Sustainable Remediation: Climate Change Resiliency and Green Remediation

A guide for Cleanup Project Managers to:

Increase resiliency of cleanup remedies to climate change impacts
-and-
Increase benefits and reduce impacts from the MTCA Cleanup Process

Toxics Cleanup Program
Washington State Department of Ecology
Olympia, Washington

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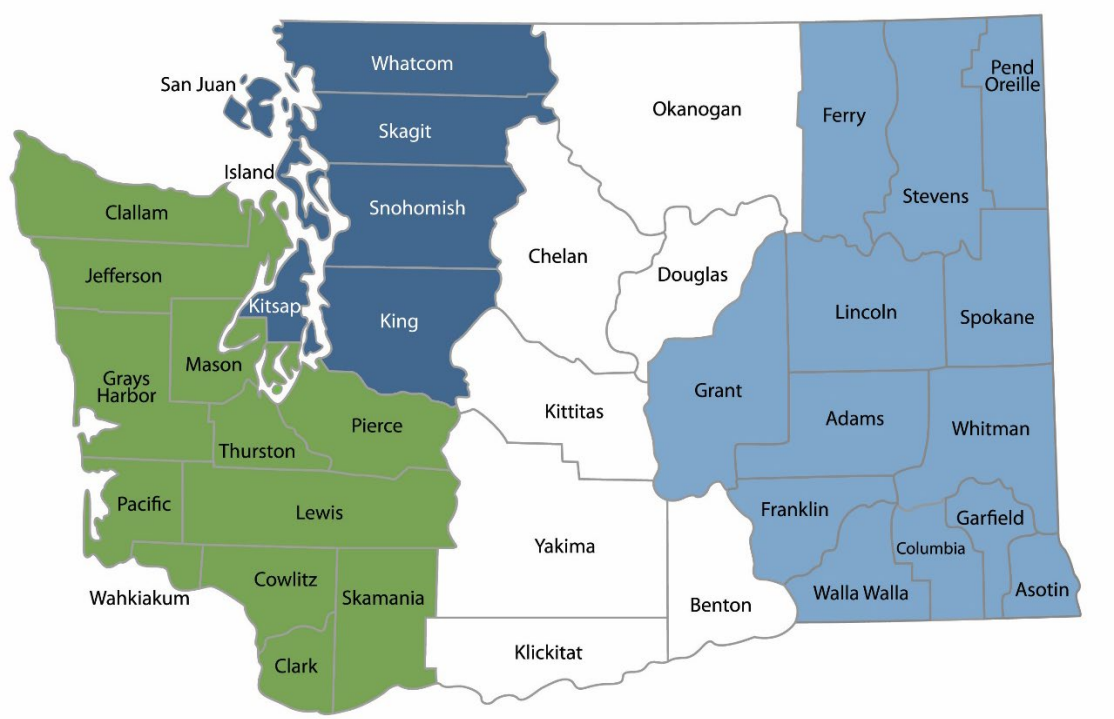
Map of Counties Served



Southwest Region 360-407-6300	Northwest Region 206-594-0000	Central Region 509-575-2490	Eastern Region 509-329-3400

Region	Counties served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	PO Box 47775 Olympia, WA 98504	360-407-6300
Northwest	Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom	PO Box 330316 Shoreline, WA 98133	206-594-0000
Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 W Alder St Union Gap, WA 98903	509-575-2490
Eastern	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 N Monroe Spokane, WA 99205	509-329-3400
Headquarters	Across Washington	PO Box 46700 Olympia, WA 98504	360-407-6000

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Acknowledgments

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Acronyms and Abbreviations

Acronym or Abbreviation	Definition
ASTM	American Society for Testing and Materials
BFE	base flood elevation (or base flood surface water elevation)
BMP	best management practice
BNSF	Burlington Northern Santa Fe Railroad
CAP	Cleanup Action Plan
CIG	Climate Impacts Group, University of Washington
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CPM	Cleanup Project Manager, also known as site manager
CREAT	Climate Resilience Evaluation and Awareness Tool
DCA	disproportionate cost analysis
DNAPL	dense non-aqueous phase liquid
DNR	Washington State Department of Natural Resources
DOD	United States Department of Defense
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management System
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FS	Feasibility Study
GIS	Global Information System
GLCC	geosynthetic clay laminated liner
km	kilometer
HDPE	high-density polyethylene
IPCC	Intergovernmental Panel on Climate Change
ISIS	Integrated Site Information System
LiDAR	light detection and ranging
LNAPL	light non-aqueous phase liquid
m	meter
MHHW	mean higher high water

Acronym or Abbreviation	Definition
MLLW	mean lower low water
MTCA	Model Toxics Control Act
NFA	no further action
NOAA	National Oceanic and Atmospheric Administration
OCCRI	Oregon Climate Change Research Institute, Oregon State University
PCBs	polychlorinated biphenyls
pH	A measure of the acidity or alkalinity of a solution on a log scale
ppb	parts per billion
ppm	parts per million
RCRA	Resource Recovery and Conservation Act
RCW	Revised Code of Washington
RI	Remedial Investigation
SCUM	Sediment Cleanup User's Manual
SEA	Shorelands and Environmental Assistance
SLR	sea level rise
SMS	Sediment Management Standards
SVOCs	semi-volatile organic compounds
TCP	Toxics Cleanup Program
USGCRP	United States Global Change Research Program
VDatum	Vertical Datum Transformation (NOAA software tool)
WAC	Washington Administrative Code
WHAFIS	Wave Height Analysis for Flood Insurance Studies

Executive Summary

The Department of Ecology's Toxics Cleanup Program (Ecology) manages the cleanup of contaminated sites to protect human health and the environment — now and in the future. We clean up contaminated sites to reduce exposure to toxic contaminants, restore habitat and natural resources, and regain productive use of terrestrial and aquatic lands. Importantly, incorporating sustainable remediation into the cleanup process will allow us to increase resilience of cleanup remedies to climate change impacts as well as increase the environmental benefits and reduce the environmental impacts from the cleanup process.

Preparing and adapting to climate change impacts is a critical challenge for Washington state. Our state is projected to experience impacts that will affect the security of our economy, the health and safety of our people, and the health of our environment and abundant natural resources. Some of these impacts include:

- Rising sea levels and increasing inundation of low-lying coastal areas.
- More extreme precipitation events and earlier spring melting of the snowpack, resulting in increasing flood hazards, erosion, and landslides.
- More severe drought in the summer months.
- Increased risk of wildfires.
- Acidification of the marine waters in Puget Sound and the Pacific coast.

By improving the resilience of our cleanup remedies to climate change impacts, we can help ensure that our efforts are effective in the long-term. By addressing climate change impacts-like sea level rise and wildfire - early in the cleanup process we can better protect the significant investment in the time, resources, and money that make cleanup happen.

This guidance provides a framework and recommendations for a cleanup project manager to:

1. Assess the risks associated with a changing climate by doing a site-specific vulnerability assessment.
2. Identify adaptation measures that increase climate-change resilience across a range of cleanup sites in different phases: site investigation; identifying resilient cleanup remedies, remedial design and implementation; and operation and maintenance.
3. Identify green remediation best management practices to increase the environmental benefits and reduce the environmental impacts from cleanup (Appendix D).

For this guidance, Ecology conducted a vulnerability assessment of the state's cleanup sites to understand the types of sites most vulnerable to climate change impacts. We found that sea level rise poses the highest potential risk to sediment and upland cleanup sites in or near marine and tidally influenced waterbodies; followed by flooding, extreme precipitation, wildfire, landslide/erosion, and drought for upland cleanup sites located further inland. Using this guidance, we can address these risks and improve the protectiveness of cleanup remedies.

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1.0 Introduction

To protect human health and the environment, Ecology's Toxics Cleanup Program is tasked with cleaning up contaminated sites in groundwater, soil, and sediment. Effective cleanups restore critical habitat and significantly reduce the risk to human health and the environment, but they are expensive. Improving our ability to anticipate and prepare for climate change impacts will help protect human health and the environment, protect the substantial financial investment in cleaning up contaminated sites, and ensure the long-term effectiveness of the cleanup remedy.

Scientific studies show that certain climate trends are occurring on global, national, and local scales. These trends include increasing sea levels, increasing ocean and atmospheric temperatures, and varying precipitation patterns and intensity (IPCC 2014, 2022; EPA 2021; NOAA 2016, 2022; CIG 2015; USGCRP 2019, 2022; Mote 2008; NRC 2012; Petersen, 2015; Reeder 2013).

> Earth's climate will continue to change over this century and beyond. Past mid-century, how much the climate changes will depend primarily on global emissions of greenhouse gases and on the response of Earth's climate system to human-induced warming. With significant reductions in emissions, global temperature increase could be limited to 3.6°F (2°C) or less compared to preindustrial temperatures. Without significant reductions, annual average global temperatures could increase by 9°F (5°C) or more by the end of this century compared to preindustrial temperatures. (USGCRP 2019, direct quote).

In Washington state, relatively modest observed climate trends are projected to accelerate in the decades ahead, contributing to an increase in sea level rise, drought, extreme precipitation events, as well as a shift from snow-to rain-dominant mountain ranges. The changes are projected to increase inundation of our coastlines and flooding of our inlands, and drive more frequent and severe drought, wildfires, landslides, and erosion. Such impacts associated with these hazards can contribute to a contaminated site's vulnerability and compromise the protectiveness and long-term effectiveness of cleanup remedies.

This guidance provides a framework and information for a cleanup project manager to assess the risks associated with a changing climate, identify and select adaptation actions at each phase of the cleanup process to increase the resilience of cleanup remedies, and identify and implement green remediation best management practices. Implementing adaptation measures during early stages of the cleanup process may increase the feasible cleanup options, maximize the integrity of the remedy, and reduce implementation costs in some situations.

1.1 Purpose of this guidance

This guidance includes information and recommendations to assist cleanup project managers to:

- **Identify and understand the impacts of climate change,** ranging from extreme (e.g., severe flooding) to chronic (e.g., sea level rise), and the vulnerabilities these impacts may pose for the protectiveness and long-term effectiveness of cleanup remedies.
- **Take adaptation steps to increase the resilience of cleanup remedies** in light of changing climate conditions.
- **Implement green remediation** best management practices.

Specifically, this guidance includes:

1. **A vulnerability assessment** that includes information and results to understand the sensitivity, exposure, and adaptive capacity of cleanup sites to climate change impacts, specifically:

    a. The types of impacts associated with climate change that have the highest potential to compromise cleanup sites.
    b. Which types of cleanup sites in specific locations are most vulnerable to climate change.
    c. Which aspects of cleanup remedies are most vulnerable to climate change.
    d. How to conduct a site-specific vulnerability assessment.

2. **Access to a GIS application** in TCP Maps as an analytical tool that helps cleanup project managers conduct site-specific vulnerability assessments (available to Ecology staff).

3. **An adaptation strategy** developed by using the knowledge gained from the vulnerability assessment to:

    a. Identify both the vulnerable and the resilient aspects of cleanup remedies.
    b. Provide practical recommendations and solutions for increasing a site's resilience at each cleanup stage.
    c. Develop adaptive management and monitoring options.

4. **Green remediation best management practices** to apply to the cleanup process to:
    a. Maximize environmental, societal, and economic benefits.
    b. Minimize environmental impacts caused by the cleanup process.

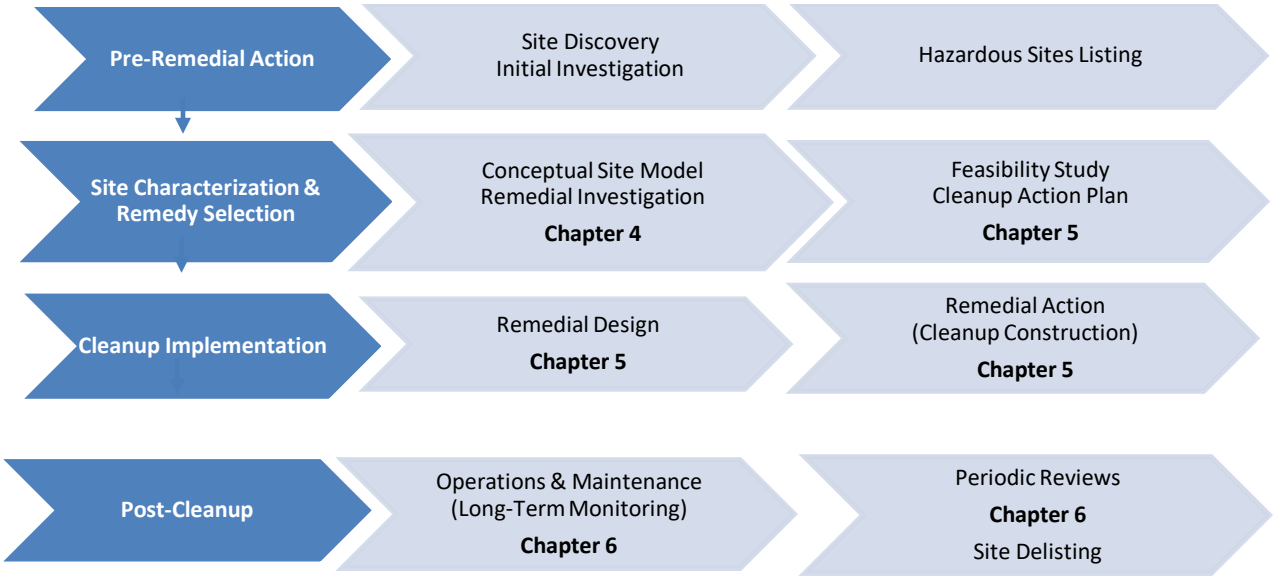
1.2 How to use this guidance

The following table is intended to help cleanup project managers find guidance and answers for the relevant stages of their cleanup sites. See also the cleanup process graphic found on the next page and at beginning of Chapters 4, 5, and 6 for cleanup stages discussed in those chapters.

Table 1: How to use this guidance

If you need to:	We recommend reading:
Learn about environmental trends and climate change projections	**Chapter 2 Background: Environmental Trends and Climate Change Projections**
Understand the key potential impacts from climate change on your cleanup site	**Chapter 3 Vulnerability Assessment.** Subsection 3.2.1 Identifying Climate Change Impacts **Appendix A Vulnerability Assessment** (for further detail)
Understand how to use the TCP Maps analytical tool to understand if a site may be vulnerable to climate change	**Chapter 3 Vulnerability Assessment.** Subsection 3.2.2 GIS Analysis and Data Collection.
Understand the vulnerabilities a cleanup site may have based on its location and type	**Chapter 3 Vulnerability Assessment.** Section 3.3 Vulnerable Types of Cleanup Sites and Remedies
Understand how to conduct a site-specific vulnerability assessment	**Chapter 3 Vulnerability Assessment.** Section 3.4 How to do a Site-Specific Vulnerability Assessment
Understand the general process to address climate change during the Remedial Investigation stage	**Chapter 4, Conceptual Site Model and Remedial Investigation**. Introductory page
Incorporate climate change in a Conceptual Site Model	**Chapter 4 Conceptual Site Model and Remedial Investigation.** Section 4.1 Conceptual Site Model and Identifying Data Gaps.
Develop a work plan for the Remedial Investigation that incorporates climate change	**Chapter 4, Conceptual Site Model and Remedial Investigation.** Section 4.2 Remedial Investigation.
Develop a Feasibility Study and conduct a remedial alternatives analysis that includes climate resilient remedies	**Chapter 5 Feasibility Study, Cleanup Action Plan, and Remedial Design**. Sections: • 5.1 When to Consider Impacts during the Feasibility Study and Remedial Design • 5.2 Screening Remedial Technologies • 5.3 Evaluating Remedial Alternatives

If you need to:	We recommend reading:
Understand the specific vulnerabilities of remedies and how to select climate-resilient remedial alternatives	**Chapter 5 Feasibility Study, Cleanup Action Plan, and Remedial Design.** Section 5.4 Increasing Resiliency of Remedial Alternatives. • Appendix C Resilient Remedy Case Studies
Understand how the disproportionate cost analysis is used to select the preferred alternative that includes resilience to climate change	**Chapter 5 Feasibility Study, Cleanup Action Plan, and Remedial Design**. Subsection 5.3.3 Disproportionate Cost Analysis and Remedy Selection
Incorporate climate change into the long-term monitoring plan	**Chapter 6 Post-Construction and Long-Term Monitoring**
Address climate change during a periodic review	**Chapter 6 Post-Construction and Long-Term Monitoring**. Sections: • 6.2 Periodic Reviews • 6.3 Responses to Identified Issues
Understand what vulnerabilities underground storage tanks may have and how to increase resilience	**Chapter 7 Underground Storage Tanks**
Learn more about adaptation strategies and climate resilience	**Appendix B Climate Resiliency Resources** **Appendix C Case Studies for Washington State**
Understand climate change and climate science terminology	The **Glossary,** which includes terms that are either used throughout this guidance or commonly used in the climate field.
Understand how to identify and implement best management practices to reduce the environmental impacts from the cleanup process.	**Appendix D Green Remediation**



Cleanup Process Figure 1: Chapters 4, 5, and 6 address different stages of the MTCA cleanup process.

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2.0 Environmental Trends and Climate Change Projections

This chapter includes the environmental trends and climate change projections relevant to the vulnerability of Washington's contaminated sites and cleanup remedies. This data informed the vulnerability assessment (Chapter 3) and adaptation strategy (Chapters 4–7) in this guidance.

The scientific data and conclusions are sourced from the Intergovernmental Panel on Climate Change (IPCC); National Oceanic Atmospheric Administration (NOAA); Environmental Protection Agency (EPA); U.S. Global Change Research Program (USGCRP); Climate Impacts Group, University of Washington (CIG); and the Oregon Climate Change Research Institute, Oregon State University (OCCRI).

2.1 Environmental trends in the Pacific Northwest

Following is a summary of observed environmental trends in Washington state specific to sea level rise, flooding, precipitation, air temperature, wildfire, snowpack, stream flow, shrinking glaciers, and ocean acidification. When Puget Sound is referenced in this chapter, it refers to Puget Sound, the Strait of Juan de Fuca, and all of the land that drains into them.

- *Relative sea level* has risen 8.6 inches at the Seattle gauge from 1900 to 2008, consistent with global trends (Figure 1). The rate of sea level rise varies at different locations in Puget Sound and on the Pacific coast due to factors such as land subsidence or uplift, weather patterns, and ocean currents. For example, Neah Bay has shown a relative sea level decrease of 0.7 inches per decade (due to land uplift); Friday Harbor an increase of 0.4 inches per decade; and Seattle an increase of 0.8 inches per decade (CIG 2015, NOAA NCEI 2022).

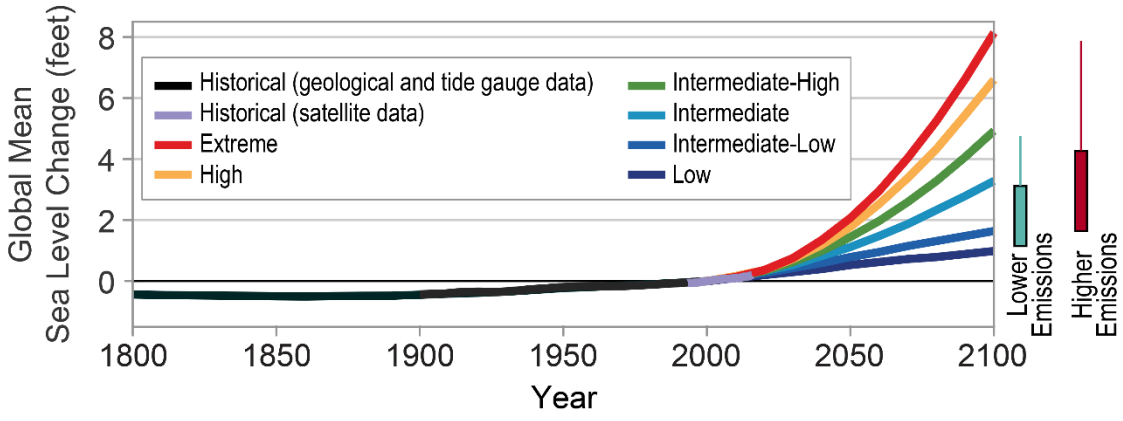

Figure 1: Observed and potential future global sea level rise from 1800 to 2100

- *Coastal flooding* in Seattle has increased from 0.90 average number of flood days per year in the 1950s to 3.33 days in the 2010s (Figure 2; NOAA 2016 & 2021).

- *Tidally influenced flooding,* also called nuisance floods, has increased and the greatest number occurred in 1997. Sea level rise is a contributor to these observed increases (Figure 3; NOAA NCEI 2022).

