determine which climate hazards pose potential threats to remedy protectiveness.

Table 1. Climate hazards included in each assessment depend on the site location.

Temperature	Precipitation and Drought	Inland Flooding	Wildfire	Storm Surge	Sea Level Rise	Landslides
 All sites	 All sites	 All sites	 All sites, focus on Western sites	 Coastal sites	 Coastal sites	 All sites, focus on mountainous terrain

Indicates geographic areas where hazards are likely to occur.

These conversations and additional research informed the selection of specific climate variables typically included in the climate exposure analysis (see Table 2). This list is based on an understanding of climate hazards that have affected sites in the past, climate hazards that may affect remedy protectiveness in the future, and data availability; it does not include all climate hazards. Some climate hazards do not have national data sources depicting future change. For climate hazards in areas where only historic data are available, this information may be used in conjunction with future climate projections to better understand a potential change. For example, in areas without future floodplain projections, FEMA historic floodplain maps may be used with return period storm projections to develop an understanding of how a 100-year floodplain might change under future conditions. As appropriate or requested, assessments may include additional variables such as runoff, snow-water equivalent (i.e., the amount of water contained within snowpack when it melts), permafrost, groundwater table depth, evapotranspiration, historic wildfire burn area, and post wildfire debris flow.

Table 2. Climate variables and data sources typically used in the climate exposure analysis for Superfund sites.

Hazard	Variable	Description	Example Data Sources
Temperature	Number of days above 95°F	Days each year when maximum temperatures reach 95°F	LOCA downscaled temperature projection data
	1-in-10-year temperature	The maximum temperature with a 10% annual chance of occurrence	LOCA downscaled temperature projection data
Precipitation	Average total monthly precipitation	Average amount of precipitation falling each month	LOCA downscaled precipitation projection data
	Largest annual 5-day precipitation event	The largest amount of precipitation to fall during 5 consecutive days in a year	LOCA downscaled precipitation projection data
	Return period storms	Amount of precipitation falling during the 1-in-100 year and 1-in-500-year storm	LOCA downscaled precipitation projection data NOAA Atlas 14 Precipitation Frequency Data

Hazard	Variable	Description	Example Data Sources
Drought	Consecutive dry days	Longest consecutive period of days without precipitation	LOCA downscaled precipitation projection data
Flooding	Historic 100-year and 500-year floodplain[6]	The area that will be inundated by a flood having a 1% (100-year floodplain) or 0.2% (500-year floodplain) chance of occurrence each year	FEMA National Flood Hazard Layer
Sea level rise	Sea level rise extent	Area inundated by sea level rise under intermediate-low and high sea level rise scenarios	NASA Interagency Sea Level Rise Scenario Tool NOAA Sea Level Rise Viewer
Storm surge	Storm surge depth	East Coast: Storm surge heights above ground level resulting from hypothetical Category 1 through Category 5 hurricanes West Coast: Storm surge heights above projected future water surface elevation	East Coast: NOAA Sea, Lake and Overland Surges from Hurricanes (SLOSH) model West Coast: Coastal Storm Modeling System (CoSMoS) | U.S. Geological Survey (usgs.gov)
Hurricane	Historic hurricane tracks	Paths of historical hurricanes and associated information (e.g., storm category and effects)	NOAA Historical Hurricane Tracks
Wildfire	Wildfire danger days	Days with 100-hour fuel moisture above the 80th (High), 90th (Very High) and 97th (Extreme) percentile model values	Climate Mapper MACA v2 METDATA downscaled projections for 100-hour fuel moisture
Landslides	Landslide susceptibility	Susceptibility of terrain to landslides based on elevation, geology, fault, roads, and forest loss	NASA Landslide Susceptibility Map

Output of the Exposure Analysis

The results of the climate exposure analysis are presented through graphs (Figure 2), maps (Figure 3), and charts (Figure 4) to help visualize the projected change in climate conditions from present day to mid-century and end of century. Maps in particular can help visualize geographic variability across a larger site.

[6] The FEMA Federal Flood Risk Management Standard (FFRMS) outlines three approaches for federal agencies to manage current and future flood risk. One approach is to use the 500-year floodplain instead of the 100-year floodplain in project siting, design, and construction decisions.

