



A GUIDE FOR EPA REGIONS ON
PLANNING LUST CLEANUPS IN A
CHANGING CLIMATE

Purpose

The purpose of this guide is to help the U.S. Environmental Protection Agency's Leaking Underground Storage Tank cleanup¹ project managers identify, mitigate, and adapt to climate change risks for corrective action projects where the EPA is the lead agency. This document supplements the [UST Flood and Wildfire Guides](#) that help owners and operators prepare for flood and wildfire effects on UST facilities. This guide also may be useful when working with Tribes, UST owners and operators, state, and federal partners.

Background

In recent years, there have been an increasing number of very costly weather-related, climate disaster events.² These natural disasters may result from or be exacerbated by intermittent extreme weather events or sustained climate change. These events can impact all types of UST sites, including active USTs and Leaking UST cleanups. Some climate change effects may be beneficial for LUST remediation, while some may not. Climate phenomena that can have adverse impacts on LUST sites include:

- Increases in frequency and intensity of extreme weather events (e.g., wildfires)
- Temperature fluctuations
- Rising seas
- Storm surges
- Inland and coastal flooding
- Changes in groundwater levels and direction
- Drought
- Permafrost thaw.

However LUST remediation efforts may benefit from changes, such as increased dissolved oxygen in groundwater from increased rainfall. In addition, climate change has significant regional variability. Coastal areas experience significant inundation and compounding effects of subsidence and sea level rise.³ Parts of the western U.S. experience droughts that have caused groundwater elevations to fall. The EPA project managers for LUST corrective actions should be aware of possible climate change impacts, both current and future, at their sites.

¹ This document uses the terms cleanup and corrective action interchangeably to refer to all activities related to the investigation, characterization, and cleanup, remediation, monitoring, and closure of an UST release.

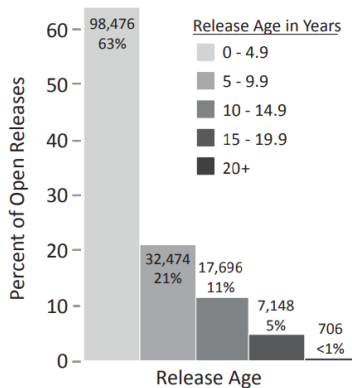
² NOAA reports that "[between 1980 and 2023, 174 Severe Storm, 41 Flooding, 22 Winter Storm, 30 Drought, 21 Wildfire, 60 Tropical Cyclone, and 9 Freeze billion-dollar disaster events affected the United States.](#)"

³ <https://www.nature.com/articles/s41893-022-00947-z>

Climate Change Mitigation and Adaptation Strategies for LUST Cleanups

Climate change effects should be evaluated throughout the LUST project lifecycle and should be incorporated into site decisions. The EPA’s LUST cleanup project managers should consider both mitigation and adaptation strategies in their corrective action projects. Where appropriate, project manager considerations should be informed by knowledge from local communities and Indigenous Knowledge that Tribal Nations and Indigenous Peoples have gained and passed down from generation to generation.

Figure 12. Age Distribution of Closed LUST Releases in 14 Participating States



In a 2011 [National LUST Cleanup Backlog: A study of opportunities](#), the EPA found that 84% of LUST cases in participating states were closed within 10 years.

The appropriate timeframe for considering climate change in LUST corrective actions is typically less than ten years, as most assessment and active remediation will be complete within this time frame, unlike many larger scale RCRA and CERCLA sites that may be addressing more recalcitrant contaminants.

When residual contamination is left in place, longer-term climate change effects may need to be considered in ongoing stewardship activities.

Recommended mitigation and adaptation strategies and examples are described in the sections below.

Mitigation

Mitigation measures for climate change at LUST cleanups typically focus on reducing energy use to decrease greenhouse gas generation. The examples below may be appropriate at many LUST sites.

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- Use high resolution site characterization techniques to minimize mobilizations and to delineate petroleum hydrocarbon plumes more accurately. More accurately defining the plume using HRSC allows the number of monitoring wells to be reduced and may reduce the time taken to either remediate or gather an adequate monitoring data set to make case decisions.
- Use less energy-intensive drilling techniques (e.g., direct push rather than hollow stem augers) to reduce energy use during transportation and investigation.
- Use less energy-intensive cleanup technologies (e.g., passive bioventing compared with dual phase extraction) where practical to achieve case cleanup objectives.
- Use renewable energy sources where available to power remediation and monitoring equipment.

For further information, go to EPA's [Greener Cleanup resources](#), particularly [Green Remediation Best Management Practices: Sites with Leaking Underground Storage Tanks](#) and ITRC's [Sustainable Resilient Remediation](#) resources, particularly [Appendix D](#).