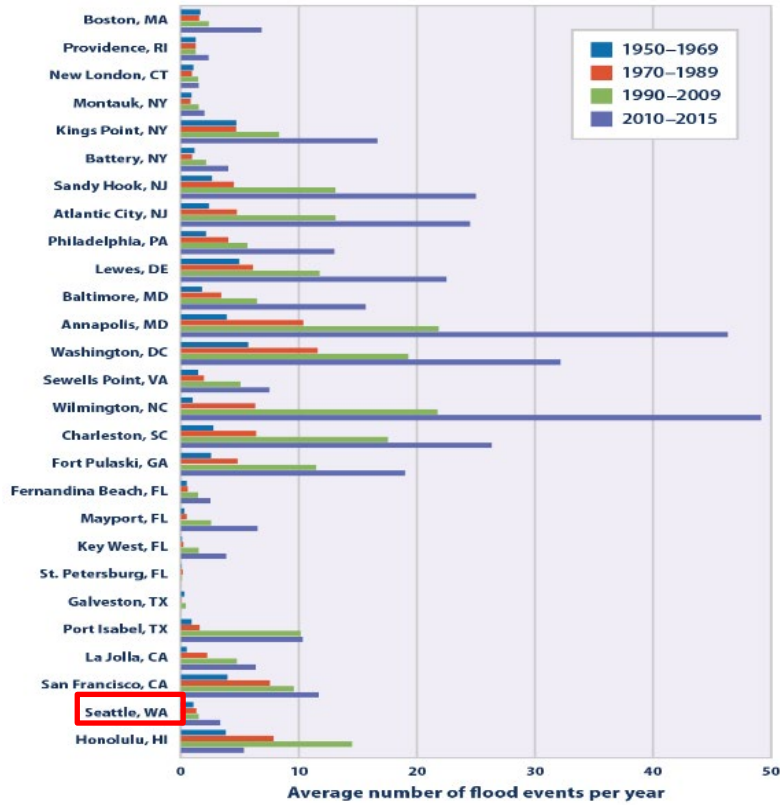

Figure 2 (above): Average number of coastal flooding events per year in the U.S. from 1950 to 2015.

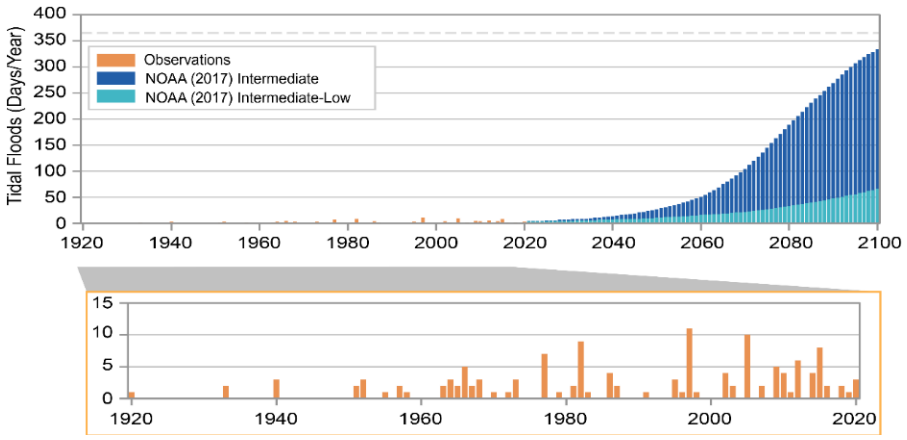

Figure 3: Observed and projected annual number of tidal floods for Seattle, WA (NOAA NCEI 2022).

- *Precipitation*, both annual and seasonal, have remained relatively constant between 1895 and 2014. However, it appears that extreme precipitation (the heaviest 1% of all 24-hour events from 1901 – 2012) has increased in frequency and intensity in Western Washington (Figure 4; NOAA 2021).

  On a national scale, a greater than normal portion of total annual precipitation is from extreme one-day precipitation events (Figure 5; NOAA 2021, EPA 2022).

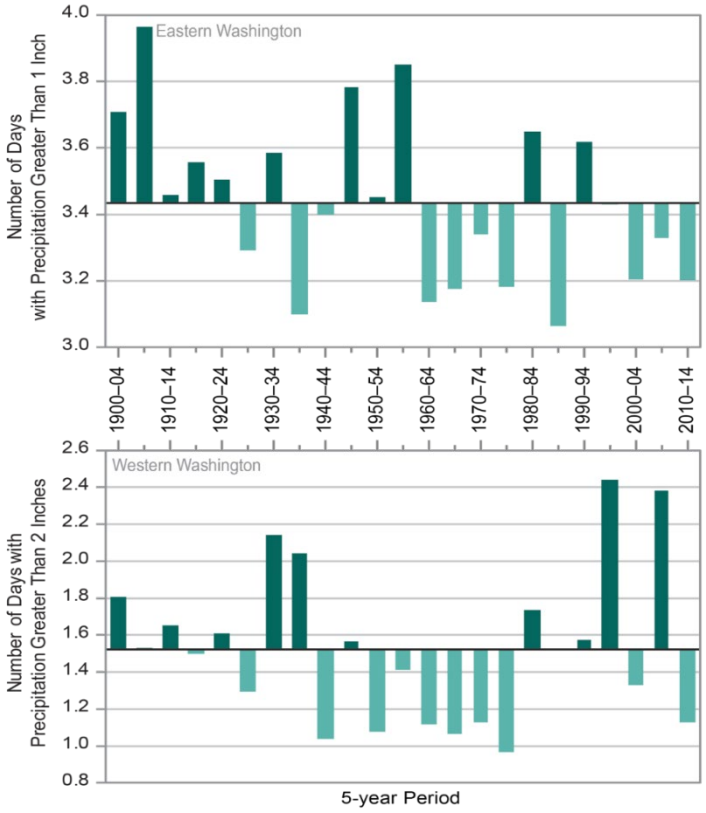

Figure 4 (above): Observed extreme one-day precipitation events in Eastern and Western Washington.

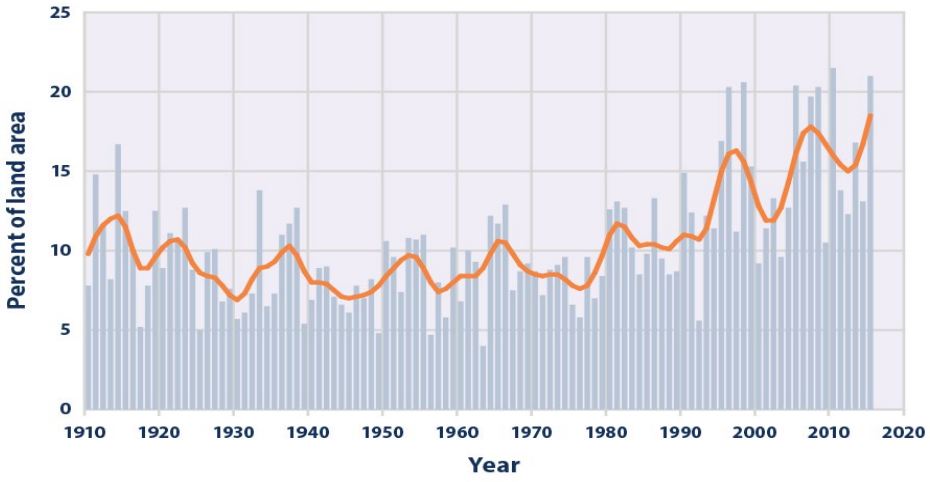

Figure 5: Extreme one-day precipitation events in the contiguous 48 states, 1910–2020.

- *Air temperature* increased by 1.7°F between 1900 and 2020 with warming occurring in winter, fall, and summer. Since 1986, temperatures have been above the long-term average between 1985-2020, with the exception of 5 years. The past three decades have been warmer than any other recorded period for the globe, with 2015 the hottest on record at ~3.7°F above the long-term average (Figure 6; CIG 2022, NOAA NCEI 2022). Nationwide, temperatures have increased by ~3.0°F in winter, ~2.0°F in spring, and ~1.5°F in summer and fall (Figure 7; NOAA NCEI 2022).

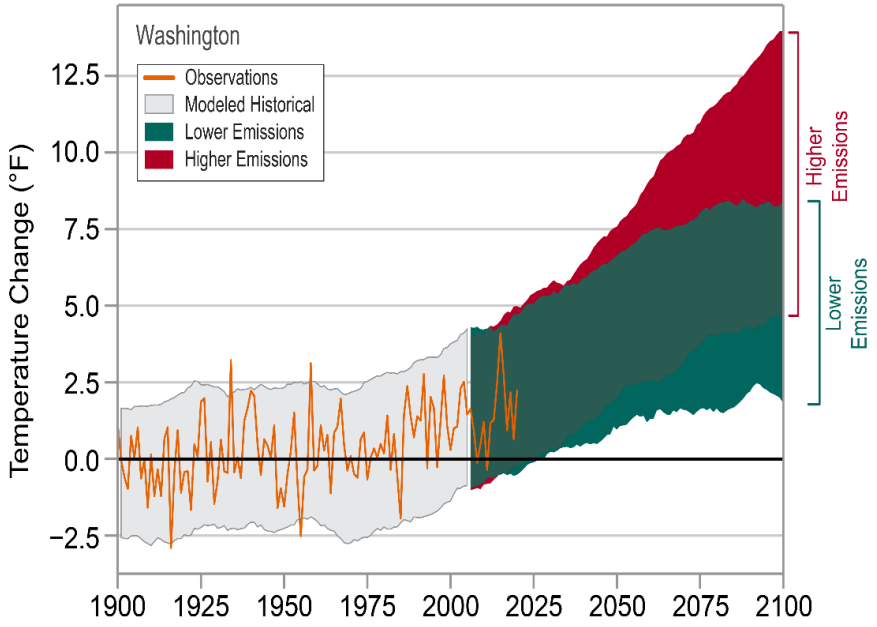

Figure 6 (above): Observed and projected temperature changes for Washington (NOAA NCEI 2022).

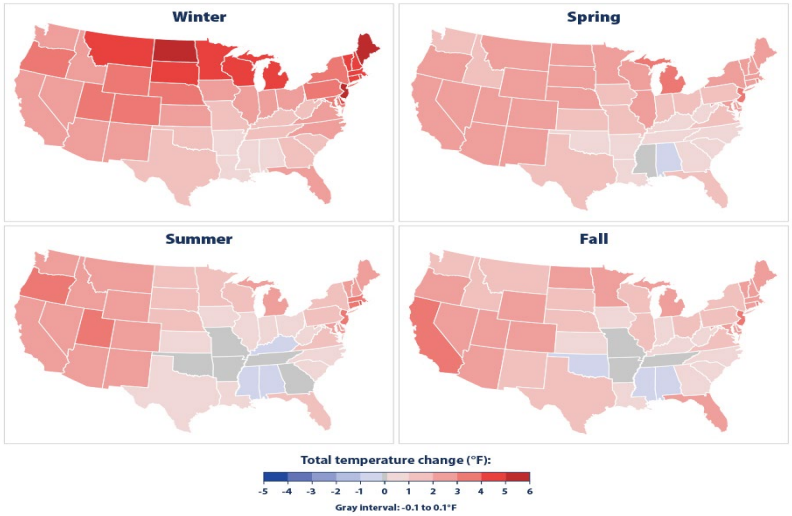

Figure 7: Change in seasonal temperature by state from 1896-2021 (NOAA NCEI 2022).

- *Nighttime heat waves* increased in frequency west of the Cascades from 1901 to 2009. Since 1990, the nighttime average of warm nights (above 60°F in Eastern Washington and 65°F in Western Washington) has been above the long-term average (CIG 2015; EPA 2021). These are defined as three or more consecutive days above the 99th percentile for the maximum temperature anomalies (for daytime heat waves) or minimum (for nighttime heat waves).
- *Frost-free season* (i.e., growing season) has lengthened by more than 30 days in the Puget Sound region from 1920 to 2014 (CIG 2015, EPA 2021).
- *Snowpack* in the spring in Western Washington (Cascade and Olympic Mountains) declined on average by about 30% from 1955-2016, with substantial natural year-to-year variability (CIG 2022, 2015).
- *Peak spring stream flow* has occurred earlier in the season by 0 to 20 days in many snowmelt-influenced rivers between 1948 and 2002 (CIG 2015).
- *Glaciers* at Mount Rainier, Olympic Mountains, and North Cascades have shrunk. Mount Rainer's glaciers decreased 14% by volume from 1970 to 2008; Olympic Mountains glaciers decreased by 7% in area and 31% in number from 1980 to 2009; and glaciers in the North Cascades have lost 56% in area from 1900 to 2009 (CIG 2015).
- *Wildfire.* There has been an increase in large, severe wildfires in the state the past few decades and increases in average acres burned (Zerbe, 2022). Although wildfires are a natural part of most Pacific Northwest forest ecosystems, warmer and drier conditions have contributed to these increases (Mote et al. 2014). While trends in observed wildfire are complicated by a history of fire suppression east of the Cascades and infrequent fires west of the Cascades, the 2015 wildfire season was the most destructive in Washington's history. Over one million acres burned, which is more than six times Washington's average (NOAA NCEI 2022). From 1970-2020 all of the state's wildfire hot spots have occurred east of the Cascade Range crest and the burned area has become concentrated in a smaller geographic area over the north-central portion of the state (Zerbe 2022).
- *Ocean acidification.* Increasing concentrations of carbon dioxide in the atmosphere raise the equilibrium level of dissolved carbon dioxide in the ocean. This increases the level of oceanic carbonic acid and reduces the pH (NOAA 2012). The global oceans have absorbed ~30% of anthropogenic carbon dioxide in the atmosphere leading to a decline in mean ocean pH of 0.1. Puget Sound is experiencing a reduction in pH, and the pH of the Northeast Pacific Ocean surface waters has decreased by -0.27 from 1991–2006 (CIG 2015).

2.2 Climate change projections for the Pacific Northwest

Below is a summary of climate projections that may impact the state's cleanup sites, followed by their potential effects for cleanup sites. Where ranges are shown, they correspond to a low-to-high greenhouse gas emissions scenario, where high equates to continued increases in greenhouse gas emissions. Where data exists, projections are included for the mid-century (i.e., the 2050s, which are defined as years 2040 to 2069) and end of the century (2100). The following future climate scenarios for the Pacific Northwest were used to conduct the vulnerability assessment (Chapter 3).

2.2.1 Sea Level Rise

Absolute sea level for Puget Sound and the Pacific coastline is projected to change and coastal areas will experience varying sea level rise due to area-specific vertical land movement. In 2018 the Washington Coastal Hazards Resilience Network (Department of Ecology, University of Washington Climate Impacts Group, and Washington Sea Grant) updated relative and absolute relative sea level rise projections specific for Washington state. The projections are probabilistic and include the likelihood of occurrence of a specified amount of sea level rise (e.g., 0.5 meters) based on different greenhouse gas emissions scenarios (e.g., low or high) (Miller 2018). In addition, the UW Climate Impacts Group developed a visualization tool to see probabilistic projects for different time frames in specific locations (https://cig.uw.edu/projects/interactive-sea-level-rise-data-visualizations/).

These projections will provide cleanup project managers more detailed information and the robust tools they need to select cleanup remedies according to the preferred risk tolerance. There are previous sea level rise projections for the Pacific Northwest, but they are not based on a probabilistic framework (Mote, et al. 2008, NRC 2012, Reeder, et al. 2014, and CIG 2015). See Chapter 3, Sections 3.3 and 3.4 for guidance on how to address sea level rise for cleanup.

Under the low greenhouse gas emissions scenario, thermal expansion of the oceans and melting of small mountain glaciers is projected to result in a likely range of ~1 to 4-feet of absolute sea level rise by 2100 on a global scale. Even with a drastic reduction in greenhouse gas emissions, sea level rise will continue through the end of the century because the oceans take a long time to respond to temperature conditions at the earth's surface. Under the high greenhouse gas emissions scenario, combining thermal expansion with glacial and ice sheet melting makes 4-feet of sea level rise by 2100 plausible on a global scale (Figure 1; NOAA NCEI 2022; IPCC 2022).

Only a limited number of studies have evaluated changes in storm surge and waves for Washington state. Current research suggests that these will not change in the future. These events may have a greater impact due to a higher base sea level, but the amount of storm surge or the height of ocean waves is not projected to change (CIG 2015).

Rising sea levels combined with high tide, storm surge, and subsidence contribute to:

- An increase in the elevation, depth, or extent of inundation along the marine and coastal shorelines.
- An amplification of the inland reach of high tides, resulting in increased flooding further inland of the coastline, especially when compounded by severe storm events.
- Movement of the saltwater wedge further upstream in tidally influenced rivers.
- Saltwater intrusion into groundwater.
- Increased landslide risk or rates of erosion along coastal bluffs.
- Sources: CIG 2015, EPA 2021, IPCC 2014, 2022, NOAA 2022; NOAA NCEI 2022

2.2.2 Precipitation

Total Annual Precipitation

The models for projected change in % precipitation in the Pacific Northwest vary, but a majority of models project a decrease in summer and an increase in fall, winter, and spring compared to historical averages from 1950 to 1999. Projections show a mean increase of ~3.8% under a low greenhouse gas emissions scenario (RCP 2.6) and ~9.3% under a high greenhouse gas emissions scenario (SSP 558) by the 2080s (Figure 8; CIG 2022a).

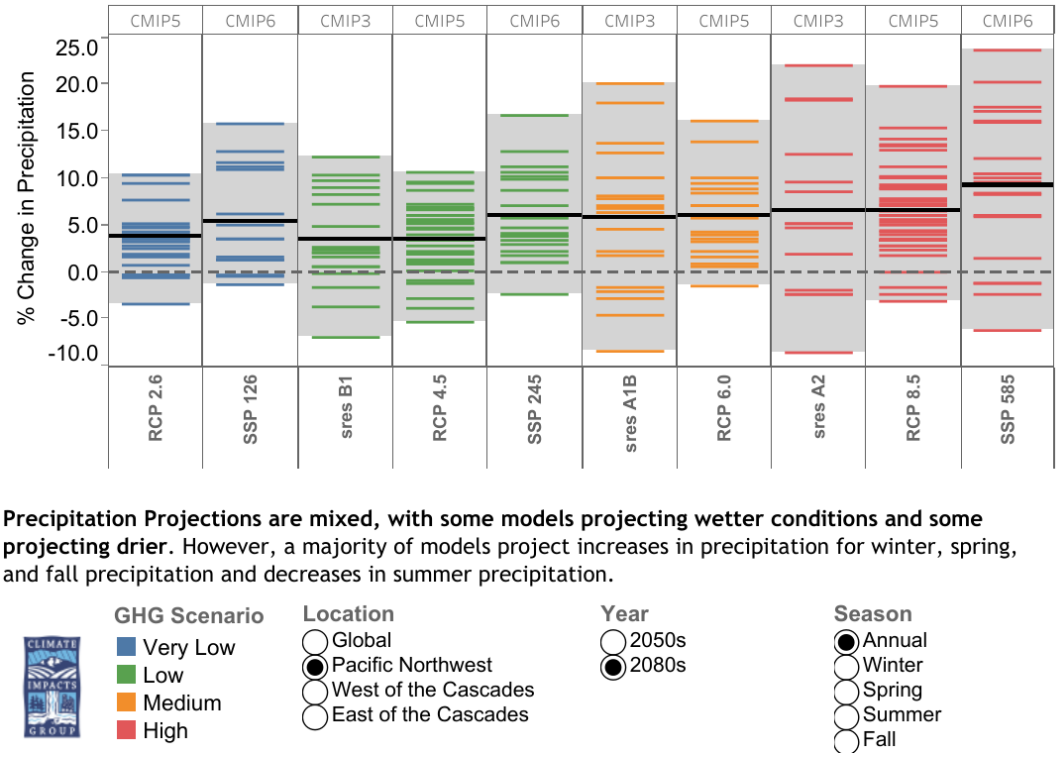

Figure 8: Projected change in total annual % precipitation for the Pacific Northwest in the 2080s relative to 1950-1999. (CIG 2022a, retrieved from PNW Climate Projection Tool).

Extreme Precipitation Events

Precipitation is projected to increase in intensity, and larger changes are projected for 1) more extreme precipitation events and 2) shorter duration precipitation events. For example, the projected change in precipitation intensity for the 25-year extreme event is larger than for the 2-year extreme event; and projected changes are largest for the one-hour extreme event and smallest for the 48-hour or 72-hour duration extreme events (CIG 2021). To understand extreme precipitation events on a regional scale, different return intervals (e.g., 25-year, 100-year), duration (e.g., one hour, 72-hours), and timeframe (e.g., 2050s, 2080s), the Projected Changes in Extreme Precipitation Web Tool from UW Climate Impacts Group can be used (https://cig.uw.edu/projects/heavy-precipitation-projections-for-use-in-stormwater-planning/).

A factor to consider with projected increased precipitation is the increasing frequency and intensity of atmospheric rivers—those moist airflows that extend from the tropical Pacific to the west coast of North America during winter. These atmospheric rivers are expected to carry more moisture in the future, causing our extreme precipitation events to become more intense (Figure 9; CIG 2015, OCCRI 2013, NOAA 2017a).