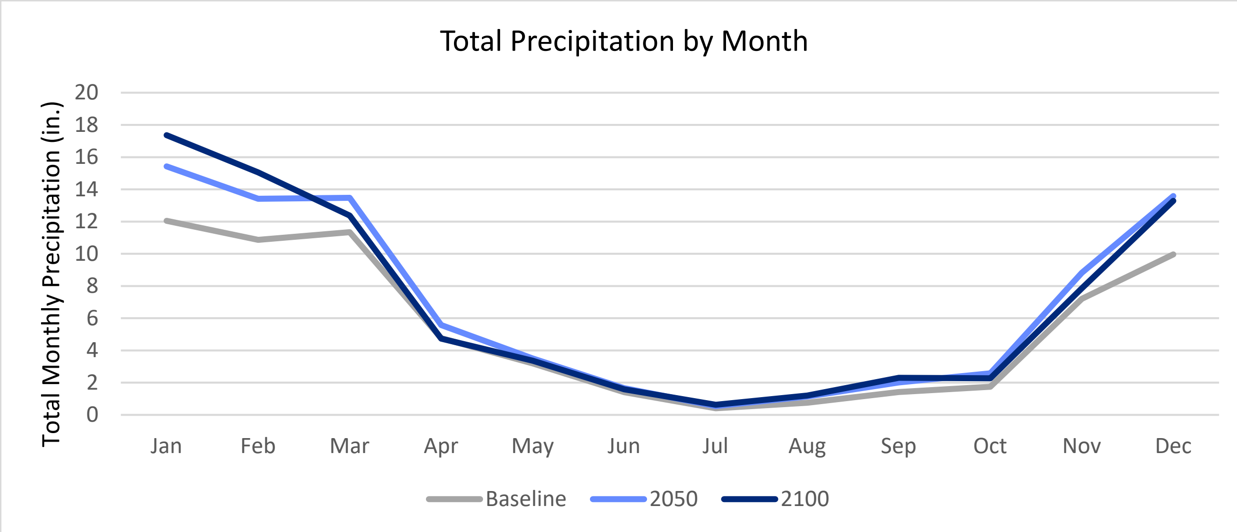


Figure 2. Example output of average total precipitation each month for mid-century and end-of-century based on RCP 8.5 90th percentile model projections.

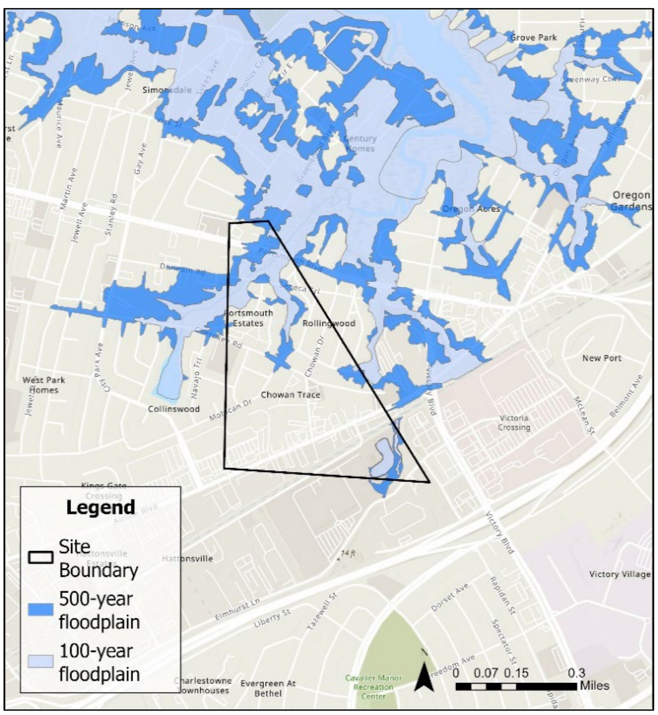


Figure 3. Map showing the 100-year and 500-year floodplain overlap with a theoretical Superfund site.