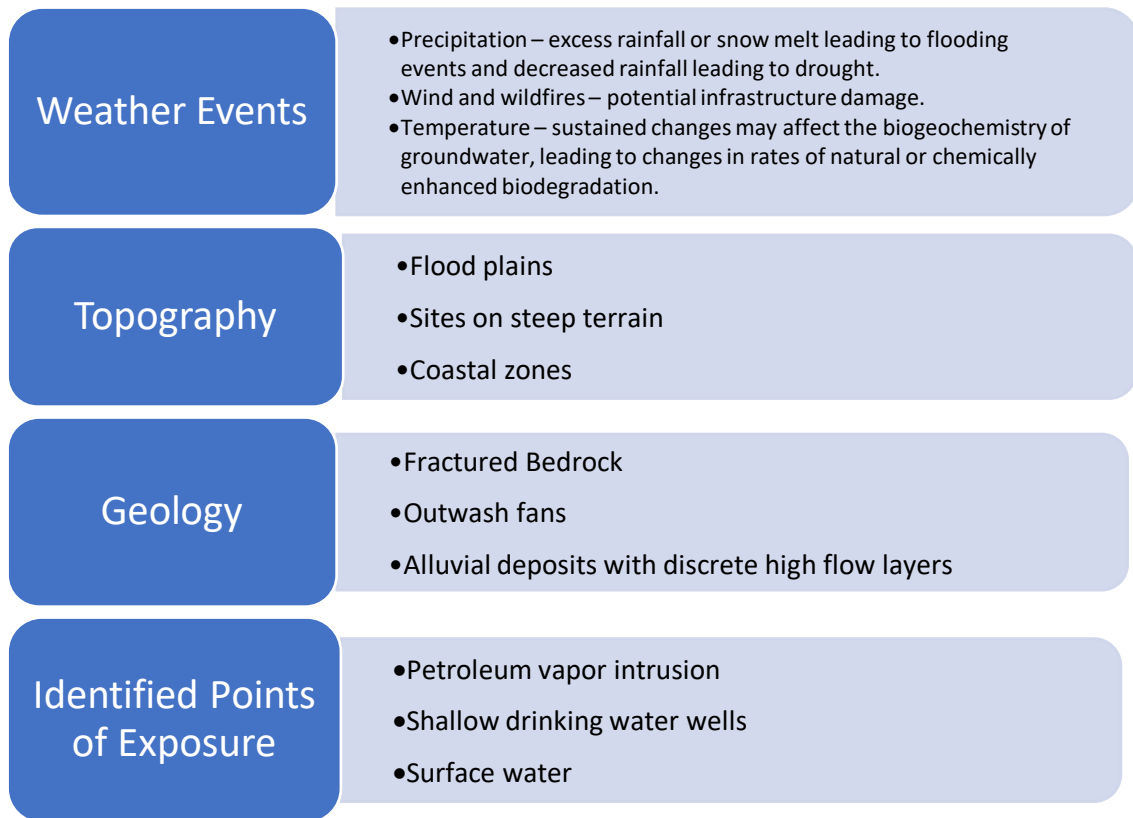
Adaptation

Climate change effects need to be considered for new cases and existing LUST cases at all project review stages (i.e., soil and groundwater investigation, corrective action plan development or modification, and before case closure). Above ground assessment and remediation infrastructure may be vulnerable to flooding, wildfires, and permafrost melt. The [UST Flood and Wildfire guides](#) provide general recommendations for UST facility infrastructure after these events. These recommendations are typically applicable to remediation equipment as well.

Climate Vulnerability Assessment at LUST sites

Certain geologic, geographic, and climate conditions can make some LUST sites more vulnerable to climate change than others. Project managers should consider the likelihood and potential consequences of climate change when assessing the climate vulnerability of a LUST site. Tools to help with climate vulnerability assessment include EPA's [Handbook on Indicators of Community Vulnerability to Extreme Events](#), [Conducting Climate Vulnerability Assessments at Superfund Sites](#), and using tools like [UST finder](#) to locate sites that are in flood plains and that are vulnerable to wildfires.

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Geologic, Geographic, and Climate Conditions to Consider

Conceptual Site Model considerations

The impact of climate change on LUST cases should be considered when developing the Conceptual Site Model and as the CSM is modified as the case evolves from initial investigation to a *no further action* determination.

At sites with a high potential for climate change to change decision making criteria (such as the depth to contaminated groundwater or LNAPL due to rising groundwater) it may be appropriate to consider adopting a post closure review process.

Project managers should ensure that LUST CSMs acknowledge both short- and long-term effects of changing groundwater elevations, whether rising from flooding and increased rainfall or falling from drought, that may result from climate change. This may be particularly important when points of exposure are vulnerable to rising groundwater elevations, transient rapid groundwater flow, or sustained changes in groundwater velocity or direction. Points of exposure at higher risk from these changes include:

- Buildings at risk from petroleum vapor intrusion.
- Shallow drinking water wells.
- Surface water.