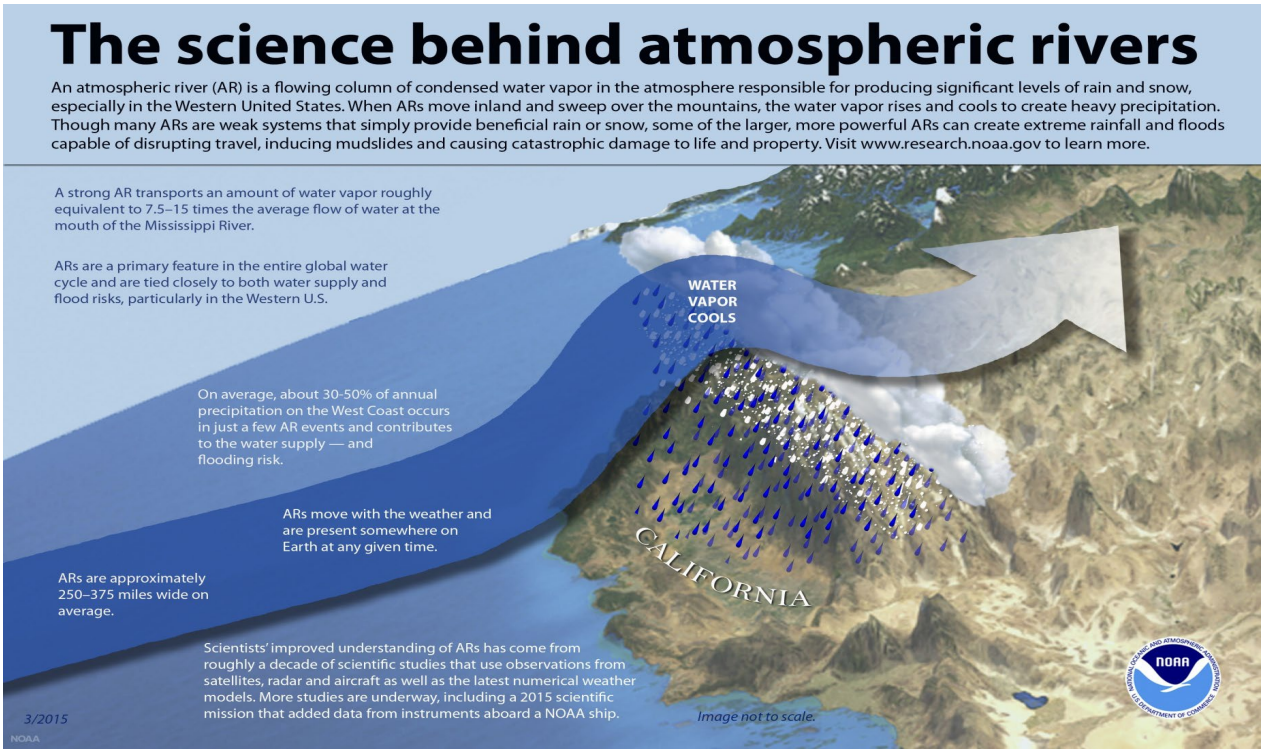

Figure 9: The science behind atmospheric rivers (NOAA 2017).

Snow to Rain Transition and Declining Snowpack

More winter precipitation will fall as rain instead of snow, and snowmelt is expected to begin earlier in the spring. Statewide average spring snowpack is projected to decline 38 to 46% by 2050s and 56-70% by the 2080s under low and moderate greenhouse gas emissions scenarios, respectively. These warming-driven changes are expected to result in a shorter snow season on average and earlier peak spring streamflow in rivers with a significant snowmelt component.

These changing precipitation patterns contribute to:

- Flow changes in major snowmelt-influenced rivers, with higher flows in winter and lower flows in summer.
- More frequent and severe river flooding.
- Increased landslide risk due to saturation of soil.
- Increased erosion and riverine sediment transport in fall, winter, and spring.
- Sources: NOAA 2021, CIG 2015.

2.2.3 Air Temperature

The average annual air temperatures in the state are projected to increase in Eastern and Western Washington. NOAA projects a state average increase above historical averages of ~1°F under a lower greenhouse gas emissions scenario and ~10°F under a higher emissions scenario by 2100 (Figure 6; NOAA NCEI 2022). Other projections show a state average increase of ~2.3°F under a low greenhouse gas emissions scenario (RCP 2.6) and ~8.7°F under a high greenhouse gas emissions scenario (SSP 585) by the 2080s (Figure 10; CIG 2022a). Although the projections differ, they all project warming for all scenarios.

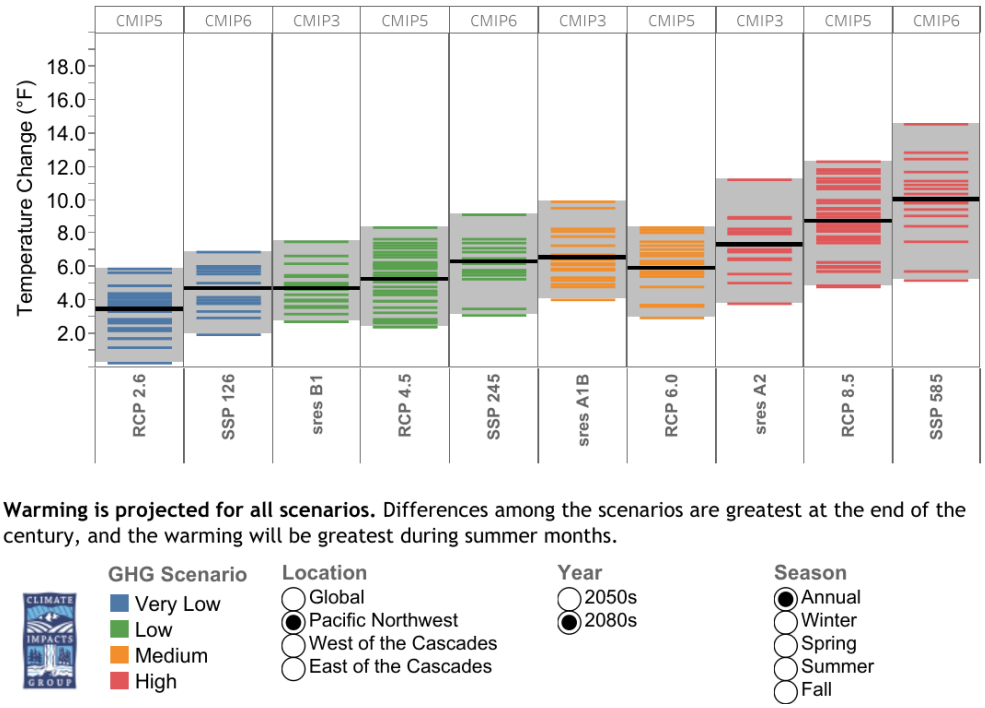

Figure 10: Projected change in average annual temperature for the Pacific Northwest in the 2080s relative to 1950-1999 (CIG 2022a, retrieved from PNW Climate Projections Tool).

These changing temperature patterns contribute to:

- Warmer water temperatures for Puget Sound, estuaries, and freshwater bodies.
- More severe drought and potentially lower groundwater tables.
- More frequent and intense heat waves in summer.
- Less frequent and intense cold events in winter.
- Reduced amount of snowpack and earlier snowmelt, which is expected to reduce an important source of water during the drier summer months and increase the frequency and intensity of summer wildfires.
- Sources: CIG 2015, EPA 2021, IPCC 2014, 2022, NOAA 2016, 2022.

2.2.4 Wildfire

In the Pacific Northwest the annual average area burned is projected to triple by the 2040s relative to historical averages from 1916-2006 under a moderate greenhouse gas emissions scenario. In Western Washington the projections for very high fire danger days (i.e., days with 100-hour fuel moisture below the historical 10 percentile) are 43 days in the 2020 decade and 48 days by the 2050s, as compared to historical 36 days from 1971-2000 (CIG 2019).

The UW Climate Impacts Group has a tool to understand likelihood and hazard of wildfire under a high or low greenhouse gas emissions scenario and for difference decadal timeframes on a statewide or county-based scale. The U.S. Forest Service has a tool with interactive maps and charts on wildfire probability amongst communities which can be used to better understand wildfire risk on a regional scale (www.wildfirerisk.org), however the data is not yet sufficient to use as projections.

Hotter and drier summers and early snowmelt projected for the state can result in drier fuels in the summer season and a lengthening of the fire season, which can contribute to an increase in wildfires (CIG 2022b). Wildfire can trigger disaster events including flooding, erosion, landslide, and sedimentation.

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3.0 Climate Change Vulnerability Assessment

3.1 Purpose

This chapter provides information on how to conduct a site-specific vulnerability assessment to understand potential impacts from climate change on individual cleanup sites. In addition, information is provided on how the vulnerability assessment was conducted for the state's cleanup sites to develop this guidance.

The vulnerability assessment for this guidance was conducted in order to:

1. Identify climate change impacts that have the greatest potential to adversely affect cleanup sites (Section 3.2).
2. Understand the scope of vulnerabilities for sites (Section 3.3), by:
    - Learning the types of vulnerable cleanup sites and where they are located.
    - Determining which specific types of remedies have high potential to be affected by climate change impacts, and what those vulnerabilities may be.
3. Develop a process for cleanup project managers to conduct a more detailed and site-specific vulnerability assessment (Section 3.4).
4. Inform the development of an adaptation strategy to increase resilience of cleanup remedies (Chapters 4–7).

3.2 Methods

The vulnerability assessment involved the following steps:

1. *Identifying climate change impacts* that posed the highest risk to cleanup sites (Section 3.2.1).
2. *Conducting GIS analysis* by collecting data related to these impacts, developing GIS layers, and analyzing their relationship with Washington's cleanup sites (Section 3.2.2).
3. *Interpreting results,* by identifying types of sites in specific locations and remedies that are vulnerable (Section 3.3).

3.2.1 Identifying Climate Change Impacts

Based on the observed climate trends and projections discussed in Chapter 2.0, the following climate change impacts were identified as having the greatest potential to adversely affect cleanup sites and remedies. These impacts were included in the vulnerability assessment:

- Rise in sea level and coastal inundation
- More severe riverine flooding
- Increased landslide and erosion risk
- More severe and frequent wildfire
- More severe drought.

3.2.2 GIS Analysis and Data Collection

This section includes details on the GIS analysis and an explanation of why these impacts were evaluated in the vulnerability assessment. For information on data limitations and assumptions, see Appendix A.

GIS Analytical Tool Assesses Vulnerability

Ecology developed an internal TCP Maps Climate Change application that provides a visualization of cleanup sites and their potential vulnerability to climate change impacts (Ecology is working to make this externally available). GIS layers were developed using data from NOAA, WA DNR, Ecology, Coastal Hazards Resilience Network, CIG, U.S. Forest Service, and FEMA to visualize the following climate change impacts:

- *Sea level rise*:
  - Areas projected to be inundated due to sea level rise at high tide (on a daily basis).
  - Areas projected to be inundated during severe storms (on an infrequent basis).
  - Links to visualize and understand probability of sea level rise at specific locations.

- *Flooding:*
  - Areas within current 100- and 500-year flood plains.
  - Puget Sound Rivers that have a projected increased risk of flooding.

- *Landslide and erosion*. Areas that have experienced landslide.

- *Wildfire*. Annual probability of wildfire risk in a specific location.

We used Ecology's Integrated Site Information System database to create GIS layers for:

- Cleanup site locations and their status (i.e., pending, in the process of cleanup, or cleaned up), and
- Type of cleanup site (sediment, soil, groundwater, landfills, mining, leaking underground storage tanks, as well as underground storage tanks).

When combined, these GIS layers can be used screen cleanup sites that may be vulnerable to the climate change impacts noted above. For more details on the GIS layers or the aforementioned impacts, see the following sections and Appendix A.

Sea Level Rise - GIS Analysis and Inundation Scenarios

To understand the influence that projected sea level changes may have on Washington's cleanup sites, we developed GIS layers to visualize areas vulnerable to inundation. The GIS layers include different contemporary tidal datums—tied to the 1983–2001 tidal epoch—as baselines for assessing sea level changes and identifying vulnerable areas. Each datum is useful for considering different inundation scenarios, so that we capture the full range of cleanup sites that may be at risk from sea level rise. These GIS layers include:

- **Daily tidal inundation scenario.** This is a base tidal elevation of mean higher high water, which is the mean tidal elevation of each day's highest tide over a period of nineteen years, based on the tidal datum in Seattle. Adding sea level increments to mean higher high water can reflect a potential daily inundation scenario during high tide (i.e., upland sites that could become part of the intertidal zone over time, or sediment sites in the intertidal zone that could become more subtidal).
- **Infrequent inundation scenario.** This is a surface water elevation expected during a 100-year flood (as currently defined by FEMA). This inundation will be infrequent, relative to tidal inundation, but could be influential inundation events despite their low occurrence. This scenario includes:
    - A base flood elevation (BFE). This is the surface water elevation that adds the 100-year flood elevation with wave action impact (known as wave runup) to stillwater (the average elevation of surface water without wind and wave action; FEMA 2020; Figure 11). Adding 1-foot sea level increments to BFE reflects a potential infrequent inundation scenario due to sea level rise and severe storm events, which includes storm surge (i.e., upland areas inundated during severe storms).
    - In coastal areas where BFE has not been calculated, adding an *additional* +3-foot sea level increment to mean higher high water can be relatively representative of BFE. This can be the base surface water elevation to add sea level increments.

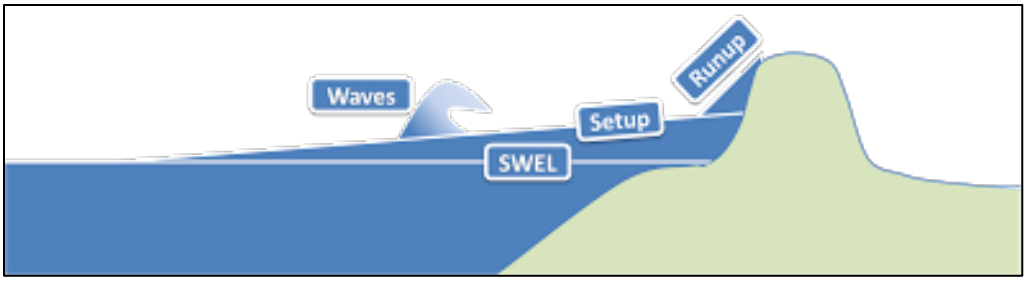

Figure 11: The storm surge stillwater elevation (SWEL) and added effects of wave setup and wave runup.

We downloaded land surface elevation data from NOAA's Coastal Viewer (a web application and sea level rise analysis) to use as the basis for all sea level rise evaluations. Visit https://coast.noaa.gov/dataregistry/search/collection/info/coastallidar for more information about how NOAA's collation and standardization process for their Digital Elevation Models. Elevations are referenced to the North American Vertical Datum of 1988 (NAVD88).

NOAA developed sea level rise projections under mean higher high-water conditions as part of their Coastal Viewer web application. We downloaded these datasets from the public data portal and used as-is. We then used NOAA's Digital Elevation Model to identify inundation extents under the infrequent inundation scenario previously described.

To assess the impact of sea level rise on BFE, we used data from BFE transects in a joint effort by Ecology's Shorelands and Environmental Assessment (SEA) program and FEMA. We converted each transect to points, creating a point every 50 feet along each transect. Each point was given the BFE value of its respective transect and points were interpolated to create a raster surface of BFE. We then followed NOAA's process (available at Mapping Sea Level Rise Inundation (noaa.gov)) to create surfaces with one-foot increments up to six feet. This resulted in one surface per foot of sea level rise, indicating areas where inundation may occur.

Flooding GIS Analysis

Flooding hazard may be magnified by various environmental events, including rapid snowmelt and extreme precipitation events, especially when rivers and groundwater levels are already high. Coastal areas or areas further inland may be vulnerable to high flooding hazard due to a number of regional and site-specific factors, such as:

- Proximity to tidally influenced freshwater rivers and tributaries affected by sea level rise.
- Amount of developed areas with non-permeable surfaces.
- Amount of low-lying land.
- Type and adequacy of flood controls.
- Locations within 100- or 500-year floodplains.

GIS layers for potential flooding was developed using the National Flood Hazard GIS Layer from the Federal Emergency Management Agency (FEMA), which is used for the National Flood

Insurance Program (FEMA 2005 & 2021). This publicly available digital database outlines updated flood hazard zones, base flood elevations, hydraulic structures, and floodway status in Washington state. For more detail on the complex variables that can increase flood hazard risk, see Appendix A. This information can help inform if the current base flood elevation (a 100-year flood event) for a river will be reached more frequently. For example, if what is currently identified as a 100-year flood event is projected to increase to a 22-year event, it means the BFE will be reached five times more often than under the current 100-year flood event scenario.

In addition, the University of Washington Climate Impacts Group Climate Mapping for a Resilient Washington tool (https://cig-wa-climate.nkn.uidaho.edu/) can be used to understand projections for peak stream flow for different 30-year timeframes (e.g., 2020-2049) under low, moderate, or high greenhouse gas emissions scenarios. Specifically,

- The percent increase in annual maximum peak streamflow relative to historic peak streamflow from 1980-2009. An increase in the magnitude of peak streamflow indicates potential for flooding and inundation during peak streamflow events.
- Frequency of peak streamflow. The 25-year peak streamflow is the daily maximum streamflow that occurs once every 25-years using data from 1980-2009. For example, a river with a value of 10 means the frequency in peak streamflow is projected to occur every 10 years as compared to the historical 25-year return interval. An increase in frequency indicates potential for flooding an inundation during peak streamflow events.

Landslide and Erosion GIS Analysis

Landslide information was obtained from the Washington State Department of Natural Resources (DNR) Geologic Information Portal. DNR produces landslide maps derived from field geologists' mapping of surficial geology. Ecology used GIS layers that map where landslides have occurred. While past landslide events are not necessarily a robust projection of where landslides may occur in the future, this is the best available local information on landslides at this time.

An additional tool that can be used in real-time is the DNR and NOAA National Weather Service landslide hazard forecast model, which is based on observational precipitation data and climate projections (DNR 2022). Using this model, DNR and NOAA develop shallow landslide hazard maps based on antecedent rainfall, and 24-hour and 48-hour predicted rainfall. This map is updated as 24- and 48-hour rainfall events are occurring and is intended to show the relative hazard of occurrence for precipitation-induced shallow landslides. This information can be accessed athttps://www.dnr.wa.gov/slhfm

Coastal areas are subject to geomorphic change resulting in increased erosion and landslide risk and well as change in habitat types. Due to a lack of data, we did not create GIS layers to account for coastal landforms and increased risks. For more detail on coastal landform changes see Appendix A, Ecology 2017a, and Shipman 2009.

Wildfire GIS Analysis

A wildfire layer was created using information from the U.S. Forest Service on wildfire risk across the state, counties, and communities (https://www.wildfirerisk.org).

3.3 Results - Vulnerable sites and remedies

This section discusses general types of cleanup sites in specific areas that were identified to have the greatest vulnerability to sea level rise, flooding, wildfire, and landslide/erosion impacts. Cleanup project managers can use this information and the TCP Maps Climate Change analytical tool (for Ecology staff) to identify site-specific risks to climate change impacts based on their location.

3.3.1 Sea Level Rise and Coastal Inundation

- *Sites vulnerable to inundation*. Upland cleanup sites adjacent to or near the marine waterfront can be vulnerable to sea level rise due to periodic inundation from daily high tides, extreme high tides, and severe storm events.

  Cleanup sites located in the following areas are most vulnerable:

  - Low-lying coastal shorelines.
  - Marshy shorelines and estuaries.
  - Barrier beaches, spits, and historically filled areas.
  - Beaches and tide flats.
  - On coastal bluffs vulnerable to increased erosion.

  The most vulnerable cleanup sites include remedies that have:

  - Contamination left in place intended for permanent isolation (e.g., soil cap, landfill).
  - Contamination undergoing in-situ treatment, other treatment, or natural attenuation (e.g., pump and treat groundwater system, passive treatment barrier wall for ground water).
  - Contamination with long natural recovery time frames (decades).
  - Upland confined disposal facilities.
  - Closed or abandoned landfills.
  - Underground storage tanks.

- *Sites vulnerable to severe storms (wave action, currents, storm surge)*. Sea level rise is expected to exacerbate the impacts of severe storms. This is important because sediment and upland cleanup sites along marine and estuarine shorelines can be particularly vulnerable during severe storm events and the majority of the state's cleanup sites are located in these areas.

These vulnerable cleanup sites may have:

- Contamination left in place intended for permanent isolation (e.g., sediment or soil cap).
- Closed or abandoned landfills.
- No or limited armoring along the shoreline to protect contaminant transport from eroding contaminated soil to surface water or sediment.
- Sediment caps and cap armoring.
- Intertidal, shoreline, or nearshore wetland habitat.
- Upland confined disposal facilities.
- Confined aquatic disposal facilities.

3.3.2 Flooding

Flooding due to increased extreme precipitation events, rain on snow, and early snowmelt may cause impacts similar to those from sea level rise inundation. In addition, sea level rise will exacerbate flooding for tidally influenced rivers since the water will not drain to coastal water as quickly.

Cleanup sites that can be vulnerable to more severe flooding are:

- Cleanup sites located:
  - Along developed shorelines in low-lying areas.
  - Beaches and tide flats.
  - Spits and barrier beaches
  - Along marshy shorelines and river deltas.
  - Downstream from a dam.
  - In 100- or 500-year floodplains.
- Upland sites located along estuarine shorelines and tidally influenced river shorelines may be more vulnerable than upstream sites, due to the exacerbating influence of both sea level rise and inland flooding.
- Sediment cleanup sites downstream from debris washout.
- Abandoned mines.

3.3.3 Wildfire

These types of cleanup sites can be vulnerable to more frequent and intense wildfires:

- Cleanup sites with infrastructure (e.g., abandoned mines, underground storage tanks) or treatment infrastructure (e.g., pump and treat systems, Baker tanks) located:
    - In treed or grassland areas subject to drought.
    - Near the urban-forest interface; or
    - Within forested areas.
- Landfills with planted vegetation as erosion control.