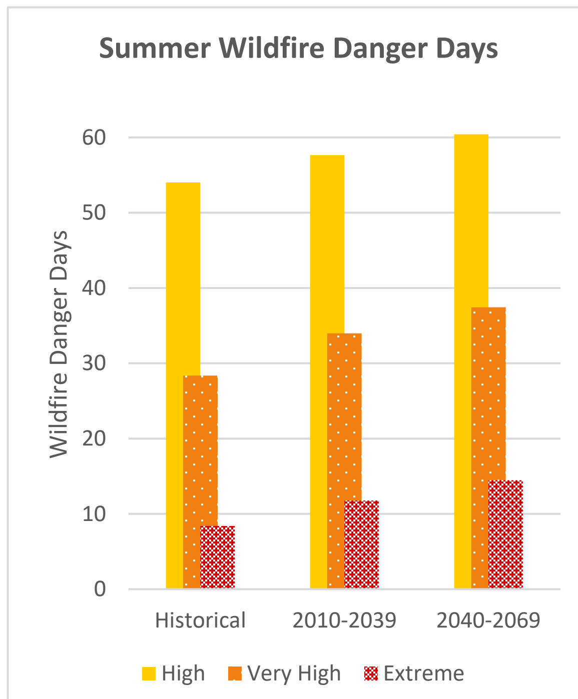


Figure 4. Example output of summer wildfire danger days based on MACA RCP 8.5 projections.

Step 3. Remedy Sensitivity and Vulnerability

The evaluation of a remedy's sensitivity to climate hazards involves **assessing the degree to which a specific climate hazard may impact the remedy's protectiveness**. The remedy sensitivity is then further analyzed in conjunction with the expected climate exposure for the site to determine actual remedy vulnerabilities.

Relevant site documents are reviewed to understand the selected or implemented remedies and contaminated media present at the site. Specific documents may include:

- Remedial Investigation/Feasibility Study (RI/FS) reports

- Decision documents
- As-built and design documents
- Five-Year Review reports
- Remedial Action Completion reports
- O&M plans
- Annual monitoring and sampling reports
- Previous climate analysis
- Relevant data from local waterboards, Army Corps., etc. as it relates to area levees, dams, or other water management features
- Corrective Measures Study
- Corrective Action Plan
- Risk Management Plan
- Analysis of Brownfields cleanup alternatives

Sensitivities associated with site remedies, proposed remedies, or current contaminated media are evaluated against the climate exposures identified for the site. The qualitative intersection between climate exposure and remedy sensitivities, as determined by remedy experts applying professional judgement, identifies site specific vulnerabilities (see Figure 5).

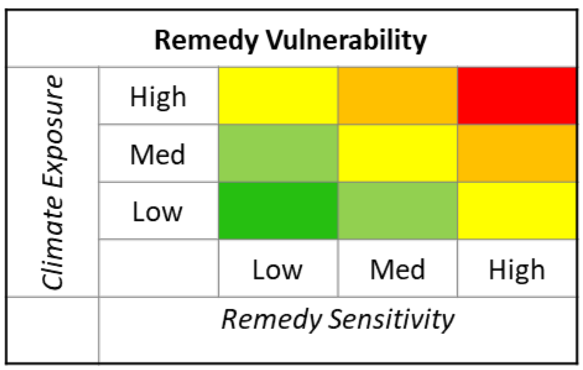


Figure 5. Qualitative depiction of remedy vulnerability. When significant changes in climate coincide with high remedy sensitivity, a vulnerable remedy is identified.

Vulnerabilities of remedial structures that may affect the remedy's protectiveness may arise from the projected increases in extreme events such as wildfires or storms, which are expected to occur at increasing intensities, durations, and frequencies as long-term climate conditions continue to change. Examples of impacts from extreme events that can influence a remedy's vulnerability include power interruption, physical damage, water damage, and reduced access.

Vulnerabilities may also occur due to climate shifts that cause long-term chronic wear and could result in releases to the environment. Specific examples of a vulnerability and the associated loss of remedy protectiveness due to changes in climate are provided in Table 3.

Table 3. Examples of specific vulnerabilities that can arise due to changes in climate and the associated impacts to remedy protectiveness.

Vulnerability	Potential Impacts to Remedy Protectiveness
Increases in precipitation amount associated with 100-year storm event exceed system capacity	Leachate treatment system designed with the capacity for a historic 100-year storm event may no longer be protective during such events
Increases in streamflow that erode unarmored portions of a cap	Migration of contaminants in the stream from cap erosion
Changes in the water table that alter the direction of groundwater flow, impacting plume capture	Migration of groundwater plume to residential drinking water aquifers, or beneath residential buildings introducing vapor intrusion concerns
Increased stress on vegetative caps from increased summer temperatures	Loss of vegetative cover causing exposure of contaminants after storm events or reduced viability of evapotranspiration (ET) covers dependent upon transpiration by vegetation
Desiccation of an unsubmerged sediment cap due to sustained drought conditions	Failure of desiccated and cracked sediment cap after storm event
Increased fluctuations in river and pond levels that cause extended periods of exposed contaminated sediment	Changes in contaminated media properties that impact contaminant migration; for example, increases in mercury methylation
Changes in pond water temperature impacting benthic community	Increased uptake of contaminants by the local biota, resulting in exposure to humans and fauna that consume fish and wild plants
Increases in wildfire hazard and heavy precipitation events increase landslide susceptibility and potential for debris flows, threatening critical infrastructure	Groundwater pump and treat system used for containment is damaged and requires lengthy repairs or replacement, resulting in loss of plume capture