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Groundwater monitoring networks need to be resilient to changes in groundwater elevation:

- Groundwater changes greater than five feet may require modifications to the well network.
- Multilevel sampling systems designed to sample at discrete intervals above and below current groundwater elevations can be used to accommodate short- and long-term changes in groundwater elevation.
- Sampling points may be needed above current average groundwater elevations to sample lateral groundwater flow in transient perched water tables and enhanced vertical flow after heavy rainfall or flood events. These transient events may affect contaminant movement and may mobilize residual contamination.

Avoid using long screen wells (ten feet or greater) to accommodate long-term groundwater elevation changes. Long screen wells create enhanced contaminant movement pathways. They have the potential to connect zones of high and low flow and groundwater bearing layers with different contaminant concentrations, resulting in misleading groundwater data (for example, diluting peak concentrations and averaging groundwater elevations in different strata). While the disadvantages of long screen lengths exist without climate change, the adverse effects are likely to be increased with fluctuating water levels and enhanced lateral flow in the unsaturated zone with high infiltration storm events.

If sites are subject to flooding or prolonged drought, groundwater conditions and contaminant flow can change, even if only temporarily. Project managers should:

- Modify groundwater sample locations and depths to account for transient flow and flooding.
- Consider additional monitoring events after flooding events.
- Ensure sampling points are appropriately rehabilitated.
- Consider the effect of soil contamination or LNAPL being submerged by rising groundwater.

Rising groundwater levels may also change basic geochemistry (e.g., dissolved oxygen levels may fall, salinity and dissolved iron content may rise) and change the biodegradation rate of petroleum contaminants. For example, rising sea levels may cause saltwater intrusion and increase groundwater salinity at a site, which may change the biodegradation rate of non-aqueous phase liquids and dissolved contaminants.

Site Characterization Infrastructure

- Protect monitoring wells and soil vapor sampling points from flooding using caps and, where site conditions permit, risers.
- Redevelop monitoring points after flood events to ensure samples are representative.
- Clear monitoring point internal surfaces of any contaminants potentially introduced by flooding.

Remediation Infrastructure and Selected Technologies

If it becomes clear during review of soil and groundwater investigation or monitoring events that groundwater conditions have changed, remediation systems may need to be redesigned.

Potential issues include:

- Groundwater extraction wells may no longer be effective.
- LNAPL recovery wells can become ineffective if groundwater falls below the level of the LNAPL source zone or if groundwater rises above and submerges the LNAPL.
- Vapor extraction or bioventing wells may be flooded.
- Groundwater chemistry may have changed.
- Assumed design parameters, such as groundwater velocity or rate of natural degradation, may need to be reassessed.
- Engineering controls may no longer work as designed.
- Less active, longer-term, strategies such as relying on natural or enhanced biodegradation, may be at more risk of failure under climate induced changes than short-term, active, strategies such as excavation.

A review of potential climate change impacts on less active remedial technologies used at LUST sites is attached at the end of this document. More active remediation technologies, such as air sparging or soil vapor extraction, are not expected to be used long enough at LUST sites to be affected by longer-term changes in site conditions during their implementation (though, as noted above, they may be affected by short-term climate events).

For above ground remediation infrastructure, follow the same principles described in the [UST Flood and Wildfire Guides](#) to ensure protection and prompt rehabilitation.

Consider whether remediation equipment (e.g., exposed water or vapor recovery piping) needs to be made resilient to extreme temperature fluctuation events, whether extreme heat or extreme cold (such as experienced during a “polar vortex”).

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Engineering Controls

Design engineering controls to accommodate long-term rising groundwater levels and potential flooding events, whether the engineering controls are used for groundwater or vapor control.

Institutional Controls

Groundwater elevation changes, rainfall events, flooding or sea level rise due to climate change are likely to increase the area impacted by a release. These impacts on residual contamination or biogeochemistry will vary the long-term risk of exposure. In such cases, consider making institutional controls more restrictive. For example, restrict the use of basements if groundwater elevations are expected to increase to levels of concern for petroleum vapor intrusion.

In conclusion, the effects of climate change, whether from sustained long-term changes such as lower rainfall or from short-term events, such as hurricanes and floods, need to be evaluated throughout the LUST project cycle and before key decision making events, such as corrective action plan development or before case closure.

Additional Resources

- [L.U.S.T.Line – Let’s Talk “Green” at LUST Sites: ASTM’s New Standard Guide for Greener Cleanups \(v.75, p. 16, 2014\)](#)
- [UST Flood and Wildfire Guides](#)
- [Superfund Climate Resilience Resources](#)
- [Climate Resilience Technical Fact Sheet: Groundwater remediation systems](#)
- [Incorporating Sustainability Principles in CERCLA and RCRA Cleanup Enforcement Actions](#)

Longer-term LUST Site Remediation Techniques Susceptible to Climate Change Impacts and Considerations for the Conceptual Site Model.