3.3.4 Landslide and Erosion

Cleanup sites may be vulnerable to landslides and erosion if they:

- Are located near or on unstable slopes (e.g., sea bluffs or cliffs). Sea level rise will increase erosion rates and landslide risk in these areas.
- Are located on coastal spits and barrier beaches, which are low-lying features that will experience more rapid erosion.
- Are located along marshy shorelines (in estuaries and river deltas), which will experience more rapid erosion.
- Are located along developed coastal and tidally influenced shorelines in low-lying areas.
- Are located in upland areas prone to erosion or slopes that have lost, or have minimal, vegetation (e.g., mine tailings piles).
- Are located in areas that have recently experienced fire, where vegetation has been destroyed.
- Have experienced recent extreme precipitation events (e.g., erosion of landfill caps).
- Are located on or adjacent to existing landslides.

3.3.5 Drought

Cleanup sites vulnerable to drought include groundwater sites vulnerable to a lowered water table, sediment sites in drought-prone waterbodies, and mines and landfills reliant on rain to irrigate and maintain vegetative cover for slope stability.

3.4 How to do a site-specific vulnerability assessment

The previous sections of this chapter provide information on conducting a general screening of a cleanup site to understand if there may be vulnerabilities that need to be addressed during cleanup. For cleanup sites identified as vulnerable to impacts described in Section 3.2.1, the recommendations provided in this section may help further evaluate the risk to individual cleanup sites based on site-specific information. See Section 3.4.5 for an example.

- **Step 1. Screen your site using the TCP Maps Climate Change analytical tool.** Use the online TCP Maps analytical tool (for Ecology staff) to determine if your site is located in an area that may be vulnerable to climate change. If it is, review Section 3.3 and Tables 2-5 and use site-specific information to confirm or understand the scope of the specific vulnerabilities.

- **Step 2. Identify the risk scenario for the site**. In this case, the term "risk" is defined as the vulnerability to potential impacts and the magnitude of damage (hazard) from the impact. For example, for a site located in a low-lying area along the waterfront of Puget Sound, daily inundation due to sea level rise (a vulnerability with a high likelihood of occurring) can result in cap failure and release of contaminants (a high magnitude impact). The process below (a–c) will help to identify the site-specific risk scenario:

    a. Depending on the site-specific characteristics, the following risk scenarios may apply:

        - Low-risk scenario. This applies to cleanup sites that will be cleaned up in the immediate future (e.g., one to two years). This would be a full removal remedy with no long-term monitoring, where the cleanup is considered final with no further action. Under this scenario, future climate projections would not need to be addressed, but potential adverse environmental conditions should be considered based on current environmental trends.

        - Short-term risk scenario. This applies to cleanup sites that have been or will be cleaned up in the short-term (within the next 10 years). This would include a full removal remedy with or without post-construction monitoring or a short-term natural attenuation remedy. Under this scenario, near-term climate projections (e.g., up to mid-century) may be most appropriate.

        - Long-term or high-risk scenario. Under this scenario, environmental projections up to the end of the century or beyond may be most appropriate. Cleanup sites with the following remedy components are subject to long-term risk:

- Contamination is left in place.
- Long-term (decades) monitored natural recovery.
- Cleanup levels are estimated to take more than 10 years to be met.
- A site where the magnitude of damage (hazard) from a potential impact is high, even if the probability of the impact occurring is low.

b. Sections 3.4.1 through 3.4.5 can be used to evaluate and understand which of the above risk scenarios apply for a particular site based on:

   - The climate impact (e.g., wildfire).
   - The type of site (e.g., sediment, landfill).
   - Location of the site relative to hazards.
   - Vulnerability of the remedy.

c. Tables 2-5 and the above information can then be used to further understand the risks (very high, high, medium, low) based on the type of site and impact.

- **Step 3.** Address the potential effect of the uncertainties in the climate projections (Chapter 2). To address uncertainties, it is important to consider their potential to cause harm or remedy failure in context of:

a. The time frame of the remedy. For example, short-term (recovery within 10-years) or long-term (permanent containment or 20+ year recovery). A long-term remedy will have more uncertainties (e.g., the amount of sea level rise) since projecting impacts long-term (i.e., for the 2050s or 2100) is based on the amount of future greenhouse gas emissions.

b. The consequences of remedy failure. For example, for a site near the coastline (but not directly on the waterfront) with a permanent containment remedy the potential impact of inundation may be severe even if the likelihood of inundation is low.

c. Our ability to adaptively manage the impacts. For example, if a 1-foot sea level rise projection used to design a remedy turns out to be an underestimate, could the impact be cost-effectively repaired or adaptively managed?

d. In these high-risk cases, it may be appropriate to plan for a more extreme impact scenario. For example, plan for sea level rise of 4 feet for 2100 rather than 1 foot.

- **Step 4. Understand the long-term maintenance requirements for the site.** Consider the continued repair of the remedy due to damage from a specific impact, such as continued erosion control and re-vegetation of a landfill cover due to extreme precipitation events. If it is uncertain that continued maintenance would retain the integrity of the remedy and remain cost effective, planning for a more extreme impact scenario may be appropriate.

3.4.1 Sea Level Rise–Understanding the Site-Specific Climate Change Risk Scenario

This section can be used to understand and identify which climate change risk scenarios for sea level rise may be applicable to the cleanup site more fully (risk scenarios are described in Section 3.4). To understand inundation potential and magnitude of impact for a specific site, there are three base elevations on which to add sea level rise increments [MHHW, base flood elevation, MHHW and +3 feet (for areas without base flood elevation established); Section 3.2.2]. The Washington State Coastal Resilience Network probabilistic sea level rise projections can be accessed through Ecology's TCP Maps Climate Change application (for Ecology staff) —which links to the University of Washington Climate Impacts Group (UW CIG) probabilistic visualization tool—and then used to identify the risk scenario. We recommend using the following sea level rise values based on the risk scenarios (Section 3.3) that are applicable to the cleanup site:

- *Low-risk scenario*. Sea level rise may not need to be addressed for this type of cleanup site since it is a full removal remedy to be conducted in the immediate future. For shoreline and sediment cleanup sites, a base tidal elevation of MHHW with a 6-inch to 1-foot sea level rise may need to be considered during cleanup construction to account for tidal flooding or severe storm impacts (see Appendix C case study).
- *Short-term risk scenario*. A sea level rise at the lower end of the range (i.e., 1 to 2 feet), with an assumption this may occur by mid-century may be appropriate. At a minimum, inundation based on the MHHW and 1 to 2 feet of sea level rise should be considered. Use the TCP Maps Climate Change analytical tool (for Ecology staff) and University of Washington Climate Impacts Group's sea level rise visualization tool to understand the probabilities for specific coastal locations.
- *Long-term and high-risk scenarios*. A sea level rise at the higher end of the range (e.g., 4–6 feet), with an assumption that it may occur before the end of the century may be appropriate. Inundation based on both BFE and MHHW tidal datums (Section 3.3.1) should be considered. Use the TCP Maps Climate Change analytical tool (for Ecology staff) and University of Washington Climate Impacts Group's sea level rise visualization tool to understand the probabilities for specific coastal locations.

3.4.2 Severe Storms–Understanding the Site-Specific Climate Change Risk Scenario

This section can be used to understand and identify which climate change risk scenario for storms may be applicable to the cleanup site more fully (risk scenarios are described in Section 3.4).

- *Low-risk scenario*. Extreme precipitation and severe storm events may not need to be addressed for this type of cleanup site, unless they have a reasonable probability of occurring during construction.
- *Short- and long-term risk scenarios*. If a cleanup site can be impacted by the following, this scenario may apply:
  - 100-year storm events, as currently defined, will occur more frequently, with an assumption that these storms will occur at least every 25 years before mid-century. In other words, a 100-year storm may become a 25-year storm in this area.
  - An increase in the frequency of extreme precipitation events (a minimum of eight days per year), which may occur within short timeframes (i.e., days) of each event.
  - More frequent and severe erosion is highly likely in areas prone to erosion.
- *High-risk scenario.* 100-year storm events, as currently defined, will occur more frequently. If a cleanup site can be impacted by more severe storms, the assumption that these storms will occur at least every ten years before mid-century may be appropriate.

3.4.3 Flooding–Understanding the Site-Specific Climate Change Risk Scenario

This section can be used to understand and identify which climate change risk scenarios for flooding may apply to the cleanup site more fully (risk scenarios are described in Section 3.4).

- *Low-risk scenario*. Flooding may not need to be addressed, unless there is a reasonable likelihood that it may occur during construction.
- *Short-term, long-term, and high-risk scenarios.* If a cleanup site can be impacted by the following, this scenario may apply:
  - If the site is identified by the TCP Maps Climate Change analytical tool (for Ecology staff) to be within the current 100-year flood plain, it may be vulnerable to more frequent "100-year" floods. In other words, a 100-year flood may become a 25-year flood, for example, in this area.
  - Sites in areas that have had minor flooding will experience more frequent and severe flooding.
  - It is possible that areas that have not flooded in the past will experience flooding in the future. However, this information has not yet been compiled by FEMA.
- *High risk scenario.* The long-term risk scenario above applies to this scenario, but a current 100-year storm event increasing in frequency (e.g., 10-year frequency) should be considered.

3.4.4 Landslide–Understanding the Site-Specific Climate Change Risk Scenario

This section can be used to understand and identify which climate change risk scenarios may apply to the cleanup site more fully (risk scenarios are described in Section 3.4).

- *Low-risk scenario*. Landslide may not need to be addressed for this type of site, unless there is a reasonable likelihood it may occur during construction.
- *Short-term, long-term, and high-risk scenarios.*
    - If the site is identified by the TCP Maps Climate Change analytical tool (for Ecology staff) to be within an area where a landslide has occurred, it may experience landslides (particularly during extreme precipitation events).
    - Sites in areas prone to erosion may experience more severe and frequent erosion.

3.4.5 Wildfire–Understanding the Site-Specific Climate Change Risk Scenario

This section can be used to understand and identify which climate change risk scenarios may apply to the cleanup site more fully (risk scenarios are described in Section 3.4).

- *Low-risk scenario*. Wildfire may not need to be addressed for this type of site, unless there is a reasonable likelihood it may occur during construction.
- *Short-term, long-term, and high-risk scenarios.* This could include sites:
    - In or near forests with short fire-return intervals (e.g., dry, east-side Ponderosa forests).
    - That have considerable burnable material, such as grasslands and heavily forested areas.
    - That have recently experienced drought.
    - In or near forested areas that have experienced pest infestations or disease outbreaks, such as mountain pine beetle or rust fungus.
    - In or near forests that have experienced changes, such as a shift from evergreen to deciduous, or a change in the distribution of age or species that may have different fire risks than the previous species.

3.4.6 Example of a Site-Specific Vulnerability Analysis

Below is an example of how to incorporate the steps described at the beginning of Section 3.4. In this example, the site is an abandoned landfill at the Cleanup Action Plan/Remedial Design stage.

Step 1: Screen your site using the TCP Maps internal analytical tool.

a. The alternatives analysis produces a preferred alternative that includes:

   - An engineered cap,
   - Planted vegetation as erosion control,
   - A leachate collection system, and
   - A landfill gas collection system.

b. The TCP Maps Climate Change analytical tool (for Ecology staff) shows the cleanup site is located where the area burned by wildfire is projected to increase by ~320%. It is not located in or near an area where landslides have occurred, nor is it located in a flood plain or near a waterbody.

c. Site-specific information shows:

   - The site is surrounded by grassland.
   - The area has experienced drought for the past year.

d. After reviewing Table 3 (potential risks for landfill sites), you conclude that the site has vulnerability to wildfire because:

   - The location near a drought ridden grassland that is projected to be at increased risk of burning (in terms of potential increase in burned area). It is understood there are uncertainties surrounding the specific projected percent of increase, but a projected increase is informative.

   - The flammable components of the remedy (equipment, piping, and electrical equipment for the leachate collection system; landfill gas collection system; and vegetation for erosion control and stabilization).

Step 2. Identify the risk scenario for the site. The site has permanent containment, is in an area with considerable burnable material (grassland) and has recently experienced drought. Additionally, the climate projection shows the area has potential for increased wildfire risk (in terms of projected increase in area burned) compared to the past. Taken together, these variables define a long-term and potentially high-risk scenario.

Steps 3 and 4. Address the potential effect of uncertainties in the climate projections and the long-term maintenance requirements for the site.

a. This is a permanent containment remedy, and the integrity of the remedy must be maintained in perpetuity.

b. The consequences of the landfill being engulfed in fire are severe: cap and side slope failure; failure of leachate collection system and potential surface or groundwater contamination; landfill gas explosion.

c. Some impact may be adaptively managed (by replanting vegetation cover with drought and fire tolerant plants, repairing minor damages to electrical equipment and piping). However, if damage to the remedy is severe, adaptive management may not be effective.

The potential magnitude of impact from wildfire and the projected increased risk of wildfire indicates that repair and maintenance of the remedy will likely not be effective in the long-term. While potential for wildfire was incorporated in the remedy selection process, the climate projections of increased risk of wildfire were not. Given this, it would be appropriate to plan for a more extreme wildfire scenario and use the recommendations in Chapters 5 and 6 to a) design the remedy to be as fire resistant as possible, b) include additional contingencies for remedy failure, and c) incorporate additional long-term monitoring requirements.

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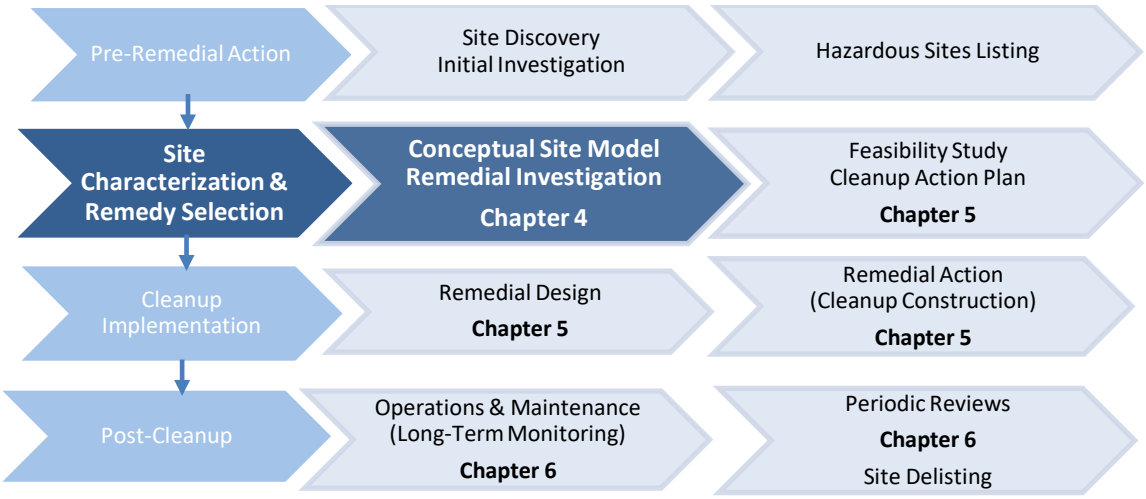
4.0 Conceptual Site Model and Remedial Investigations



Cleanup Process Figure 2: Steps in the cleanup process. Chapter 4 applies to steps shaded the darkest tones.

In Washington state, the Model Toxics Control Act (MTCA; WAC 173-340-350) and Sediment Management Standards (SMS; WAC 173-204-550) require adequate characterization of cleanup sites, including understanding potential impacts and vulnerabilities associated with climate change. Chapter 4 provides guidance on how to evaluate and understand these potential impacts at the investigation phase on a site-specific basis. It includes recommendations to develop the Conceptual Site Model and conduct the Remedial Investigation for each type of site (e.g., soil). The process to evaluate climate change vulnerabilities for a particular cleanup site at those site characterization phases are:

- **Step 1.** Review the vulnerability assessment in Chapter 3 (Sections 3.3 and 3.4).
- **Step 2.** Use the interactive TCP Maps Climate Change analytical tool (for Ecology staff) as a screening tool to identify the vulnerabilities to climate change that a cleanup site may have, based on its location and type of site (e.g., sediment, groundwater).
- **Step 3**. Use information in this chapter to evaluate the cleanup site based on the vulnerabilities identified in Step 2.
- **Step 4.** Carry this information into the Remedy Selection process (Chapter 5) to understand 1) the risks for specific types of cleanup sites and 2) recommended remedies to increase resilience of the remedy.

4.1 Conceptual Site Model and identifying data gaps

Summarizing known information and developing the Conceptual Site Model are the first steps to identify data gaps and determine what to include in the remedial investigation work plan. Review Chapter 3 and use the TCP Maps Climate Change analytical tool (for Ecology staff) to determine:

- Whether the cleanup site is in an area that may be impacted by sea level rise, landslides/erosion, flooding, or wildfire.
- Which of the above climate change impacts may apply to the cleanup site and should be identified in the Conceptual Site Model to inform decision making (Chapter 3, Section 3.2; TCP Maps Climate Change analytical tool).
- For any vulnerabilities identified, which risk scenario may apply to the cleanup site (Chapter 3, Sections 3.3 and 3.4).
- What timeframes and climate change impacts should be evaluated based on the applicable risk scenario (Chapter 3, Section 3.4).

4.1.1 Identifying the Risk Scenario and Cleanup Site Vulnerabilities

The risk scenario may vary for each type of climate impact based on site-specific circumstances (Chapter 3, Sections 3.3 and 3.4). For some or all climate change impacts, the vulnerabilities for a particular cleanup site may be non-existent or pose a low risk. In this case, further evaluation of climate change impacts may not be necessary. In other cases, there may be one impact (such as sea level rise) that a cleanup site is vulnerable to and that poses a high risk, or multiple vulnerabilities with varying degrees of risk. Section 3.3's summary of climate impact information may need to be included in a Conceptual Site Model.

If the area is vulnerable to periodic climate change impacts, such as flooding or wildfires, there may be more recent site-specific information on climate change and climate projections (i.e., more recent than data found in Ecology's TCP Maps Climate Change analytical tool for Ecology staff). For example, the interactive internal TCP Maps tool includes data for 100- and 500-year floodplains, but FEMA floodplain maps may have been recently updated, so more cautious analyses are recommended for areas with older floodplain maps.

4.1.2 Identifying Data Gaps

The TCP Maps Climate Change analytical tool (for Ecology staff) is intended to be used as a screening tool to understand if a cleanup site may be vulnerable to climate change impacts. The data that informs the tool is as current as possible, and Ecology will work to keep the data updated. However, the tool may not be sufficient to understand all site-specific vulnerabilities, such as the potential for saltwater intrusion or alterations made to the shoreline intended to protect against severe storm events. Any data gaps pertaining to a cleanup site's vulnerability to climate change impacts should be included in the Conceptual Site Model data gaps summary. Some of this site-specific information can be gathered during the Remedial

Investigation, and the Feasibility Study and remedial design may need to take any uncertainties into account.

Such data gaps should be evaluated and prioritized to determine how and whether the missing information would influence development of remedial alternatives and remedy selection (see Chapter 5). A remedial investigation Work Plan task should be developed if the data gap represents important information needed to:

- Understand the natural processes occurring at the cleanup site.
- Screen technologies and develop remedial alternatives.
- Evaluate and select a remedial alternative.
- Design the remedy.

If the information identified in the data gaps analysis does not rise to any of these levels, it can be retained as an uncertainty that should be considered during the Remedial Investigation and Feasibility Study.

4.2 Remedial Investigation

Both MTCA and SMS have similar requirements for the Remedial Investigation, many of which are directly applicable to characterizing vulnerability to climate change (WAC 173-340-350(7)(c)(iii)(A) – (D) and WAC 173-204-550(6)(e)(i) – (iii)).

Climate-related impacts can have many site-specific effects on surface water hydrology, sediment, soil, and groundwater—each of which can be evaluated during the Remedial Investigation. The climate-related information described below should be gathered during the Conceptual Site Model phase and used along with the TCP Maps Climate Change analytical tool (for Ecology staff) to identify which Remedial Investigation work plan tasks should be conducted. Additional resources are included in Appendix B of this guidance that may be useful during the remedial investigation.

To address potential climate-related vulnerabilities, site managers should use the Conceptual Site Model, Section 3.4's risk scenarios and information, and the internal TCP Maps Climate Change analytical tool to determine which of the following conditions apply to their cleanup site.

4.2.1 Surface Water and Sediments

For cleanup sites involving surface water and sediments, MTCA and SMS require investigation of the following environmental features related to climate change (WAC 173-340-350(7)(c)(iii)(A) and WAC 173-204-560(6)(e)(i)):

- Surface water drainage patterns, quantities, and flow rates.
- Areas and rates of erosion and sediment deposition.

- Surface waters, floodplains, and actual or potential contaminant migration routes toward and within these features.
- Properties of surface and subsurface sediments that are likely to influence the type and rate of contaminant migration and recontamination of sediment.
- Properties that are likely to affect the ability to implement alternative cleanup actions, including recontamination potential.

Upland Cleanup Sites (Inland)

For upland sites vulnerable to erosion or inundation from flooding, it is important to have current/up-to-date climate projections including severe storm and extreme precipitation events. A site reconnaissance, preferably after a storm or extreme precipitation event, should be conducted to identify drainage patterns; surface water flow; flooding or standing water; and areas susceptible to erosion or landslide. The locations of any vulnerable areas with respect to existing contamination should be mapped.

Upland Cleanup Sites (Along the Shoreline)

For sites located along or near the shoreline (marine, estuarine, or freshwater), it is important to understand projected sea level rise, currents, wind and wave action, the frequency and magnitude of extreme events such as storms and high river levels, flooding and potential inundation, and bank erosion potential to select and design an appropriate remedy. If possible, the site should be visited at high tide or king tide to evaluate current levels of inundation, and sea level rise projections should be reviewed to identify areas of the site that may be inundated in the future. Accurate and current elevations and topography should be used.