When assessing a remedy's vulnerability to future changes in climate, identifying changes in the climate hazards relevant to the operating period of the remedy is essential. The following examples show how projections may change given the site remedy's operating period:

- **Mid-century projection:** Groundwater pump-and-treat systems are often designed to operate for 30 years or longer. Identifying sensitivities to mid-century climate hazard projections would be appropriate for this system, while the end-of-century projections may not be relevant.
- **End-of-century projection:** Reviewing end-of-century projections would be appropriate to evaluate sensitivities for remedy components such as an engineered cap for which hazardous waste will remain on site indefinitely.
- **Future projections not needed:** Finally, short-term in situ groundwater treatment, such as thermal treatment that would be implemented and completed within the next decade, may not need to be included in a climate vulnerability assessment that focuses only on long-term changes to climate hazards.

In addition to the direct impacts changing climate hazards may have to a remedy's protectiveness (examples provided in Table 3), impacts to ancillary systems on which the site may rely should also be considered. Examples of ancillary system vulnerabilities that should be considered include:

- **Regional access concerns:** Climate hazards, including wildfires and landslides, may impact transportation infrastructure and inhibit access, particularly for remote sites with limited access roads.

- **Regulated waterways:** In addition to directly impacting sites near bodies of water, changes in climate, such as increases in heavy precipitation or periods of drought, may be exacerbated by changes in the management of the waterway by upstream dams.
- **Nearby stormwater controls:** Stormwater runoff associated with increases in extreme precipitation may be exacerbated by changes in nearby land use, such as development of adjacent vegetated areas that previously mitigated runoff, resulting in impervious surfaces that hinder natural infiltration and generate additional stormwater runoff that could impact the site; stormwater controls for a municipality designed to provide capacity for a historic 100-year flood may no longer provide sufficient protection during future 100-year events.
- **Regional water management:** In addition to decreases in infiltration of local aquifers, extended drought conditions may increase regional water demand, resulting in greater groundwater pumping rates and therefore decreasing groundwater levels. Lower groundwater levels may impact plume capture success and require modification of pumping and monitoring wells. Lower groundwater levels may also induce subsidence, which can affect the protectiveness of a cap or alter surface drainage patterns.

Step 4. Adaptation Measures

The *Evaluation of Remedy Resilience at Superfund NPL and SAA Sites* report (EPA, 2018) identified that significant redundancies are often designed into Superfund remedies. For example, the existing stormwater management system may have been designed with sufficient capacity to exceed historic stormwater runoff rates and provide sufficient capacity for future projected runoff. While not always identified as "climate adaptation measures," these measures do provide adaptive capacity and hence are also reviewed as part of a CVA. Remedies determined to demonstrate sufficient adaptive capacity to the identified vulnerabilities may require no modification at present . Assurance of sufficient capacity is an iterative process. Monitoring the performance of the remedy and reassessing the remedy's vulnerability to future climate change should be performed periodically as required to ensure remedy protectiveness. When determining the appropriate adaptive capacity to future climate change events, additional consideration may be given to the potential release of contaminants that would have a disproportionate impact on nearby communities or ecological receptors. For example, at a site with contained hazardous material located adjacent to a riverbank, potential adaptation measures may include:

- Armoring along the base of the cap to add resilience to projected changes to streamflow conditions
- Updating monitoring plans to require site inspections after storm events to assess the performance of the armoring

For remedy components that lack sufficient adaptive capacity or are in a pre-design phase, additional considerations regarding adaptation measures may be provided. Examples of considerations regarding improving adaptive capacity for identified vulnerabilities include:

- Designing waste management areas away from future flood zones
- Completing wells above future expected flood stage and adding well-head housing
- Procuring a backup power supply and remote access to groundwater treatment systems
- Adding capacity to storm water management structures
- Implementing additional monitoring of vegetative cap after extreme events and planning a transition toward flood, drought, or salt tolerant plants; a mix of native plant species often provide resilience to climate change
- Maximizing thickness of the gravel layer in sediment cap to prevent water-related erosion associated with increased flood events