Remedy Type	Climate Change Impacts on the CSM
<p>Bioremediation. (carbon/nutrient addition, biowalls and biozones, compost systems, bioaugmentation, landfarming, bioventing–bioslurping–oxygen enrichment). The use of microorganisms to transform, degrade, or immobilize contaminants to remedial objectives. May include bioaugmentation (adding bacteria) and biostimulation (adjustment of the subsurface environment by nutrient addition and/or geochemical manipulation).</p>	<p>Hydrologic impacts from severe drought:</p> <ul style="list-style-type: none"> • Reduction in soil moisture. • Temperature increases outside of the effective bioactive range. • Drying of organic matter. • Increased salt content negatively impacts biological activity. <p>Hydrologic impacts from excessive recharge:</p> <ul style="list-style-type: none"> • Increase in dissolved oxygen (DO) may reduce anaerobic microbial activity. • Mobilization outside of the bioactive zone. • Excess moisture. • Increase in groundwater velocity may decrease contaminant residence time in the bioactive zone. • Dilution of bioactive agents and microbial population.
<p>Monitored natural attenuation. The use of unenhanced natural (including physical, chemical, and biological) processes and reaction to mitigate chemical contaminants as part of a site remediation strategy.</p>	<p>Impacts from changing hydrologic conditions:</p> <ul style="list-style-type: none"> • Changed groundwater gradient creates a potential loss of plume control and expansion of contaminant plume toward receptors. • Changed plume dimensions may evade the existing monitoring network. • Changes in groundwater velocity outside of the plume stability regime reduced the ability of natural processes to promote complete contaminant mitigation (destruction or immobilization). • Changed recharge conditions could cause systematic or acute changes to geochemical conditions (e.g., DO, pH, redox) by which MNA processes have stabilized contaminant migration and reduction—these changes may create a need to implement active remedies to control the expanding plume.
<p>In situ chemical oxidation. Chemical oxidants are injected or placed within subsurface to oxidize chemical contaminants to less toxic and/or less mobile constituents.</p>	<p>Exceptional precipitation events may:</p> <ul style="list-style-type: none"> • Create excessive dilution of the oxidant or change plume geometry away from the remedy implementation area. • Results may substantially increase oxidant demand and reduce effectiveness.

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Remedy Type	Climate Change Impacts on the CSM
<p>Phytoremediation. The use of vegetation (including trees, shrubs, and flowering plants) to remove contaminants through groundwater uptake or reduce/degrade contaminants through root zone processes.</p>	<p>Impacts from long-term drought:</p> <ul style="list-style-type: none"> • Excessive stress on vegetation creates weak growth and insufficient hydraulic capture. • Concentration of salt content in soil. • Potential increase in both air and groundwater temperatures creating stress on vegetation health. <p>Impacts from rising seas or lowering groundwater.</p> <ul style="list-style-type: none"> • Reduced availability of fresh water (for most species). • Increased salt content in groundwater and soil. • Inability to capture mobile contaminants. • Increased stress in bioactive root zone limiting microbial-enhanced contaminant mitigation.
<p>Permeable reactive barrier (PRB). Engineered in situ remedy whereby the contaminant treatment material is placed in a defined geometry within the subsurface—often across and perpendicular to a plume -- to mitigate the occurrence or migration of chemical contaminants through physical, chemical, and/or biological processes.</p>	<p>Impacts from changing hydrologic conditions.</p> <ul style="list-style-type: none"> • Changed groundwater gradient creates a potential loss of capture. • Changes in groundwater velocity outside of design residence time promote incomplete contaminant mitigation (destruction or immobilization). • Both increased and decreased recharge may cause an increase or a decrease in ambient dissolved inorganic loading of groundwater, a change in dissolved oxygen content, and a change in pH conditions—all of which may not be consistent with design aspects of the PRB treatment media.
<p>In situ chemical reduction. Remedial process by which chemical reductants are injected or placed within the subsurface to chemically reduce chemical contaminants to less toxic and/or less mobile constituents.</p>	<p>Exceptional precipitation events may:</p> <ul style="list-style-type: none"> • Create excessive dilution of the reductant or change plume geometry away from the remedy implementation area. • Add excessive oxygen to the system increasing reductant loss and reducing the effectiveness of the contaminant reduction process.

Adapted from Warner, S. D., Bekele, D., Nathanail, C. P., Chadalavada, S., & Naidu, R. *Climate-influenced hydrobiogeochemistry and groundwater remedy design: A review. Remediation*, 33, 187–207. March 2023. <https://doi.org/10.1002/rem.21753>. Reused courtesy of Creative Commons Attribution License 4.0.