Sediment Cleanup Sites

For sediment sites, it is important to understand the water body's hydrodynamics, including tides and projected changes in sea level; currents; wind and wave action; the frequency and magnitude of extreme events such as storms and high river levels; sediment transport; sediment and bank erosion; and deposition under both normal and extreme conditions.

Sediment properties that may affect sediment and contaminant transport include sediment grain size and compaction. The transport of sediments in dynamic areas can be disproportionately affected by extreme weather events and may result in substantial erosion and deposition in upstream, downstream, and lateral directions (depending on the system). It's important to understand these events and their probable effects on the system, to know where sediment contamination exists currently, where it may be transported in the future, and what remedy selection and design is appropriate.

4.2.2 Soils

For cleanup sites involving soils, MTCA and the SMS requires investigation of the following environmental features related to climate change (WAC 173-340-350(7)(c)(iii)(B) and WAC 173-204-560(6)(e)(i)):

- Properties of surface and subsurface soils that are likely to influence the type and rate of hazardous substance migration. This includes the recontamination potential of sediment from eroding soil.
- Properties that are likely to affect the ability to implement alternative cleanup actions.

Upland Cleanup Sites (Inland)

For upland sites with erosion or landslide vulnerability, the geology of the site should be carefully assessed to evaluate the potential for these events under heavily saturated soil conditions. If the site is in an area where wildfire has recently occurred, the potential for soil erosion or landslide if overlying vegetation is burned should be considered.

Upland (Along the Shoreline) and Sediment Cleanup Sites

For upland sites with steep banks, the banks should be investigated to determine the potential for erosion, slumping, or landslide into sediment, particularly under heavily saturated or high-flow conditions. Shoreline banks should be investigated to determine whether soil contamination is present that could recontaminate a cleaned-up sediment site if bank failure occurs. Much of Puget Sound developed shorelines are comprised of artificial fill containing wood waste that, when released into the aquatic environment, can be toxic to biota and degrade habitat. An assessment of the type of fill material should be done to understand this potential hazard.

4.2.3 Geology and Groundwater System Characteristics

With respect to geologic and groundwater characteristics, MTCA and SMS require investigation of the following environmental features related to climate change (WAC 173-340-350(7)(c)(iii)(C) and WAC 173-204-560(6)(e)(ii)):

- The description, physical properties, and distribution of bedrock and unconsolidated materials.
- Groundwater quality, flow rate, gradient, direction, and groundwater divides.
- Areas of groundwater recharge and discharge.

Upland Cleanup Sites (Inland)

For upland sites with known or potential groundwater contamination, several aspects of the groundwater system may be important. Groundwater table elevations may be lowered by drought or raised by increasing rainfall or flood in some areas. Both possibilities exist with respect to climate change. In addition to measuring existing groundwater elevation, evaluating seasonal and long-term changes in groundwater elevation in recent years or decades may be helpful when designing monitoring or treatment systems (for example, to ensure that monitoring well screens are placed at the appropriate level). Failing to account for these potential shifts could result in the need to redevelop wells, which would increase operations and management costs over time.

Upland Cleanup Sites (Along the Shoreline)

For shoreline sites, in addition to the issues noted above, tidal variations in the groundwater level and/or salinity should be determined, to evaluate whether saltwater intrusion is, or may occur, with sea level rise. Salinity is an important consideration for groundwater monitoring wells or treatment systems, as it may affect the integrity of the equipment and the efficacy of the treatment method. If saltwater intrusion is occurring, the following measurements may be helpful in determining corrosion potential:

- pH
- Presence of chlorides and/or sulfates
- Oxygen content
- Soil type
- Soil resistivity
- Conductivity

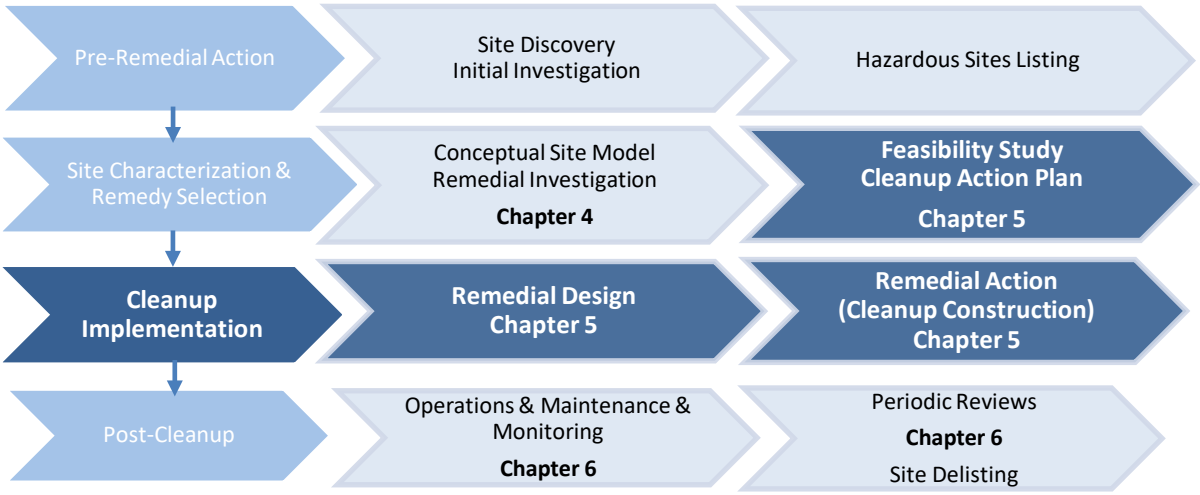
4.2.4 Air and climate

With respect to air and climate, MTCA and SMS require investigation of the following environmental features related to climate change (WAC 173-340-350(7)(c)(iii)(D) and WAC 173-204-550(6)(e)(iii))):

- Local and regional climatological characteristics that are likely to affect:
  - Surface water hydrodynamic
  - Groundwater flow
  - Migration of sediment contaminants
- Seasonal patterns of rainfall.
- The magnitude and frequency of significant storm events.
- Temperature extremes.
- Prevailing wind direction, variations in barometric pressure, and wind velocity.

Investigating these features can provide key information important for understanding current and projected future impacts from climate change.

5.0 Feasibility Study, Cleanup Action Plan, and Remedial Design



Cleanup Process Figure 3: Steps in the cleanup process. Chapter 5 applies to steps shaded the darkest tones.

Chapter 5 provides guidance on evaluating the resilience of remedies at the Feasibility Study and Remedial Design phases, with a brief discussion of the Cleanup Action Plan. Recommendations found in this chapter can also be applied to cleanup sites that haven't yet reached these stages. For example, strategizing for the remedial design can begin even before it starts by understanding the vulnerabilities identified in Chapter 3 (Section 3.3) then later updating it using recommendations in this chapter. This chapter, in combination with other chapters in this guidance, can be used to understand specific vulnerabilities based on the site's:

- *Location*. Climate vulnerabilities will vary depending on where the site is located.
  - **Step 1**: Use Chapter 3 Section 3.3 and them TCP Maps Climate Change analytical tool (for Ecology staff) to do an initial screening to understand if the site may have vulnerabilities to climate change.
  - **Step 2**: If the initial screening shows potential vulnerabilities, you may need to follow up with a more site-specific assessment using Section 3.4
- *Cleanup stage.* If the site is at the Feasibility Study stage, the following steps are recommended:
  - **Step 1**: Use Chapter 5 Section 5.2 to conduct an initial screen of remedial alternatives.
  - **Step 2**: Use Chapter 5 Section 5.3.1 to conduct a threshold evaluation of remedial alternatives.

- **Step 3***:* Use Chapter 5 Section 5.3.2 to conduct a further detailed evaluation of remedial alternatives.

- *Risks to the site and remedy.*
  - **Step 1**: Identify the risk scenario that most appropriately applies to the site to develop resilient remedies on a site-specific basis (Chapter 3 Section 3.4 and Tables 2-5).

  - **Step 2**: Use Section 5.4 to further understand the site- and remedy-specific vulnerabilities and options to increase remedy resilience based on the type of site.

5.1 When to consider impacts during the Feasibility Study and Remedial Design

Implementation of adaptation measures during early stages of the cleanup process may increase the feasible remedial options, maximize the integrity of the remedy, and reduce implementation costs in some situations. Resilience to climate-related impacts can be considered at various points in the Feasibility Study and Remedial Design process, including:

1. Screening technologies and developing remedial alternatives;
2. Evaluating remedial alternatives and selecting the preferred alternative; and
3. Remedial design.

The following sections describe how increasing resilience from climate change impacts can be addressed at each of these three stages. Information is also provided that may help when selecting technologies, evaluating alternatives, and designing the cleanup site remedy.

By the time the Feasibility Study and Remedial Design are underway, any climate vulnerabilities for the cleanup site will have been identified and evaluated as part of the Remedial Investigation, using recommendations in Chapter 3, and the Conceptual Site Model and Remedial Investigation process in Chapter 4. Only the vulnerabilities that apply to the specific site need to be addressed during the Feasibility Study and Remedial Design. If no vulnerabilities were identified, no special considerations of climate change impacts are necessary.

5.2 Screening remedial technologies

When screening technologies to develop cleanup alternatives, there will generally be two evaluations:

1. Determining that one technology is preferable to another within the same class of technologies, and

2. Determining that an entire class of technologies is or is not appropriate to include for at least one alternative.

Screening out technologies also means eliminating those that don't address the specific climate change vulnerability, based on technical feasibility, protection of human health and the environment, and long-term effectiveness—such as when better choices exist within the same class, or when technologies can't be implemented at all or in part of a cleanup site.

Examples of comparing technologies within the same class:

- Evaluating different treatment technologies for volatile organic compounds (VOCs) in soil and groundwater.
- Evaluating different dredging technologies or types of caps for a sediment cleanup site.

  Climate considerations may play a role when deciding between technologies—for example, choosing a treatment approach more resilient to salinity in groundwater, or a containment technology more resilient to flooding and erosion.

Examples of evaluating an entire class of technologies for all or part of a cleanup site:

- Determining that sediment capping is not feasible due to erosional forces and wave energy from more severe storm events coupled with sea level rise.
- Determining that a confined disposal facility located along the shoreline is not feasible due to anticipated inundation from flooding or sea level rise.

In these cases, an entire class of technologies may not be possible to use for all or part of a cleanup site, and other types of technologies would need to be incorporated into feasible alternatives.

Once the technologies have been screened, they should be assembled into a range of alternatives. Section 5.3 describes how climate resilience can be addressed when evaluating the remedial alternatives and selecting a preferred alternative. Section 5.4 describes engineering considerations related to cleanup alternatives for different types of cleanup sites with climate change vulnerabilities.

5.3 Evaluating remedial alternatives

Remedial alternatives (alternatives) are evaluated in three steps, any of which may incorporate climate resilience considerations:

- Threshold evaluation of the alternatives.
- Detailed comparative evaluation of the alternatives.
- Disproportionate cost analysis to identify the alternative that is permanent to the maximum extent practicable.

5.3.1 Threshold Evaluation in MTCA and SMS

Both the MTCA and SMS rules require that alternatives meet threshold criteria (except for the "no action" alternative that is kept for comparison). The threshold evaluation is designed to eliminate alternatives yet retain a wide enough range of remedies to allow more detailed evaluation. Alternatives eliminated during the threshold evaluation are those clearly a) not protective of human health or the environment; b) not in compliance with applicable regulations; or c) not implementable. Accordingly, high-level issues like those below should be the focus for a threshold evaluation of remedies for cleanup sites with potential vulnerabilities to climate change impacts.

Threshold criteria that should be used to evaluate whether an alternative is resilient to climate change impacts include:

- Protection of human health and the environment:
  - SMS: WAC 173-204-570(3)(a) [2]
  - MTCA: WAC 173-340-360(2(a)(i)

- Permanent to the maximum extent practicable, which includes long-term effectiveness:
  - SMS: WAC 173-204-570(3)(d) and WAC 173-204-570(4)
  - MTCA: WAC 173-340-360(3)[3]

Critical failure modes should be evaluated to determine if the alternative might fail due to a climate change related vulnerability (Section 5.2). **If so, that alternative may need to be screened out as neither permanent to the maximum extent practicable nor protective of human health and the environment. Below are examples of this type of critical failure:**

- Loss of cover or side-slope material due to flooding, erosion, or landslide such that contaminated soils or mine tailings are released into a sensitive area (e.g., waterbody).
- Erosion of a sediment cap during a storm or high river flow event sufficient to expose contaminated sediments and transport them downstream.

[2] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-204-570 (Selection of cleanup actions.)
[3] https://apps.leg.wa.gov/wac/default.aspx?cite=173-340-360 (Selection of cleanup actions.)

- Erosion or blowout of a landfill containment system resulting in a release of leachate into a surrounding aquifer or landfill gases into a neighborhood.
- Failure of containment structures due to flooding (particularly for cleanup sites located in flood plains), inundation, or a storm event resulting in a release of contamination.

5.3.2 Evaluating Alternatives in Detail

In many cases, climate resilience can be addressed through the preferred alternative's remedial design and won't necessarily affect selection of the alternative. For example, at a groundwater cleanup site minor increases in salinity over time due to seawater intrusion could be addressed by selecting appropriate materials for the underground infrastructure that will come into contact with saline groundwater.

In other cases, climate vulnerabilities may be significant enough that they could change the scores the alternatives would receive under the disproportionate cost analysis, which would potentially affect identification of the preferred alternative. For example, a cleanup site located in an area with increasing likelihood of substantial sea level rise, severe storm effects, shoreline erosion, or frequent inundation might have permanent removal remedies ranked higher (and cap-in-place remedies ranked lower) than if just historical climate data were considered.

A detailed evaluation of alternatives is also part of the disproportionate cost analysis (see next section), in which the benefits of the alternatives are ranked against their costs to identify the alternative that is permanent to the maximum extent practicable.

These criteria should be used for a detailed evaluation of the alternatives:

- *Protectiveness*. The degree to which risks to human health and the environment are reduced by the alternatives would generally be evaluated in the same manner as usual. However, assessing risk reduction should be done in the context of the potential for future releases from the cleanup site, or for climate change impacts (e.g., sea level rise, more severe storms, or severe flooding) to compromise the success and ultimate protectiveness of the remedy.
- *Permanence*. Remedies that are more vulnerable to climate change related events would be considered less permanent. The hierarchy of remedy permanence would be the same as identified in MTCA and SMS, but the risk and/or consequences of selecting a less permanent remedy may be greater for a cleanup site vulnerable to climate change impacts. The risk scenarios identified in Chapter 3, Section 3.4 can help evaluate this criterion.
- *Cost*. Cost estimates for the alternatives should consider any additional costs associated with increasing remedy resilience, such as additional slope or cap armoring; overdesign of stormwater management systems; backup systems for storm or flooding events; or additional monitoring requirements. In addition, maintenance and repair costs should be included if damage from a climate change-related impact is expected.

- *Long-term effectiveness*. This criterion addresses the level of certainty that the remedy will be effective over the long-term, and any climate change related vulnerabilities that may increase uncertainty about the remedy's effectiveness over time must be considered. Uncertainties about future climate conditions should also be considered, such as the amount of sea level rise affecting shoreline cleanup sites. Consideration of climate change impacts will be more important for containment remedies or for those cleanup sites with long restoration timeframes.
- *Management of short-term risks*. This criterion would include the potential for climate change impacts to affect construction or implementation of the remedy. The longer the restoration timeframe, the more likely such impacts may affect the cleanup. The likelihood or frequency of such events should be considered.
- *Technical and administrative implementability*. This criterion includes any engineering, permitting, scheduling, logistics, or other challenges that climate change impacts could present, as well as the feasibility of successfully resolving these challenges.
- *Consideration of public concerns*. Any comments received from the public, tribes, or agencies should be considered under this criterion if the comments address possible climate change impacts on the remedial alternatives or cleanup site.

In addition to referencing MTCA and SMS rule criteria, see Appendix B of this guidance. It describes online resources developed by the Environmental Protection Agency and others for evaluating climate resilience and green cleanup.

5.3.3 Disproportionate Cost Analysis and Remedy Selection

It may not be necessary to include climate resilience at the disproportionate cost analysis stage. Once the detailed evaluation of alternatives has been carried out, the disproportionate cost analysis is conducted per MTCA and SMS/SCUM (for sediment cleanup sites) to select the preferred alternative. Since alternatives with critical failure modes will have been screened out, and since scores for each alternative will already have taken climate change considerations into account, there may be no need to conduct further analyses related to climate change vulnerabilities at this stage. In other words, *any alternatives identified as vulnerable to climate change impacts may have been screened out before the disproportionate cost analysis stage.*

5.4 Increasing resilience of remedial alternatives

This section provides options for increasing resilience of remedial alternatives. Each subsection is organized by site type. Each one identifies potential climate change impacts and vulnerabilities; describes in detail how they might affect soil, groundwater, sediment, landfill, and mine site remedies; and offers suggestions for increasing remedy resilience. While many of these considerations can be addressed during the Remedial Design phase, some "bigger picture" issues are discussed at the beginning of each subsection that could affect selection of the preferred remedy.

See Appendix B for more resources for evaluating and increasing remedy resilience. A particularly relevant resource are the EPA's remedy-specific Technical Fact Sheets for increasing remedy resilience. See Appendix C for case studies on how Washington state has addressed some impacts from sea level rise and more severe storm events.

5.4.1 Soil and Groundwater Cleanup Sites

Pump and treat, funnel and gate, and barrier wall systems are typically designed based on static assumptions about groundwater level, flow direction, and geochemistry—all of which are based on historical data (e.g., maximum/minimum water table levels) rather than future projections. Changes in any of these environmental conditions may affect the long-term performance of the system and its ability to achieve cleanup standards. In addition, the heterogeneous geologic strata can complicate contaminant removal and/or treatment at many cleanup sites in the state.

Sea Level Rise – Potential Vulnerabilities

Sea level rise may affect soil and groundwater cleanup sites along the shoreline through changes in the groundwater table, saltwater intrusion into groundwater aquifers, and inundation. Sea level rise may also exacerbate the impacts from coastal storms and flooding (especially in low-elevation areas, estuaries, and tidally influenced rivers).

Changes in contaminant migration pathways. In tidally driven groundwater, sea level rise can change the base groundwater elevation, tidal fluctuations, and flow directions near the shoreline. Contaminant plumes, particularly light non-aqueous phase liquid and dense non-aqueous phase liquid, may migrate in different directions or be redistributed over different areas.

Saltwater intrusion and changes in geochemistry. The degree of saltwater intrusion depends on the geologic strata or composition of fill material, as well as the hydraulic head along the shoreline. Seawater flooding due to coastal storms or higher tides can cause saltwater to infiltrate into soil and groundwater and change their geochemistry. The pH of marine water may change the ionization of metals, potentially increasing leaching of metals from contaminated soils.

Changes in groundwater geochemistry can:

a) Impact treatment technologies (e.g., through cation/anion reactions);
b) Impact the performance of biological and chemical injection systems;
c) Compromise slurry walls and treatment barriers; and
d) Increase corrosion of underground infrastructure.

If natural attenuation is part of the remedy, changes in salinity and its potential effect on natural attenuation mechanisms should be evaluated.

Severe storm events – compromised structures. Sea level rise can also exacerbate the effects of severe storm events. This could physically compromise slurry or sheet pile walls through development of leaks or cracks, tie back or anchor failure, and wave overtopping. Increased wave energy could compromise shoreline stabilization structures. In addition, shorelines and

waterfront property that may not be part of cleanup sites can be compromised by severe erosion which can impact cleanup sites. Throughout much of Puget Sound, developed shorelines and waterfront property are made of artificial fill such as wood waste. This wood waste is highly organic debris that can be toxic to aquatic biota and degrade nearshore habitat when released—in this case through erosion during storm events (Ecology 2015).

Flooding and Extreme Precipitation Events – Potential Vulnerabilities

Inundation. Current floodplains and floodway areas are identified by FEMA and are projected to be more extensive in the future (CIG 2015). If a cleanup site is in or near a floodplain, it could be subject to more frequent and severe flooding. In addition, the percentage of area flooded and magnitude of flooding for rivers flowing into Puget Sound are projected to increase. Extreme precipitation events are also projected to be more frequent and severe, and areas not currently vulnerable to flooding may experience erosion and flooding, potentially causing the following:

- Inundated pump and treat systems may cause system failures due to corrosion, power failures, and biofouling.
- Treatment systems with *in situ* components, often coupled with above ground operations can fail, specifically extraction or aeration pumps, wells, monitoring equipment, flow-through treatment units (e.g., granular activated carbon, clarifiers), and disposal and discharge systems.
- Changes in groundwater recharge rates, bank storage, and increased groundwater elevation levels and flow dynamics.
- Higher than normal river, lake, or stream water levels associated with heavy rainfall may flood or overtop barrier walls along shorelines that are designed to contain NAPL or support pump and treat systems.
- Power outages may take treatment systems offline.

Changes in soil porosity. Soil vapor extraction systems under buildings can also be impacted by flooding since they depend on dry subsurface conditions and head space under the buildings to operate. At the Feasibility Study stage, if the soil in the vadose zone could be a source of contamination to groundwater or surface water, and flooding or groundwater table rise is possible, the implications of the unsaturated zone potentially becoming saturated should be considered and included in the design. Sub-slab depressurization systems used for vapor intrusion mitigation may have similar potential impacts from soil moisture and high groundwater.