Step 5. Climate Vulnerability Assessment Presentation

The site team first receives a preliminary results presentation of the climate vulnerability assessment, which typically includes the following information:

- Charts and quantitative results from the climate exposure analysis
- Discussion of remedy sensitivities and vulnerabilities
- Identification of existing adaptation measures that ensure remedy resilience
- Considerations for adaptation measures to maintain remedy protectiveness under future climate scenarios

This presentation is an opportunity for the site team to provide feedback on the initial findings before the assessment is finalized as a written report. The site team and independent experts may discuss inclusion of additional climate exposure analyses in the written report as well as specific considerations regarding identified vulnerabilities and potential adaptation measures. As the characteristics of every site are unique, additional site-specific requests may include providing:

- Model inputs of climate data to site team for use in water quality or fate and transport models
- Geospatial shapefiles of climate hazards
- Additional design considerations for adaptation measures

Step 6. Climate Vulnerability Assessment Report and Application of Results

The site team then receives a climate vulnerability assessment report, which begins with a description of the scope and methodology of the assessment. Quantitative results from the climate exposure analyses document a range of projected changes in climate conditions at the site. Remedy sensitivities are described and analyzed in conjunction with the climate exposure. If there is a specific climate exposure and a potential sensitivity to the remedy, the vulnerability is identified and considerations regarding potential adaptation measures are provided. The text box below summarizes the main sections of the report.

Text Box 4. Example Climate Vulnerability Assessment Report Structure

- **Executive Summary**
- **Introduction**: scope and purpose of the assessment
- **Site Background**: location and history, primary contaminants, remedial and removal actions, map of site features
- **Climate Exposure**: projections and data visualizations for relevant climate hazards
- **Remedy Vulnerability and Resilience**: specific sensitivities for planned or in-place site remedies and identification of vulnerabilities for which climate exposure and remedy sensitivities intersect; adaptive capacity of the remedy and considerations for additional adaptation measures
- **References**: documents reviewed and cited as part of the assessment
- **Appendix:** additional climate projection data

The goal of the climate vulnerability assessment report and the data discussed within it is to assist the RPM with the following activities:

- **Investigation and assessing alternatives:** Address concerns regarding the long-term protectiveness of the remedial alternatives considered during the investigation and feasibility study.
- **Remedy selection:** Identify known vulnerabilities for remedies selected in decision documents and provide considerations on how to address them in design.
- **Remedy design:** Ensure specific adaptation measures are incorporated into the design to provide resilience to future climate impacts.
- **Remedy operation:** Evaluate the remedy during periodic reassessment and implement adaptation measures as needed to ensure long-term protectiveness; evaluate future reuse options for the site.
- **Community engagement:** Provide documentation of existing remedy resilience and plan for proactively addressing vulnerabilities to future climate conditions.

5. Summary

This issue paper introduces the process for conducting a climate vulnerability assessment at a Superfund site, including:

1. **Engagement and scoping**: Determine whether a climate vulnerability assessment is necessary at a site either through a screening or discussion with technical experts. If the climate vulnerability assessment is required, scope the assessment.
2. **Climate exposure**: Evaluate current and future climate conditions to understand how site exposure to various climate hazards may change over time.
3. **Remedy sensitivity and vulnerability**: Assess how future climate conditions could affect remedy protectiveness and mobilization of contaminants.
4. **Adaptation measures**: Consider the effectiveness of additional adaptation measures in reducing risk.
5. **Climate vulnerability assessment findings**: Present and discuss findings of the climate vulnerability assessment with the RPM and other key staff.
6. **Climate vulnerability assessment report**: Document findings and outline next steps.

6. Acknowledgements

This issue paper was prepared by the U.S. EPA Office of Superfund Remediation and Technology Innovation in collaboration with the Technical Support Project Engineering Forum.

7. Notice and Disclaimer

The EPA Technical Support Project Engineering Forum authored this issue paper. This document has been reviewed in accordance with EPA procedures and has been approved for publication as an EPA publication. The information in this paper is not intended, nor can it be relied upon, to create any rights enforceable by any party in litigation with the United States or any other party. This document is neither regulation nor should it be construed to represent EPA policy or guidance. Use or mention of trade names does not constitute an endorsement or recommendation for use by EPA.

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A PDF version of this issue paper, *Conducting Climate Vulnerability Assessments at Superfund Sites,* is available to view or download at the U.S. EPA TSP–Engineering Forum website: *https://www.epa.gov/remedytech/technical-support-project-engineering-forum*.

8. Selected Resources

Superfund Climate Resilience | US EPA is regularly updated with resources on climate resilience and adaptation.

Climate Exposure Screening Tools

- EPA, 2023. EPA Climate Data Geoplatform. https://segs-epa.hub.arcgis.com/pages/climate-change
- USGCRP, 2023. Climate Mapping for Resilience and Adaptation (CMRA) Assessment Tool. https://resilience.climate.gov/#assessment-tool
- NOAA, 2023. U.S. Climate Resilience Toolkit Climate Explorer. https://crt-climate-explorer.nemac.org
- FEMA, 2023. National Risk Index. https://hazards.fema.gov/nri/

Superfund Climate Vulnerability Assessment (Example Data Sources)

- Temperature and Precipitation: Statistical Downscaling Using Localized Constructed Analogs (LOCA). Journal of Hydrometeorology, 15(6), 2558-2585. Pierce, D.W. 2014. https://doi.org/10.1175/JHM-D-14-0082.1
- Flooding:

  U.S. National Flood Hazard Layer. Federal Emergency Management Agency (FEMA). https://www.fema.gov/flood-maps/national-flood-hazard-layer

  U.S. Atlas 14 Precipitation Frequency Data. U.S. Federal Government, National Oceanic and Atmospheric Administration (NOAA), 2023. https://hdsc.nws.noaa.gov/pfds/
- Sea Level Rise: Interagency Sea Level Rise Scenario Tool and NOAA Sea Level Rise Viewer. National Aeronautics and Space Administration (NASA). https://coast.noaa.gov/slrdata/
- Storm Surge:

  Sea, Lake and Overland Surges from Hurricanes (SLOSH) model. National Oceanic and Atmospheric Administration (NOAA). https://www.nhc.noaa.gov/nationalsurge/

  Development of the Coastal Storm Modeling System (CoSMoS) for predicting the impact of storms on high-energy, active-margin coasts. Natural Hazards, Volume 74 (2), p. 1095-1125. Barnard, P.L. 2014. http://doi.org/10.1007/s11069-014-1236-y
- Hurricanes: Historical Hurricane Tracks. National Oceanic and Atmospheric Administration (NOAA). https://coast.noaa.gov/hurricanes
- Wildfire: Climate Mapper: Downscaled projections for 100-hour fuel moisture (MACA v2 METDATA). Climate Toolbox. April 2022. https://climatetoolbox.org/tool/climate-mapper

- Landslide: Landslide Hazard Assessment for Situational Awareness (LHASA) Model. National Aeronautics and Space Administration (NASA). July 2022. https://gpm.nasa.gov/landslides/projects.html

Climate Change and Adaptation Reports

- Consideration of Climate Resilience in the Superfund Cleanup Process for Non-Federal National Priorities List Sites. U.S. Environmental Protection Agency (EPA). OLEM Dir. No. 9355.1-120. June 2021. https://semspub.epa.gov/work/HQ/100002993.pdf
- Climate Adaptation Action Plan. EPA 231-R-210-01. U.S. Environmental Protection Agency (EPA). October 2021. https://www.epa.gov/system/files/documents/2021-09/epa-climate-adaptation-plan-pdf-version.pdf

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U.S. Environmental Protection Agency. 2019b. Climate Resilience Technical Fact Sheet: Contaminated Waste Containment Systems. EPA 542-F-19-004. October. https://www.epa.gov/sites/default/files/2019-12/documents/cr_containment_fact_sheet_2019_update.pdf

U.S. Environmental Protection Agency. 2019c. Climate Resilience Technical Fact Sheet: Groundwater Remediation Systems. EPA 542-F-19-005. October. https://www.epa.gov/sites/default/files/2019-12/documents/cr_groundwater_systems_fact_sheet_2019_update.pdf

U.S. Environmental Protection Agency. 2021a. Consideration of Climate Resilience in the Superfund Cleanup Process for Non-Federal National Priorities List Sites. OLEM Dir. No. 9355.1-120. June. https://semspub.epa.gov/work/HQ/100002993.pdf

U.S. Environmental Protection Agency. 2021b. Climate Adaptation Action Plan. EPA 231-R-210-01. October. https://www.epa.gov/system/files/documents/2021-09/epa-climate-adaptation-plan-pdf-version.pdf

U.S. Environmental Protection Agency. 2023. Shared Enterprise Geodata & Services (SEGS): Climate Change. Accessed August 4, 2023. https://segs-epa.hub.arcgis.com/pages/climate-change

Appendix A. Determining if a Climate Vulnerability Assessment Is Needed at Your Site

If a vulnerability assessment is needed at the site and assistance is required to perform the assessment, remedial project managers can submit requests for EPA Headquarters support through the Climate Vulnerability Assessment Engagement Form (access through VPN required). The EPA Headquarters lead will review the request and schedule a scoping call.