Landslides and Erosion – Potential Vulnerabilities

Slope failure. This vulnerability is not as significant for cleanup sites where most of the contamination is underground (e.g., in the groundwater). Containment remedies may not be an ideal choice in areas subject to slope failures. While this engineering concern is already evaluated at most cleanup sites, climate change creates a greater potential for erosion and

slope failure due to 1) periodic heavy saturation of soils from extreme precipitation events and flooding and 2) increased wave action due to sea level rise and more severe storms.

Wildfires – Potential Vulnerabilities

Burn damage. In areas prone to wildfires, buildings that contain groundwater treatment equipment are vulnerable to fire, and the exposed equipment itself is vulnerable. The appropriateness of long-term pump-and-treat approaches should be carefully considered in areas subject to frequent wildfires, since these remedies may require decades of maintenance.

Changes in soil hydrophobicity. In areas exposed to higher temperature from fire, known as burn scars, the soil can form a hydrophobic layer from organic soil materials. This can reduce water infiltration and increase the vulnerability to flash flood and debris flow—particularly on steep slopes—by keeping water at the surface while simultaneously increasing the risk of debris flows by mobilizing the materials trapped above (USGS 1997; NWS 2017).

Changes in porosity. Wildfire can the porosity of near-surface and surface soils and change the groundwater flow dynamic and exposure pathways.

Drought – Potential Vulnerabilities

Groundwater elevation and flow. In areas subject to drought changes in groundwater elevation levels, flow regimes, and evapotranspiration may occur. This can be due to natural factors—such as low rainfall recharge, low river stage, decreased snowpack, and human factors—such as greater groundwater extraction for agricultural or other uses. The changes caused by drought may have the same impact on a remedy's resilience as groundwater table fluctuations caused by rising sea levels, but their effects may be episodic in nature and fluctuate more from year to year. These changes may result in decreased groundwater capture, increased vadose zones, well screens that no longer intercept groundwater, and dessication of clay layers which may impact the integrity of barriers against movement of contaminants.

Recommendations to Increase Resilience of Soil and Groundwater Remedies

Over the past few decades, groundwater remedial technologies have shifted away from long-term pump-and-treat systems to methods that involve: 1) source and soil removal; 2) initial intensive treatment, which may use short-term pump-and-treat or in situ treatment methods; and 3) long-term natural attenuation, with the possibility of follow-up in situ treatment events as needed. In situ treatment may involve biological, chemical, or thermal methods.

These three approaches have several advantages:

- They reduce long-term maintenance needs and exposure of infrastructure to climate-related impacts.
- The remedial alternative does not need to be designed around a specific groundwater elevation, flow regime, or geochemical condition and can be adjusted to reflect changing conditions.

- They are more likely to achieve lower-concentration cleanup levels, particularly for chlorinated compounds.

The following recommendations may improve the resilience of soil and groundwater remedies even further.

Recommendations for: Sea level rise/inundation, flooding, or severe storm events

1. For containment remedies along the shoreline, and to stabilize shoreline banks or unstable slopes, consider shoreline stabilization techniques such the following (see also Case Studies in Appendix C):

    a. Wave attenuation structures.

    b. Berms of sand and vegetation.

    c. Build, or allow riverine systems to naturally build, wetlands and marsh to act as natural buffers for shorelines and waterfront lands.

    d. Reconfigure the shoreline and cut back the shore or taper it out further to a 3:1 slope or similar stable design.

    e. Soft armoring (vegetation, netting, or synthetic fabric).

    f. Hard armoring (rocks), fortified with anchors or cables if necessary, and finished with materials to restore natural habitat.

    g. And keep in mind:

        i. There is a trade-off between speed and long-term utility when deciding between hard and soft armoring. For example, rip rap and concrete channelization are typically faster and easier than softer fortification, but can reduce accessibility, utility, suitable habitat, and aesthetics.

        ii. Soft armoring options are preferred for maintaining productive nearshore habitat.

2. Take the projected changes into account when designing extraction, treatment, or monitoring wells, and when determining well placement, appropriate depths, and lengths of screens.

3. Install alarm systems and the capability to remotely stop pumping equipment during storm events or fires.

4. Have backup power and built-in redundancy for extreme events and identify specifics in the emergency response plan.

5. Design containment remedies to withstand more severe storm events and flooding.

6. Use “green” infrastructure or low impact development and flood control systems (e.g., marsh and wetlands; stormwater modular wetland passive treatment systems; earthen structures; permeable pavement; vegetated swales; berms; retention ponds) to reduce flood or stormwater overflow on land, and limit drainage to the sediment cleanup site or surface water.

7. Build treatment systems on platforms elevated above future sea level projections.

8. Ensure concrete pads and anchors are of sufficient size and strength to withstand severe storm and flood events.

9. Install retaining walls around the well or equipment pad.

10. Use sheet pile walls and enclosures to protect from the weather.

11. Protect wellheads and equipment with housing materials such as concrete or polyethylene.

Recommendations for: Geochemical or hydrological changes

1. If changes to the groundwater flow regime are anticipated, monitoring should be conducted to observe these changes over time. Adjust groundwater treatment and/or evaluation of natural attenuation accordingly.
2. In areas with salinity intrusion, cathodic protection for pump and treat systems or monitoring wells may be needed, such as those currently used for underwater pipelines in the ocean, oil platforms, and offshore wind turbines.
3. Install wells to reduce pressure from elevated groundwater levels.

Recommendations for: Drought and wildfire

1. Plant drought resistant vegetation (trees, shrubs, grasses) to minimize erosion.

2. Create fire buffers or barriers around treatment systems.

3. Install fire-resistant materials to protect buildings.

4. It is possible that, depending on the contaminants, lower groundwater levels can provide opportunity to use SVE and cost effectively accelerate cleanup.

5.4.2 Landfills

For purposes of this guidance, “older” landfills are those constructed before the Resource Recovery and Conservation Act (RCRA) was implemented in 1976. Older landfill cleanup sites may be particularly vulnerable to climate change impacts, as they often lack planning elements or features that safeguard against common risks.

They may not:

- Be sited in stable areas where permanent containment is possible.
- Be constructed with liners.
- Be engineered and designed for closure of side slopes and caps.
- Have long-term stormwater management infrastructure.
- Have management plans for waste decomposition and landfill gases.
- Have monitoring requirements after closure.

Problems that commonly occur with abandoned or closed landfills include subsidence (decomposition of waste resulting in uneven or disturbed surface caps) and flooding or surface water runoff causing erosion—all of which can be exacerbated by climate change impacts. Some landfills were constructed directly on a waterfront or in floodplains, which conflicts with current zoning regulations. Such landfills may become inundated gradually or episodically as sea levels rise, the severity of storms increases, and the magnitude of floods increases.

Stormwater management, flooding, and wildfire protection are common concerns for both operating, abandoned, and closed landfills. Erosion of the landfill cover, side slope failure, and waste blowout are the most common remedy failures, as well as release of contaminated leachate and landfill gases into the surrounding environment. Landfills that are improperly managed can cause serious hazards and quality of life concerns to surrounding communities and the environment, triggering combustion, odors, hazardous vapors, release of trash, and contaminated surface water and groundwater.

Sea Level Rise – Potential Vulnerabilities

Landfills located along the shoreline of coastal or estuarine areas will likely be impacted by sea level rise. Waves, tidal fluctuations, and severe storm events may undermine side slopes, eroding the landfill cover and potentially releasing waste materials into the environment (Figure 12). In some cases, substantial portions of landfills have been compromised or lost in large storm events, especially those accompanied by flooding.

Figure 12: Waste blowout of the March Point landfill cleanup site in Padilla Bay, Washington, caused by erosion and storms.

Rising groundwater tables within a landfill, as well as tidal fluctuations, may result in release of leachate to surrounding groundwater, and seeps through the side slopes. Seeps can further erode the side slopes and cause eventual failure. Seep water may carry odors, conventional pollutants, and hazardous chemicals. Changes in groundwater elevations and chemistry may impact the landfill contents and chemistry in unpredictable ways, potentially resulting in subsidence, increased, or slowed decomposition of wastes, and changes in aerobicity and production of landfill gases.

Flooding and Extreme Precipitation Events – Potential Vulnerabilities

Many of the concerns that relate to coastal erosion and sea level rise (above) also apply to landfills in flood plains. Large floods and extreme precipitation events may cause erosion or failures of side slopes or cap material, potentially resulting in loss of waste material.

Landfills have large flat surfaces that are often tiered. For operating landfills, these areas may have stormwater management systems or spillways designed to manage water from storms of a specific size. Abandoned landfills may have inadequate stormwater controls or none. In addition, subsidence over time can result in depressions in the landfill cover, in which stormwater may pool and infiltrate the landfill. Cracks in containment caused by subsidence can also allow infiltration of surface water during flooding or rainfall.

For both operating, abandoned, or closed landfills: if a storm exceeds the design capacity, significant erosion of the cover material may occur, along with erosion of preferential flow paths into side slopes. This can damage constructed and vegetated layers, and damage infrastructure such as landfill gas or leachate collection systems and liners. In some cases (especially older landfills), erosion may extend into the waste material and cause a release to the environment. In other cases, entire landfills have washed away in particularly large floods.

Increased saturation of the interior of the landfill can have similar impacts as described for sea level rise. It can affect leachate production and seeps, and change waste decomposition, landfill geochemistry, and gas production rates.

Landslides and Erosion – Potential Vulnerabilities

Landslides are mainly a concern for older landfills that may have been sited improperly in areas with unstable slopes. However, the additional saturation created by extreme precipitation events, flooding, and rising groundwater tables may increase the likelihood and magnitude of slope failures in areas already prone to them. Large landslides may damage nearly any component of a landfill and cause a release of waste materials to the environment.

Wildfires – Potential Vulnerabilities

Wildfires are a significant concern—particularly for operating landfills in arid environments and rural areas. Wildfires may burn vegetative cover that had been intentionally planted for erosion control or ignite naturally occurring grass and brush. This loss can increase the risk of erosion after wildfires. If the wildfire reaches the landfill, it may burn or melt pumps and piping infrastructure, including underground pipes such as leachate or landfill gas collection systems. These can be difficult to repair if they are buried under waste or surface lifts.

Recommendations to Increase the Resilience of Landfill Remedies

Many of the current remedies for landfills address climate vulnerabilities. However, it is possible that the current remedy for a particular site may not have accounted for the impacts from climate change and be sufficiently protective. The following recommendations can increase a landfill's resilience.

Recommendations for: Sea level rise/inundation, flooding, and severe storm events

1. Use erosion protection such as geomembrane liners, geotextile fabrics, armoring, and vegetation.
2. Install berms, swales, wetlands, or engineered diversion channels to prevent flooding from reaching the landfill.
3. Increase stormwater detention and/retention capacity.
4. Increase the capacity and armoring of stormwater runoff channels.
5. Install extraction wells with above ground pumps to minimize groundwater upwelling.
6. Reduce the angle of side slopes.
7. Repair caps to address differential settling and reduce pooling of surface water.
8. Install French drains or other interceptors for seep water collection and treatment or disposal.
9. Strengthen unstable slopes with hard armoring (rocks, concrete) or soft (vegetation, netting) and fortify with anchors or cables as necessary.
10. Stabilize river or waterfront banks with hard armor (rip rap) or soft (vegetation or synthetic fabric) and restore natural habitat.
11. Plant drought resistant vegetation (trees, shrubs, grasses) in the surrounding area to minimize erosion.
12. Excavate or remove landfills or portions of landfills. This may be needed if repairs are not feasible or if environmental and human health risks are significant, such as odors, leachate, gases, subsurface fires, or loss of waste material. Excavation or removal would apply especially if the landfill were located in an area that will experience increased inundation or flooding over time and cannot realistically be redesigned to withstand these climate chance impacts.

Recommendations for: Wildfire

1. Use high-density polyethylene (HDPE) piping that is more resistant to burning and breakage.

2. Mow brush and grass around pipes or laying gravel around vulnerable piping and equipment to prevent melting and burning.

3. Establish firebreaks around the entire landfill and maintaining them during fire season or when there is a risk of wildfire in the vicinity.

4. Plant vegetation that is more drought and fire resistant and can re-grow quickly.

5.4.3 Mining Cleanup Sites

There are several common challenges associated with abandoned mine reclamation sites:

- Failed re-vegetation efforts, due to less-than-optimal rainfall and soil and/or mine tailings' geochemistry.
- Eroded slopes and failed berms.
- Inadequate surface water drainage and treatment systems to address runoff and ongoing mine discharges.
- Changes in stream flows and channels that result in flooding, undermining of containment structures, and mobilization of mine tailings into floodplains and surface water bodies.

Many of these challenges are likely to be exacerbated by climate change, described next.

Flooding and Extreme Precipitation Events – Potential Vulnerabilities

Depending on the location of the mine, groundwater or surface water flows may increase or decrease with climate change. Some areas are expected to experience more extreme precipitation events and flooding. This could temporarily increase groundwater flows and result in escalating mine discharges with potentially different geochemistry. The amount or chemistry of the groundwater could in turn affect the performance of water treatment or dewatering systems.

Surface water flows are also expected to be more severe during storms, which result in flash flooding. Since mine tailings piles are frequently close to rivers or streams, changes in river levels could directly affect the integrity of the containment system by:

- Eroding the toe of the slope;
- Changing channels and undermining berms; or
- Infiltrating the tailings pile.

This can ultimately lead to loss of slope integrity or collapsed slopes, berms, or caps. The tailings may be transported into the riverbed both at the cleanup site and downstream of it, and onto floodplains.

Landslides and Erosion – Potential Vulnerabilities

As noted above, substantial failures of tailings piles and containment systems have occurred due to erosion by surface water. Natural soils may be similarly affected during extreme precipitation events or when saturated by flooding, particularly in Washington's Cascade Mountain Range where mining cleanup sites may be located on steeper slopes that are prone to landslides. Major landslides can impact tailings piles, reroute streams, and destroy infrastructure such as buildings, roads, and treatment plants.

Wildfires – Potential Vulnerabilities

Mining cleanup sites located in arid areas, or on the eastern slopes of the Cascade Range, may be at particular risk of wildfires. Wildfires can exacerbate many of the aforementioned impacts by destroying vegetation that provides erosion control on both tailings piles and natural slopes. Wildfires may damage buildings, equipment, treatment plants, mine hole covers, and other infrastructure. Mines can be located in remote areas where firefighting is challenging or not available at all. The firefighting efforts themselves could also increase erosion or cause further contamination if large volumes of water or fire suppressants are used.

Recommendations to Increase the Resilience of Mining Site Remedies

The following recommendations can help improve the resilience of remedies at mining cleanup sites:

1. Design water treatment and dewatering systems for projected more severe storm events, flooding, and groundwater flow, as well extreme precipitation events and more variable stream flow.

2. Increase slope stabilization to withstand projected more severe storm events, flooding, and groundwater flow, which could also shift stream channels. Slope stabilization strategies can include:

    a. Re-vegetation for erosion control of slopes and mine tailings piles.

    b. Stormwater and surface water drainage systems.

    c. Greater setbacks from surface water bodies.

3. Design fire prevention and control measures based on an increase in frequency and intensity of wildfires.

4. Create fire buffers or barriers around vulnerable areas.

5. Install fire-resistant materials to protect buildings.

5.4.4 Sediment Cleanup Sites

In many ways, coastal areas and river systems are on the front lines of climate change. These areas are buffeted by impacts ranging from gradual (slow sea level rise) to catastrophic (major storm events that reconfigure channels, undermine shoreline infrastructure, wash away shorelines, and transport sediments in unexpected ways). Puget Sound—where most of Washington's sediment cleanup sites are located—is relatively insulated from major oceanic storms compared to the Pacific coastline but is still subject to sea level rise and impacts from more severe storm events.

Smaller, cumulative climate change impacts can significantly alter a site's conditions by changing the biological community, impacting habitat restoration efforts, and affecting conventional water quality parameters (such as temperature and dissolved oxygen). Since sediment is the receiving environment not just for shoreline and inland cleanup sites but for contaminated municipal stormwater runoff, any increase in upland releases due to climate change impacts may also contaminate sediment or lengthen natural recovery times for cleaned up sites.

Sea Level Rise and Storm Events – Potential Vulnerabilities

Damage from waves and currents on a sediment cleanup site can be exacerbated by sea level rise, which can increase the severity of coastal storms and high tides. The events can compromise shoreline stabilization structures and alter sediment transport processes. For example, similar to landfills, confined disposal facilities may be impacted by rising groundwater tables, erosion, or inundation. These effects may change bathymetry, sediment transport, and deposition/erosion, which may impact natural recovery and recontamination processes.

Sea level rise coupled with a severe storm event can also affect a cap's integrity and performance. Scouring and erosion, for instance, can damage armor caps, isolation caps, thin-capping and habitat layers, and in-situ treatment caps, especially those located in shallow water or intertidal zones.

Habitat restoration is an important part of sediment cleanup, particularly for large-scale cleanup sites such as rivers or bays. Like cleanup remedies, habitat restoration planning should consider the potential for long-term climate change, particularly since intertidal, mudflat, and marsh areas are considered high-value habitat for restoration. This portion of the shoreline will experience the greatest impacts from increased water depth, and some habitat may be lost due to movement of intertidal habitat further up the shoreline (Figures 13 and 14). Similarly, there may be alteration or loss of wetland or riparian habitat necessary for treating or buffering intertidal zones. Freshwater habitat may become estuarine, and estuarine habitat may become marine, as the salt wedge encroaches further upriver.

Figure 13: Eelgrass habitat in the intertidal zone (photo courtesy of King County).

Figure 14: Intertidal habitat mix to support surf smelt spawning.

Upland waterfront areas can also be compromised by severe erosion and impact sediment sites. Many of the developed shorelines along Puget Sound are comprised of artificial fill such as wood waste. This wood waste is highly organic debris that can be toxic to aquatic biota and can degrade nearshore habitat when released—in this case, through erosion during storm events (Ecology 2015).

Flooding, Extreme Precipitation Events, and Erosion – Potential Vulnerabilities

Shoreline areas are particularly vulnerable to damage from intermittent high river stage, high tides, and extreme precipitation events. Damage to riverbanks or shoreline stabilization structures may occur at upland cleanup sites along the waterfront, along with potential loss of integrity and release of contaminants to sediment. Intertidal or capped areas may be impacted by various materials carried by high river stage, such as large woody debris or vessels breaking away from moorings (Figure 15). Erosion and scour impacts similar to those from sea level rise and more severe storm events would also be expected with increased extreme precipitation and flooding.

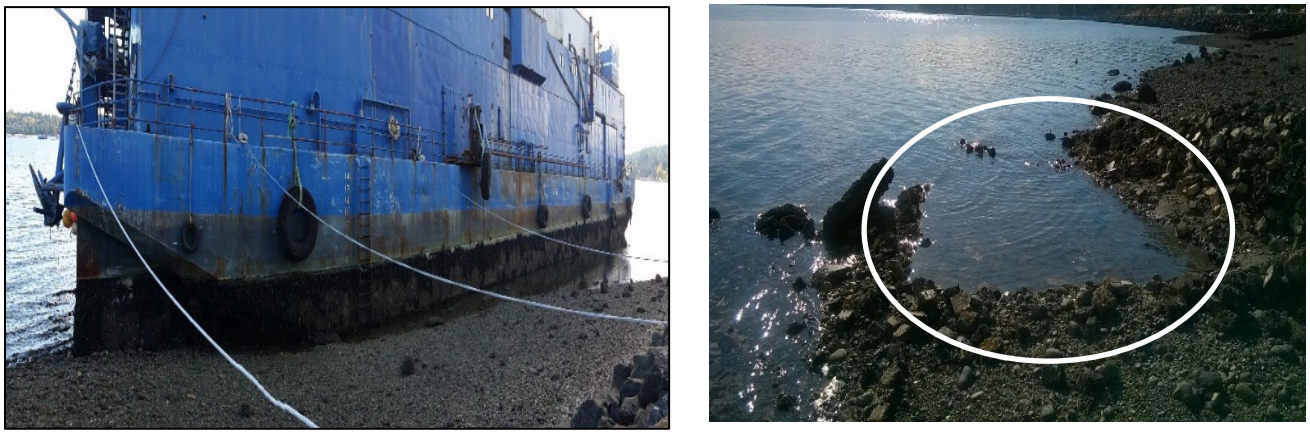


Figure 15a and b: Vessel that broke loose from its mooring during a severe storm event in Puget Sound (left) and resulting damage to a sediment cap (right, circled in white).

During high-flow conditions, shear stress increases along the bottom of the river, causing sediment transport and triggering unpredictable results. In some cases, cleaner sediment may move downstream, settle out, and enhance natural recovery. However, high flow events may also mobilize caps and contaminated sediment and disperse it downstream, into floodplains, or in estuaries.

Drought and Increased Temperatures – Potential Vulnerabilities

Increased temperatures, aridity, or lower water flows due to drought will primarily impact vegetation used for bank stabilization, habitat restoration, and vegetated buffer zones. The sorbent layer of reactive caps in the riparian zone may also be damaged due to desiccation.