- **Candidates for an assessment include:**
  - Sites that have performed a climate screening and determined more information and analysis is needed
  - Sites with remedies that have or are currently experiencing damage or disruption from climate or severe weather-related hazards
  - Sites that may not have incorporated future climate data
  - Sites requiring documentation of remedy resilience to address community or other site stakeholder concerns
  - Sites from which a potential release of contaminants caused by climate change would have a disproportionate impact
- **The following list of questions can aid in the decision-making process:**
  - Has forward-looking climate data been evaluated for the site?
  - Have there been previous climate-related impacts at the site?
  - What is the capacity to respond if a release were to occur?
  - Were selected remedies with vulnerabilities implemented? If still in place, are they expected to remain in place for more than 10 years?
  - Were adaptation measures incorporated into the remedial design, monitoring, and/or operation and maintenance?
  - When is the operation of the remedy anticipated to commence, and what is the timeframe for the remedy to be in place?
  - Are there other remedial actions planned (or operable units without a signed decision document) that may have vulnerable infrastructure?
  - Has the community raised concerns about climate impacts to the site?

Appendix B. Previous Efforts Related to Climate Change and Adaptation

In June 2011, EPA issued a Policy Statement on Climate-Change Adaptation (revised 2014; EPA, 2014a) that recognized that climate change can pose significant challenges to EPA's ability to fulfill its mission (see Figure 6). It called for the agency to anticipate and plan for future changes in climate and incorporate considerations of climate change into its activities. In response, OSRTI conducted a program-wide vulnerability analysis in 2011—2012 that resulted in the internal February 2012 report *Adaptation of Superfund Remediation to Climate Change* (EPA, 2012). This analysis considered to what degree Superfund sites were vulnerable to flooding and sea level rise, and selected candidate sites to use as case studies for assessing how project managers evaluated and responded to the effects of climate change on Superfund remedial actions.

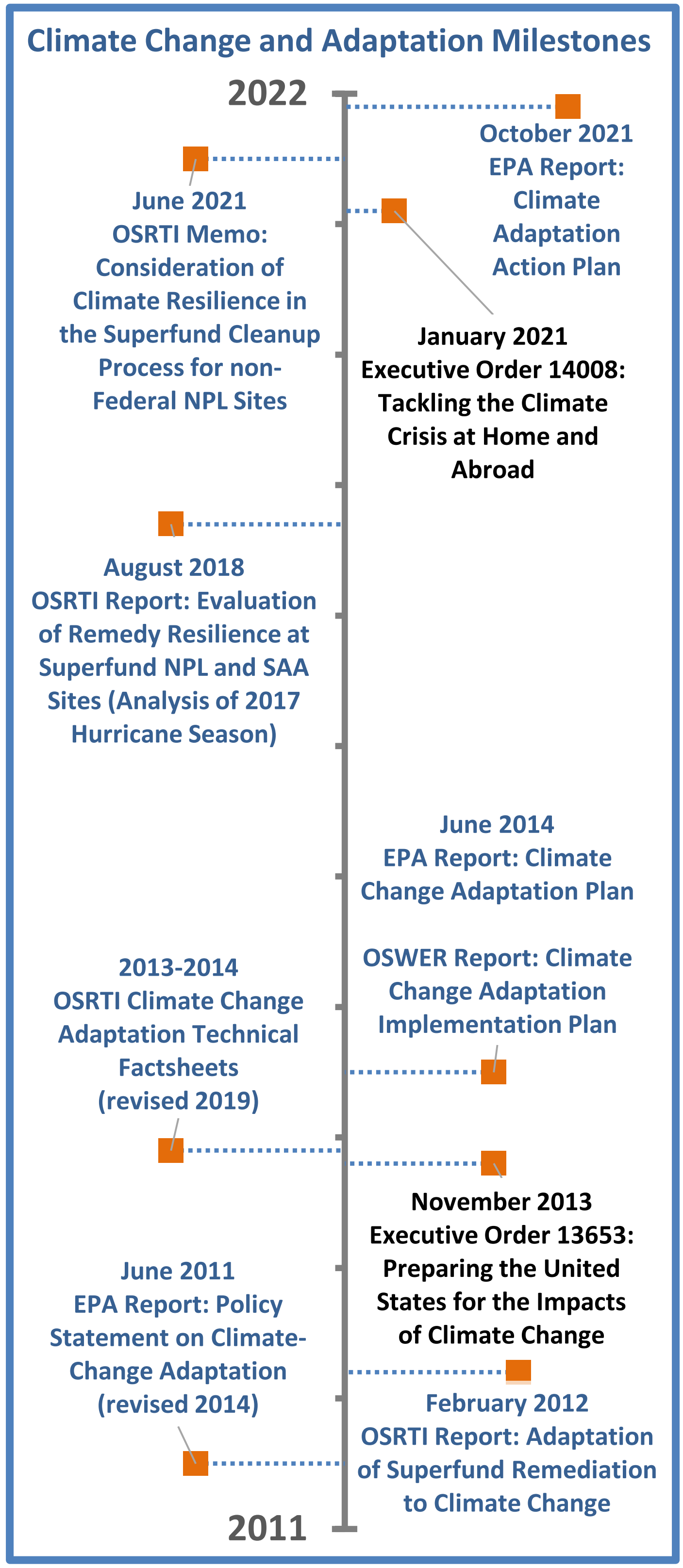

Figure 6. Timeline of key Superfund-related climate change and adaption milestones.

In 2013, federal agencies were directed by Executive Order 13653 to consider how climate change may affect their capacity to implement their core missions. Based on the findings of the OSRTI February 2012 report, and as part of the Agency and the Office of Land and Emergency Management's (OLEM) response to the executive order, EPA determined that the existing regulatory framework included the authorities and guidance needed to address the challenge, and no changes were needed. Therefore, EPA focused on developing technical resources, support, and training to raise awareness among stakeholders, including remedial project managers. The technical resources were designed to be "program neutral" and could be used at any contaminated site cleanup, regardless of the regulatory framework under which it was conducted.

OLEM participated in the cross-agency workgroup that developed EPA's Climate Change Adaptation Plan. The final Climate Change Adaptation Plan released in 2014 (EPA, 2014b) examined how EPA programs may be vulnerable to a changing climate and how the Agency can accordingly adapt so it can continue meeting its mission of protecting human health and the environment. In addition to the Agency's Climate Change Adaptation Plan, the 2011 Policy Statement also directed every EPA program and regional office to develop an Implementation Plan that provides more detail on how it will meet the priorities and carry out the work called for in the agency-wide plan. In June 2014, the Office of Solid Waste and Environmental Response (OSWER)[7] released its Climate Change Adaptation Implementation Plan (EPA, 2014c), which described OSWER's process for identifying climate change impacts to its programs and the plan for integrating consideration of climate change impacts in the office's work. Furthermore, OLEM continued to monitor the status of climate science—particularly as it relates to known or anticipated impacts on OLEM's program areas, as well as the effectiveness of its program activities under changing conditions—and update or adjust its direction as necessary.

As part of OLEM's commitment to developing and maintaining technical guidance, OSRTI released a series of Climate Change Adaptation Technical factsheets (revised in 2019; EPA, 2019a; EPA, 2019b; and EPA, 2019c), which incorporated input from the TSP Engineering Forum, focusing on adaptation measures that may be considered to increase a remedy's resilience to climate change impacts. Following the 2017 hurricane season that included three major hurricanes (Harvey, Irma, and Maria) making U.S. landfall, EPA sought to gather information on the performance of remedies in areas recently impacted by the three hurricanes. The report (EPA, 2018) evaluated the impacts from the hurricanes and summarized EPA's response, and incorporated input from the TSP Engineering Forum. The study concluded that damage was limited, and resilience measures are being implemented at Superfund NPL and Superfund Alternative Approach sites where remedies are in place.

In October 2021, EPA released its new Climate Adaptation Action Plan (EPA, 2021b) in response to Executive Order 14008. The plan accelerates and focuses attention on priority actions the Agency will take to increase human and ecosystem resilience as climate changes and the disruptive impacts increase.

[7] EPA changed the name of the Office of Solid Waste and Emergency Response (OSWER) to the Office of Land and Emergency Management (OLEM), effective December 15, 2015.