Recommendations to Increase the Resilience of Sediment Remedies

An adaptive management approach may be necessary for sediment cleanup sites to monitor changes in water depth and salinity, intertidal/riparian/shoreline habitat, benthic community structure, salinity, and wetland buffers. This is particularly true for cleanup sites estimated to have very long restoration timeframes (i.e., decades) in which climate change impacts may become increasingly evident.

Recommendations for: Sea level rise and severe storm events

1. Design cap armoring for a) increased water depth in shoreline, intertidal, and subtidal areas, and b) increased wave energy in intertidal and shoreline areas.

2. Consider shoreline stabilization techniques to stabilize the shoreline to withstand increased wave energy and erosion like the following, and see Appendix C case studies for more information:

    a. Conduct wind/wave modeling to determine engineering specifications to ensure shoreline stabilization is protective over the long-term.
    b. Build, or allow riverine systems to naturally build, wetlands and marsh to act as natural buffers for shorelines and waterfront lands.
    c. Build wave attenuation structures.
    d. Construct berms of sand and vegetation.
    e. Reconfigure the shoreline and cut back the shore or taper it out further to a 3:1 slope or similar stable design.
    f. Install soft armoring (vegetation, netting, or synthetic fabric).
    g. Install hard armoring (rocks) that are fortified with anchors or cables if necessary and finished with materials to restore natural habitat.

        i. There is a trade-off between speed and long-term utility when deciding between hard and soft fortification. For example, rip rap and concrete channelization are typically faster and easier than softer fortification but can reduce effectiveness, accessibility, utility, suitable habitat, and aesthetics.

ii. To maintain productive nearshore habitat, soft armoring options are preferred.

3. Increase armor rock size to resist increased wave energy (see Appendix C).

4. Install additional or deeper layers of rock armoring, followed by habitat layers.

5. Anchor reactive or geotextile fabric caps.

6. Reinforce isolation cap layers with more durable armoring.

Recommendations for: Severe flood events

1. Install soft armoring on banks to attenuate wave or water energy.

2. Use “green” infrastructure or low impact development (wetlands, stormwater modular wetland passive treatment systems, earthen structures, permeable pavement, vegetated swales, retention ponds) to reduce stormwater overflow to the sediment cleanup site.

3. Increase stabilization of caps, which would require finishing with material to restore habitat:

    a. Increase armor rock size to resist increased wave and current energy (see Appendix C).
    b. Anchor reactive or geotextile fabric caps.
    c. Reinforce isolation cap layers with more durable armoring, followed by habitat layers.

Recommendations: Increased salinity

1. Restore freshwater habitat to estuarine or marine salinities or use species with a wide range of salt tolerance.

2. Periodically re-evaluate benthic community health and sediment and porewater chemistry.

3. Use native vegetation (i.e., shrubs, grasses) that are resistant to drought for erosion control, bank stabilization, wetland, and riparian habitat.

4. Plan habitat restoration projects to span a wide range of elevations from subtidal to upland, allowing species to migrate up the slope as the sea level changes.

5.5 Feasibility Study Report and Cleanup Action Plan

The Feasibility Study Report will generally follow the same structure and contain the same information as usual. Climate resilience should be discussed if it influenced selection of technologies; screening or evaluation of the remedial alternatives; or selection of the preferred alternative. In these cases, climate resilience considerations should be mentioned under the specific technology and/or alternatives evaluation criteria for which it was relevant, rather than as a separate consideration.

The Cleanup Action Plan will include a more concise version of this information, which is typically placed in the description of how the preferred alternative was selected. The Cleanup Action Plan's summary of the Remedial Investigation should also include information on which climate vulnerabilities were identified. Also identified there are those climate vulnerabilities that will need to be considered during the Remedial Design and in the long-term monitoring plan, based on the selected remedy.

5.6 Remedial design

As discussed in Section 5.4, some technologies and approaches to increasing climate resilience can be applied during remedial design, rather than during the remedy selection itself. Even if climate vulnerabilities were not addressed during the Remedial Investigation/Feasibility Study process or development of the Cleanup Action Plan, climate resilience can generally be incorporated into the remedial design if the need for it becomes apparent. For example:

- Changing the size and type of culverts or stormwater conveyance channels to capture increased stormwater flow during extreme precipitation events.
- Elevating equipment to reduce impacts from more frequent flooding during high tide.
- Incorporating soft buffering systems to reduce shoreline erosion from more frequent and severe storm events.

In this guidance manual, all of the technical information pertaining to remedy resilience has been placed in Section 5.4, for ease of reference. This information can be applied regardless of what stage of the process a cleanup site has reached when climate considerations are being addressed. See Appendix C for examples of case studies where technologies to increase climate resilience were incorporated at various stages of the process, including the feasibility study and remedial design. This information can also be used during long-term monitoring if climate change impacts are observed, or if the need to address climate resilience becomes apparent during a Periodic Review.

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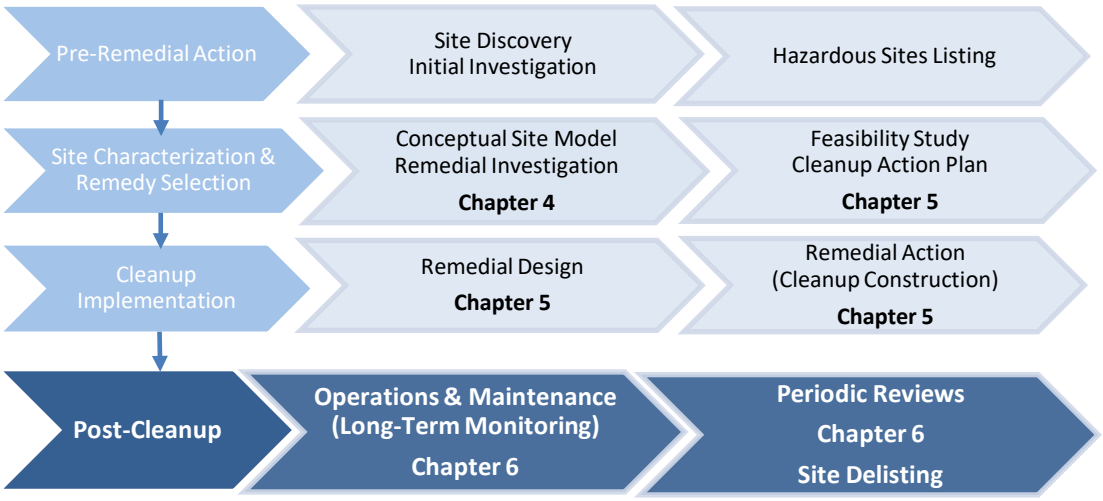
6.0 Operation and Maintenance



Cleanup Process Figure 4: Steps in the cleanup process. Chapter 6 applies to steps shaded the darkest tones.

This chapter provides guidance on:

- Developing effective long-term monitoring plans to address climate vulnerabilities that have been identified during the Remedial Investigation/Feasibility Study, Cleanup Action Plan, or remedial design process.
- Conducting MTCA-required periodic reviews of cleaned up sites, including sites that did not originally address vulnerability to climate change impacts.
- Potential responses if impacts occur during monitoring or if key vulnerabilities are identified during a periodic review.

6.1 Post-construction and long-term monitoring

This section provides guidance for cleanup sites that are currently proceeding through the investigation and cleanup process and assumes that climate change considerations have been reviewed and included in the Remedial Investigation/Feasibility Study process. Whether or not a cleanup site monitoring plan should include climate change elements depends primarily on:

- The climate vulnerabilities that have been identified for the cleanup site as part of the Conceptual Site Model and Remedial Investigation, and
- The remedy that has been selected for the cleanup site and the corresponding risk scenario identified in Chapter 3, Section 3.3.

6.1.1 No- to Low-Vulnerability Cleanup Sites

Sites for which no significant vulnerabilities were identified, or where the selected remedy results in a short-term or low-risk scenario (for example, full removal of contaminated soil), generally will not need monitoring elements related to climate change, except possibly during construction. Permanent remedies for which a No Further Action letter is granted with no monitoring required will generally fall into this category, because there is no longer contamination remaining at the site above risk-based levels.

6.1.2 Vulnerable Cleanup Sites with Long-Term Containment Remedies or Recovery Timeframes

Sites with identified climate vulnerabilities and long-term remedies should be monitored to ensure that the remedy remains effective and protective over time. Monitoring may be required:

- **Until cleanup levels are reached**, for alternative remedies that are relying on a) treatment, b) monitored natural attenuation, or c) monitored natural recovery.
- **Indefinitely**, for alternative remedies that are relying on containment that could be breached by extreme events (storms) or chronic climate change impacts (e.g., sea level rise).

For long-term containment remedies, monitoring is frequently discontinued at a cleanup site after a set number of years has passed, under an assumption that monitoring has demonstrated that the remedy is functioning as designed. However, this may not be appropriate if long-term climate change is expected to increase the risk of containment failure over time. In such cases, it may be appropriate to decrease the frequency of monitoring to correspond to the expected pace of changing conditions once the initial monitoring period has been completed.

6.1.3 Establishing Climate Vulnerability Monitoring Plans

As with any monitoring plan, all climate vulnerability monitoring elements should have:

- A defined purpose.
- Quantitative thresholds or trigger values at which the remedy would be impacted or put at risk of failure.
- Contingency actions if the identified thresholds are reached.
- For long-term changes such as sea level rise, sufficient buffers should be built into the threshold level to allow time for design and implementation of the contingency action before impacts begin to occur.

There are two types of climate-related impacts that should be addressed in the monitoring plan:

- Those that may occur gradually, such as warming temperatures, ocean acidification, and sea level rise.

- Those that may occur as extreme events episodically, such as flooding, storms, landslides, and wildfires.

For gradual changes, routine monitoring on a set frequency is appropriate, with the frequency based on the expected rate of change. For extreme events, immediate monitoring during or after an event may be appropriate, triggered by the event itself.

Recommendations to Improve Resilience of Monitoring Plans

The following monitoring elements may be appropriate to address climate-related impacts:

Sea level rise

1. Groundwater elevations.
2. Groundwater salinity, pH, or other geochemical attributes.
3. Sea level as outlined in Chapter 3, Section 3.3, including king tides.
4. Long-term impacts along the shoreline, such as wave erosion, flooding of stormwater systems, or overtopping of seawalls or groundwater barrier walls.

Extreme precipitation events and flooding

1. Inspections during or after a flood or extreme precipitation event that check for erosion, equipment damage, surface water drainage, habitat, or vegetated cover damage.
2. For sediment cleanup sites, inspections for sediment or cap erosion, deposition from upstream, bank erosion, or impacts to armoring or habitat features.

Landslides and erosion

1. Periodic inspection of containment caps and side slopes to identify cumulative erosion, slumping, subsidence, or other signs of instability.
2. Immediate mobilization and response in the case of landslide or containment failure.

Drought and wildfire

1. Groundwater elevation or geochemical changes due to drought.
2. Stressed vegetative cover or habitat quality due to drought or warming.
3. Immediate inspection after wildfire to evaluate damage to infrastructure, vegetated cover, potential erosion, landfill gases, or fires.
4. For critical and isolated containment facilities or large landfills (e.g., Hanford Site in Eastern Washington or large landfills such as Roosevelt in Klickitat County), equipment and mobilization to protect the facility when fires are in the vicinity.

6.2 Periodic reviews

During a periodic review, if a climate vulnerability assessment has not previously been conducted for a cleanup site, the TCP Maps Climate Change analytical tool (for Ecology staff) can be used to assess potential vulnerabilities. If any are identified, the information in this guidance and Tables 2-5 can be used to determine whether a more in-depth assessment or action is warranted, as Section 6.3 describes.

If climate change vulnerability was considered during the RI/FS, CAP, or remedial design process, the reviewer can begin by determining 1) whether the cleanup site continues to have climate vulnerabilities (Chapter 3), and 2) whether the selected remedy was permanent or otherwise designed to fully address the identified vulnerabilities (Chapter 5).

If vulnerabilities were identified and monitoring elements were included to assess the long-term effectiveness of the remedy, the monitoring results can be reviewed to determine the performance of the remedy. If issues or failures are identified in the review, see Section 6.3 for suggested responses.

6.3 Responses to identified issues

If issues are identified based on monitoring results, or during the periodic review, the appropriate response will depend primarily on the degree of climate impact to the selected remedy and the risk posed by the remedy's failure. In some cases, possible or actual events may be short-term and high-risk, such as the release of large volumes of confined contaminated material. In other cases, impacts may be frequent and cause an ongoing need for maintenance. Both the frequency of the event and the level of risk to human health and the environment should be considered.

Tables 2-5 show the relative degree of concern associated with various types of cleanup sites, remedies, and impacts to inform the appropriate response. Individual cleanup sites may vary, but this table provides a guide and a starting point for determining the appropriate response.

- *No Risk.* An appropriate response may be to continue monitoring as planned or confirm that the no further action (NFA) determination was appropriate.
- *Low Risk.* If monitoring is ongoing, a cost-effective monitoring element could be added to monitor the risk. If an NFA has been granted, the site manager should use their judgment to determine whether an inspection or other cost-effective approach could be taken to evaluate the risk and whether this would be appropriate for the specific cleanup site.
- *Moderate Risk.* If the cleanup site is undergoing monitoring, additional requirements could be added to evaluate the risk. If a moderate risk is identified after monitoring and/or an NFA has been granted, an additional inspection or evaluation of the cleanup site may still be warranted to ensure that the remedy remains effective. If impacts are

observed during the monitoring period or a post-monitoring inspection, the remedy may need periodic maintenance or modification.

- *High Risk.* These may warrant some contingency actions. For example, if it becomes apparent during a periodic review or from monitoring results that an abandoned landfill along the shoreline will become inundated and shoreline erosion is likely, leachate and garbage could be released. In this case, the cleanup site may need to be re-evaluated. Cost-effective technologies to improve resilience of the remedy design should be reviewed and considered for implementation.
- *Very High Risk*. This category includes critical failure events that could significantly impact human health or the environment or result in substantial release of contamination to the environment. If these are identified during a periodic review, the remedy may need to be reopened and redesigned. If such an event occurs during monitoring, it may need to be treated as an emergency response and cleaned up to the extent possible, while the remedy is re-evaluated and redesigned.

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7.0 Underground Storage Tanks

Underground storage tanks are mainly vulnerable to sea level rise, flooding, and wildfires. In addition to the issues detailed in Section 5.3.1 for soil and groundwater cleanup sites, additional impacts specific to underground storage tanks are detailed below.

7.1 Potential impacts to underground storage tanks

Sea Level Rise

Salt water intrusion may change the pH of soil by increasing chloride salts, which will yield higher levels of ionizable chemicals and cause the soil and/or groundwater to become more conductive. Greater conductivity can accelerate the corrosion of exposed metal surfaces, and sensors may be compromised over time.

In addition to impacting chemistry, sea level rise can also have a direct physical impact on tanks. Pull-down straps may rust, and sensors can become compromised. Tanks located in areas that will be subject to regular inundation by sea level rise can potentially come loose from their anchoring systems. Tanks are not typically designed to be completely submerged, and their required liquid-tightness means that they are likely to become buoyant in water as they empty. Even full tanks could come unmoored if conditions are right (which depend on the density difference between the stored substance and relatively higher density sea water, compared to the lower salinity groundwater the seawater is replacing).

Flooding

Coastal, riverine, and extreme weather event flooding may cause the groundwater table to rise. In addition to the types of impacts described for soil and groundwater cleanup sites, the following could also occur:

- Buoyancy forces could compromise tank anchoring, backfill, or pavement, and cause the tank to shift in its backfill and leak the product. If the tank is unanchored or improperly anchored, it could lift out of the ground and compromise its connecting pipes. This may be particularly relevant for tanks installed before 1983. Buoyancy concerns associated with sea level rise inundation are also applicable to flooding, although floodwater will typically lack the chemical changes that can speed equipment decay.
- If water enters and overfills the tank, contaminants can be released.
- Pull-down straps may rust, and sensors may be compromised, particularly in saline floodwater.
- The electrical system can be damaged.

- The soil cover and backfill can erode and scour due to rapidly moving floodwater or fast-moving debris. The tank or connecting pipes could shift, resulting in a release of product.
- Depending on the volume of water, the above-ground pressure can collapse a tank.

Wildfires

Wildfires may be especially dangerous for underground storage tanks that contain product, as exposure to fire could result in explosion; destruction of the tank and its associated infrastructure; and release of tank contents.

7.2 Increasing resilience of underground storage tanks

The following recommendations can mitigate the specific impacts noted above. Many of these recommendations may already be in place for some tanks. For other tanks, however, their design and construction may not have incorporated the potential for climate change impacts (sea level rise, more severe flooding, and increased risk of wildfire). See EPA's *Underground Storage Tank Flood Guide* (EPA 510-B-20-001) for more details on addressing flood impacts on tanks and EPA's *Wildfire Guide: Preparation and Underground Recovery for Underground and Aboveground Storage Tank Systems* (EPA 510-B-21-001) for details on what to do when a fire approaches a facility and recovering from a fire.

1. For protection in fire prone areas:
    a. Protect above-ground infrastructure from fire with housing materials such as concrete or polyethylene.
    b. Install alarm systems and the capability to remotely stop pumping equipment during fire events.
    c. Create fire buffers or barriers around tank areas.
    d. Have backup power and built-in redundancy for fire events, along with an emergency response plan.

2. For tanks located in floodplains or areas near waterbodies projected to have increased risk of floods:
    a. Install alarm systems and the capability to remotely stop pumping equipment during storm events.
    b. Have backup power and built-in redundancy for storm events, along with an emergency response plan.
    c. The calculations for tank installation should include empty tanks submerged in water, but this may not always be the case for tanks installed before 1983. To address the buoyancy force of saturated soil, tanks should be installed to remain

in place based on three main criteria: 1) concrete above the tank, 2) backfill around the tank, and 3) hold down straps/deadman anchors.

d. If appropriate, increase the burial depth or amount of concrete above the tank, but do not exceed the maximum burial depth recommended by the tank manufacturer without manufacturer approval. If the tank is buried too deep the effectiveness of the concrete above the tank is compromised. Typical maximums per the Petroleum Equipment Institute Recommended Practice 100 are:

   i. Steel tank – 5' deep maximum

   ii. Fiberglass reinforced plastic tank – 7' deep maximum

e. Install automatic shut-off valves and fuel lines above the projected flood level.

f. Add vent pipe extensions.

g. Water can enter tanks from the probe and fill risers and ethanol vapors can oxidize adaptors (bumps, corrosion) and degrade the cap gaskets. This can result in improperly sealed gaskets which can be exacerbated with head pressure during flooding. On both probe and fill risers conduct an annual cleaning of the adaptors and caps and replace them every few years.

h. A pressure decay test on tanks can detect potential vapor leaks which can become entrance points for flood water.

3. For tanks subject to frequent inundation from sea level rise:

   a. Re-locating or re-designing the tank may be necessary, as well as conducting frequent monitoring to determine if the tank has been compromised.

   b. Install alarm systems and the capability to remotely stop pumping equipment during storm events.

   c. Have backup power and built-in redundancy for storm events, along with an emergency response plan.

   d. In areas with salt-water intrusion (from sea level rise), cathodic protection for pump and treat systems or monitoring wells may be needed, like those currently used for marine infrastructure.

   e. Water can enter tanks from the probe and fill risers and ethanol vapors can oxidize adaptors (bumps, corrosion) and degrade the cap gaskets. This can result in improperly sealed gaskets which can be exacerbated with head pressure during flooding. On both probe and fill risers conduct an annual cleaning of the adaptors and caps and replace them every few years.

   f. A pressure decay test on tanks can detect potential vapor leaks which can become entrance points for flood water.

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Glossary

The following list defines terms in this guidance. Some definitions have also been included to clarify differences between terms commonly used to communicate climate change issues.

Term	Definition
Adaptation	A process that includes developing tools and implementable actions to reduce the vulnerability (i.e., increase the resilience) of human or ecological systems from climate change.
Adaptation strategy	For this guidance, a framework developed using the knowledge from the vulnerability assessment to increase the resilience of the state's contaminated sites (cleanup sites) to climate change.
Atmospheric river	A sinuous, relatively narrow plume of water vapor in the atmosphere that transports water away from the tropics. When the plume makes landfall and sweeps up over the mountains, water vapor is released in the form of rain or snow. Because these rivers are rich in water vapor and associated with strong winds, they are capable of severe storm events, rainfall, and floods.
Base flood elevation	The surface water elevation expected during a 100-year flood. This includes stillwater elevation plus the added effects of wave actions (i.e., wave set up and wave runup).
Climate	The long-term average of conditions in the atmosphere, ocean, ice sheets, and sea ice, as described by statistics such as means and extremes.
Climate change	A significant and persistent change in the mean state of the climate or its variability. Climate change occurs in response to changes in the Earth's environment, such as regular changes in Earth's orbit about the sun, re-arrangement of continents through plate tectonic motions, or changes to the atmosphere caused by humans.
Climate forecast	A prediction about average or extreme climate conditions for a region in the medium-term future (from seasons to a year or so).
Climate change projection	A plausible scenario for future climate conditions for a region in the long-term future (from decades to centuries).
Climate variability	Natural changes in climate that fall within the normal range of extremes for a particular region, as measured by temperature, precipitation, and frequency of events. Drivers of climate variability include the El Niño Southern Oscillation and other phenomena.

Term	Definition
Fossil fuels	Energy sources such as petroleum, coal, or natural gas, which are derived from living matter that existed during a previous geologic time period.
Global warming	Another term used to describe climate change caused by human activities (i.e., “anthropogenic climate change”).
Greenhouse gas	A gas that has the property of absorbing infrared radiation (net heat energy) emitted from the Earth’s surface and reradiating it back to the Earth’s surface.
Green Remediation	For this guidance, this includes identifying and implementing best management practices to increase the environmental benefit and reduce the environmental impacts from the cleanup process.
High emissions scenario	Term used by the Intergovernmental Panel on Climate Change (IPCC) to indicate the potential future conditions in which carbon emissions are not reduced to any significant extent.
Mitigation	Human activities intended to reduce the sources or emissions of greenhouse gases or enhance the sinks that remove carbon from the atmosphere.
Nuisance flooding	Events where water levels exceed the local thresholds for minor impacts set by NOAA’s National Weather Service.
Resilience	Ability of a human or ecological system to anticipate, prepare for, adapt to, recover from, or withstand the impacts of climate change.
Sea level rise	• Absolute sea level change refers to the height of the ocean surface above the center of the earth, whether nearby land is rising or falling. • Relative sea level change is how the height of the ocean rises or falls relative to the land at a particular location.
Stillwater elevation	The projected surface water elevation to which floodwaters would rise during a 100-year flood in the absence of wind and wave action.
Storm surge	The average increase in sea level above the predicted astronomical tides resulting from high winds and low atmospheric pressure during storm events.

Term	Definition
Sustainable Remediation	Clean up of contaminated sites that includes climate change resiliency (increasing resiliency of cleanup remedies to climate change impacts) and green remediation (increasing the environmental benefits and reducing the environmental impacts from the cleanup process). This differs from other definitions which includes economic and social factors.
Swash	Turbulent layer that washes up on the beach after a breaking wave.
Vulnerability	The degree to which a system is susceptible to, or unable to cope with, climate change impacts (e.g., climate variability and extremes). Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, and its sensitivity and adaptive capacity.
Vulnerability assessment	For this guidance, this is a process to identify the sensitivity, exposure, and adaptive capacity of the state's contaminated sites to climate change impacts.
Wave runup	The rush of water that extends inland when waves come ashore.
Wave height	The vertical distance between the wave crest and wave trough.
Weather	The specific conditions of the atmosphere at a particular place and time, measured in terms of variables that include temperature, precipitation, cloudiness, humidity, air pressure, and wind.
Weather forecast	A prediction about the specific atmospheric conditions expected for a location in the short-term future (hours to days).

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Tables

Table 2: Potential risk of climate change impacts on remedial alternatives for soil and groundwater cleanup sites.

Type of Remedy	Sea Level Rise	Coastal Storms	Saltwater Intrusion	Ground-water Table Changes	Extreme Precipitation & Flooding	Landslide	Wildfire	Drought
Soil excavation and off-site disposal	None	None	None	None	None	None	None	None
Soil containment onsite	Moderate	High	Low	Low	Moderate	Very High	Low	None
Soil vapor extraction	Moderate	Moderate	Low	Moderate	High	Very High	High	None
In situ treatment	Low	Low	Moderate	Low	Moderate	Moderate	Low	Low
Pump and treat	Moderate	High	High	High	High	Very High	Very High	Moderate
Barrier & treatment walls and slurries	Moderate	High	Moderate	Moderate	High	Very High	Low	Moderate

Low: Potential impact resulting in typical monitoring.

Moderate: Potential impact resulting in infrequent repair and/or maintenance and/or additional monitoring.

High: Potentially severe impact resulting in frequent repair, maintenance, and additional monitoring.

Very High: Potentially catastrophic impact resulting in remedy failure.

Table 3: Potential risk of climate change impacts on remedial alternatives for landfill cleanup sites.

Landfill Element	Sea Level Rise	Coastal Storms	Saltwater Intrusion	Groundwater Table Changes	Extreme Precipitation & Flooding	Landslide	Wildfire	Drought
Caps and side slopes	Moderate	Very High	None	Moderate	Very High	Very High	High	None
Liners	High	Low	Low	High	Moderate	Moderate	Low	Low
Stormwater collection systems	Low	High	None	None	Very High	Very High	High	None
Leachate collection systems	Moderate	Moderate	Low	Moderate	Moderate	High	High	Low
Landfill gas collection systems	Moderate	Moderate	Moderate	Moderate	High	Very High	Very High	Low
Pump & treat systems	Moderate	High	High	High	High	Very High	Very High	Moderate

Low: Potential impact resulting in typical monitoring

Moderate: Potential impact resulting in infrequent repair and/or maintenance and/or additional monitoring.

High: Potentially severe impact resulting in frequent repair, maintenance, and additional monitoring.

Very High: Potentially catastrophic impact resulting in remedy failure.

Table 4: Potential risk of climate change impacts on remedial alternatives for mining cleanup sites.

Type of Remedy	Extreme Precipitation & Flooding	Landslide	Wildfire	Drought
Tailings containment	Very High	Very High	High	Low
Revegetation/erosion control	Very High	Very High	Very High	High
Surface water management	High	Very High	High	None
Pump and treat systems	High	Very High	Very High	Low
Passive water treatment systems	Moderate	High	High	None

Low: Potential impact resulting in typical monitoring

Moderate: Potential impact resulting in infrequent repair and/or maintenance and/or additional monitoring.

High: Potentially severe impact resulting in frequent repair, maintenance, and additional monitoring.

Very High: Potentially catastrophic impact resulting in remedy failure.

Table 5: Potential risk of climate change impacts on remedial alternatives for sediment cleanup sites.

Type of Remedy	Sea Level Rise	Coastal Storms	Salt Wedge Movement	Extreme Precipitation & Flooding	Landslide	Wildfire	Drought
Dredging and off-site disposal	None	None	None	None	None	None	None
Capping	None	Very High	None	Very High	Moderate	None	None
Cap armoring	None	High	None	High	Low	None	None
Shoreline stabilization	High	Very High	None	Very High	High	Low	Low
In situ treatment	None	Very High	Low	Very High	Low	None	None
Enhanced natural recovery	None	Moderate	None	Moderate	None	None	None
Monitored natural recovery	None	Low	None	Low	None	None	None
Habitat restoration	High	Moderate	Moderate	Moderate	Moderate	Low	Moderate
Source control & stormwater management	Low	High	None	High	Low	Low	None

Low: Potential impact resulting in typical monitoring

Moderate: Potential impact resulting in infrequent repair and/or maintenance and/or additional monitoring.

High: Potentially severe impact resulting in frequent repair, maintenance, and additional monitoring.

Very High: Potentially catastrophic impact resulting in remedy failure.

Appendix A. Vulnerability Assessment

A.1 Sea level rise and coastal flooding

Sea level rise is expected to increase the frequency and magnitude of periodic inundation along marine, estuarine, and tidally influenced shorelines by amplifying the inland reach of:

- High tides and
- Storm surge (the increase in sea height above the projected astronomical tide due to high winds and low-pressure systems during storms).

Coastal flood height is driven by:

- Sea level rise and
- Storm tide (tide and storm surge).

Water levels rise in response to low atmospheric pressure which can occur during coastal storms), with an estimated 10 mm increase in sea level for every millibar drop in barometric pressure. Extreme coastal water levels in the state tend to occur when the above processes combine. For example, when a high tide corresponds with low atmospheric pressure and winds that build large waves. Long-term changes in sea level is the "baseline" on top of which these processes operate. So, we can think of one of the impacts of sea level rise as changes in the return frequency, or probability of occurrence of coastal water level events that we currently think of as extreme.

Regional sea level rise can be affected by a number of factors:

- Rate of global sea level rise
- Ocean currents
- Wind patterns
- Changes in land elevation (subsidence and uplift)

Regarding the latter, the Pacific Northwest has active tectonic plates that, along with other factors, can change land elevation. These in turn can either lessen the effect of sea level rise (in the case of uplift) or worsen it (in the case of subsidence). For example (CIG 2015):

- In Seattle, subsidence is occurring at a rate of ~0.5 inches per decade (from 1972 – 2015) and sea level has risen at a rate of ~0.8 inches per decade (total of 8.6 inches from 1900 to 2008).

- Neah Bay uplift is occurring at a rate ~1 inch per decade (from 1975 - 2015) and sea level has dropped at a rate of ~0.7 inches per decade (total of -5.2 inches; 1934 - 2008).
- Friday Harbor subsidence is occurring at a rate of ~0.05 inches per decade (from 1972 – 2015) and sea level has risen at a rate of ~0.4 inches per decade (from 1934 – 2008).
- Port Angeles uplift is occurring at a rate of ~0.4 inches per decade (from 1972 – 2015).
- Port Townsend subsidence is occurring at a rate of ~0.3 inches per decade (form 1975 – 2015).

These factors should be considered when determining which sea level rise to use on a site-specific basis to assess risks to cleanup sites. For example, a sea level rise value at the top of the range would be overly conservative for cleanup sites located along the Olympic coast line, while a sea level rise value at the bottom of the range would not be conservative enough for cleanup sites in Puget Sound.

Storm Surge. Storm surge refers to the average rise in sea level above the anticipated astronomical tide that is associated with low barometric pressure and higher wind speeds during a storm. Storm surge happens when the long fetch of winds spiral inward toward the storm, and a low pressure-induced dome of water is drawn up under and trails the storm center (Figure 13). Storm surge will have greater impact due to sea level rise and even a small amount of sea level rise will exacerbate the flood height associated with a high tide or storm tide, resulting in a particularly high storm surge if the storm occurs during high tide (CIG 2015, NOAA 2016, and FEMA 2005).

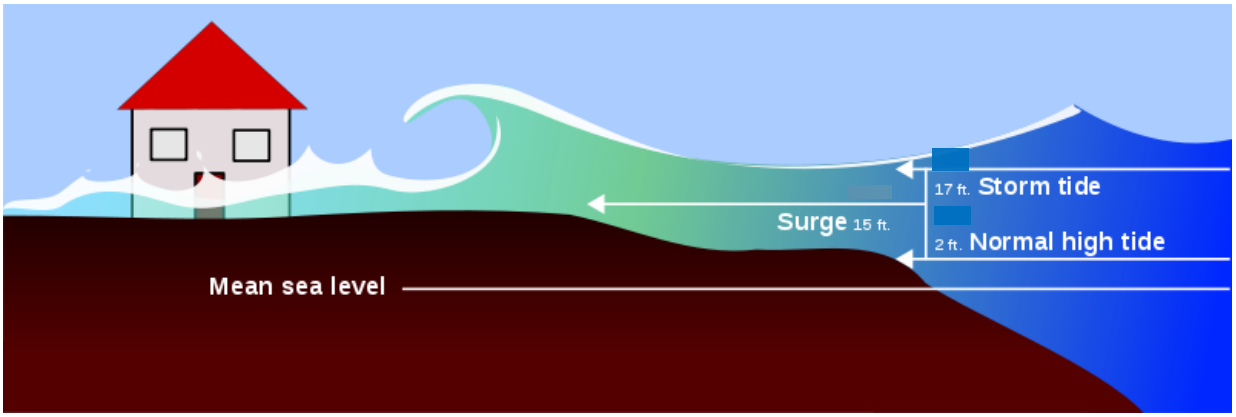

Figure 16: Illustration of storm tide, normal tide, and storm surge. Source: Wikipedia.

Coastal Flooding. The frequency of coastal flooding events is projected to increase with sea level rise. For the City of Olympia to incorporate storm surge and the influences of the other processes above into planning, for example, they have calculated that:

- With a 1-foot sea level rise, the current 100-year flood event (1% annual chance) could become an every other year event (50% annual chance). One foot of sea level rise could result in downtown flooding 30 times per year (City of Olympia 2011).
- With a 2-foot sea level rise, the current 100-year flood event could become an annual event, resulting in downtown flooding 160 times per year (City of Olympia 2011).

A.1.1 Development of GIS Layers

Land surface elevation data used as the basis for all sea level rise evaluations was downloaded from NOAA, which were published as part of NOAA's Coastal Viewer web application and sea level rise analysis. See https://coast.noaa.gov/dataregistry/search/collection/info/coastallidar for more information about the collation and standardization process of their Digital Elevation Models. Elevations are referenced to the North American Vertical Datum of 1988 (NAVD88).

GIS layers were developed to illustrate areas at risk of inundation where sea level rise increments of 1 to 6 feet can be added to MHHW and BFE to understand the inundation scenario during high tide and severe storm events.

Sea level rise projections under mean higher high water (MHHW) conditions were developed by NOAA as part of their Sea Level Rise and Coastal Flooding Impacts web application. We downloaded these data from the public data portal and used as-is. We then used NOAA's Digital Elevation Model to identify inundation extents under the infrequent inundation scenario:

- **Daily Inundation Scenario.** MHHW plus a given amount of sea level rise (1-foot increments up to 6 feet).
- **Infrequent Inundation Scenario.**
    - Base flood elevation (BFE) plus a given amount of sea level rise (1-foot increments up to 6 feet).
    - MHHW plus a given amount of sea level rise, plus 3 feet (to represent storm effect where BFE has not been established).

To assess the impact of sea level rise on BFE, we used data from BFE transects in a joint effort by Ecology's Shorelands and Environmental Assessment (SEA) program and FEMA. We converted each transect to points, creating a point every 50 feet along each transect. Each point was given the BFE value of its respective transect and points were interpolated to create a raster surface of BFE. We then followed NOAA's process (available at Mapping Sea Level Rise

Inundation (noaa.gov))[4] to create surfaces with one-foot increments up to six feet. This resulted in one surface per foot of sea level rise, indicating areas where inundation may occur.

A.1.2 Base Flood Elevation

Base flood surface water elevation (BFE) includes stillwater (100-year flood elevation in the absence of waves) plus the added effects of wave set up and wave runup (Figure 16) (https://www.fema.gov/base-flood-elevation). Wave runup is defined as the rush of water that extends inland when waves come ashore. These elevations are higher than the stillwater elevations. In addition to the effects of wave runup and storm surge, an increase in water level can be caused by waves breaking ashore during a storm, called wave setup. Wave setup is affected by the height of the waves, the speed at which waves approach the shore, and the slope of the ground near the shore. FEMA has conducted an overland wave analysis throughout most of Puget Sound to determine BFE using a model called Wave Height Analysis for Flood Insurance Studies (WHAFIS).

A 100-year flood or base flood is a flood level that has a 1% chance of being equaled or exceeded in any given year. Wave runup is defined by FEMA as the height above the stillwater elevation (tide and surge) that is reached by the swash (turbulent layer that washes up on the beach after an incoming wave has broken; FEMA 2005). Wave runup has been measured in certain areas of Puget Sound, based on field measurements on beaches or laboratory measurements on structures.

A.1.3 Tidal Elevation

As a baseline to understand the potential effects of sea levels rise, Ecology used tidal data measured at Seattle as a surrogate for the rest of Puget Sound. A gauge was installed in Commencement Bay in 1996, but not enough time has passed to calculate statistically meaningful sea level rise trends. We recognize tidal data from one location is not necessarily an accurate datum to apply to all of Puget Sound and other marine shorelines, but sufficient records do not exist elsewhere in Puget Sound. In some cases, the Seattle tide gauge may underestimate tides in the rest of Puget Sound. For example, the City of Olympia developed a site-specific return period tidal elevation by calculating a ratio between astronomical high waters at Seattle and Olympia and adding the tidal residual. Using the NOAA program VDatum to establish the tidal relationships, the MHHW elevation is 14.56 feet above MLLW at Olympia, and 11.36 feet at Seattle corresponding to a ratio of 1.28 (City of Olympia 2011).

A number of processes can affect tide levels during a storm:

- Direct wind
- Earth's rotation
- Near shore waves

[4] https://coast.noaa.gov/data/digitalcoast/pdf/slr-inundation-methods.pdf

- Rainfall
- Barometric pressure

A.1.4 MHHW as a Datum Reference

MHHW is used when referencing observed storm tides so it can be understood by the majority of people at risk of coastal flooding. If there is an observed water level of 7 feet above MHHW, it is likely that nearby upland (dry) areas are or were inundated by as much as 7 feet. Using MHHW as a frame of reference during Hurricane Sandy in 2012 was relatively accurate. The maximum water levels measured by tide gauges at the Battery in Manhattan, New York, and Sandy Hook, New Jersey, were between 8 and 9 feet above MHHW. In addition, high water marks measured by the U.S. Geological Survey after the storm verified inundations of 8 to 9 feet above ground level in Sandy Hook and Staten Island (USGS 2012).

A.2 Wildfire and landslide

Landslide. Landslide risk is projected to increase in winter—as a result of declining snowpack and decrease in summer—as a result of declining streamflow and soil water content (CIG 2015). Landslides can move in different ways, from shallow landslides (such as shallow slumps and rock topples) to deep-seated landslides. Extreme weather events can increase landslide risk by disturbing the supporting strata. Subsurface conditions are determined in part by soil factors (such as type, porosity, organic content), but are physically sculpted over time by liquids passing through the soil matrix. Smaller particles are mobilized by flow, which allows them to shift through pores left by larger particles and settle at lower horizons. As the rate of sculpting speeds up and energy expands (during high-flow, flash storms, for example), it can disrupt the existing patterns of deposition and undermine the surface—resulting in landslide.

Although the coastal environment is extremely variable, the geomorphic threats it faces can generally be grouped into erosion, landslide, and change in type of habitat. Coastal landforms (e.g., bluffs, river deltas, estuaries, spits, barrier beaches, tide flats) are subject to the same causes of landslide, erosion, and destructive change in habitat type as their inland counterparts but are also vulnerable sea level rise and coastal inundation. These landforms and habitats are not static but can be transformed and re-contoured by weather (e.g., storms and increased wave action, flooding) and dynamic oceanic processes in relatively short timeframes.

Change in habitat type can be a result of a destructive reformation of the landscape or can be the result of more gradual processes that change the salinity, water availability, or physical construction of potential habitat. The specific impacts will depend on local features, and so will require their own analyses at each site (Shipman 2009). For a more detailed discussion of changes in different types of coastal landforms, see Shipman 2009 or Ecology 2017a.

Wildfire. As Washington state experiences increasingly warm and dry conditions, wildfire risk and the annual area burned by forest fires are expected to increase (Snover et al. 2013). Projected decreases in summer precipitation and increases in summer temperatures would reduce moisture of existing fuels, facilitating fire, while earlier snowmelt should lead to earlier

onset of the fire season. Most of Washington state has a long growing season and a clear distinction between the rainy and dry seasons. These factors contribute to the state's vulnerability to large wildfires. Climate change has the potential to further increase this vulnerability.

In some watersheds, the state is experiencing a snow to rain transition, which can increase the amount of water to ecosystems that normally have limited available water during this season. Increased available water and warmer temperatures may promote rapid plant growth, providing ample fuel for wildfires in drier months.

Escalating temperatures and more frequent and severe drought can also increase the risk of more frequent and severe wildfires. Parched plants are more susceptible to sparks and higher temperatures increase the volatilization of chemicals and oils in plants. This combination can make combustion take hold more easily. A dry landscape (lacking moist plants and surface water features that might otherwise serve as a firebreak) provides ample fuel sources and increases the likelihood of severe wildfires.

A.3 Flooding

The risk of flooding is due to a complex number of variables, but there are three factors that have high potential to contribute to increased flood risk (Mauger 2015):

1. **Declining snowpack will increase winter streamflow.** The primary mechanism for storing water in a watershed is snow that holds water for summer and keeps it out of the rivers in winter. In the Pacific Northwest, we have seen a 25% decrease in snowpack from 1955 – 2016 (EPA 2021), which is expected to worsen to 37% to 55% decrease for the 2080s (CIG 2015).

2. **Sea level rise in coastal environments and estuaries, as well as storm surge.** Although not projected to increase, the storm surge effect will be exacerbated by sea level rise because it limits the ability of inland floodwaters to drain into Puget Sound. With a 2-feet sea level rise, the 100-year storm surge event will become an annual event.

3. **Extreme precipitation.** While projected changes in annual precipitation are small, extreme precipitation events are projected to increase in both frequency and intensity. By the 2080s, these events are projected to increase in intensity (CIG 2021).

A.4 Assumptions and data limitations

Several background and simplifying assumptions were made when developing the TCP Maps GIS layers in order to identify cleanup sites that may be vulnerable to the impacts discussed in Chapter 3. Risk scenarios developed to understand vulnerability of cleanup sites and based on these assumptions necessarily include some level of uncertainty.

Sea Level Rise

Assumptions

- When the sea level rise projections for a high greenhouse gas emissions scenario are used to assess vulnerabilities for cleanup sites that could be critically impacted it represents a worst-case scenario and is presumed more protective than a low greenhouse gas scenario projection. For example, using a 4-foot sea level rise (for 2100) for a site may be a scenario with a low likelihood of occurring but a high impact if it does, is a more protective approach than using a high likelihood sea level rise value (e.g., 1–2 feet).
- Changes to sea walls, etc. are assumed to not change over time, so changes in shoreline engineering cannot be factored into the analysis.
- MHHW measured at Seattle is representative of other areas in Puget Sound, coastlines, and estuarine shorelines. The effect of this assumption is that it may be an under or over estimate for other coastal areas.
- The shoreline is not significantly changing over time.

Data Limitations

- There is not a clear consensus among scientists on which greenhouse gas emissions scenario is most likely to occur, because of both the uncertainty about future greenhouse gas emissions and challenges in simulating the complex climate system. As a result, best practice for using climate change projections in risk assessment and planning is to develop a resilient response based on examination of multiple future climate scenarios.
- Hydrology of Washington's coastal areas is not fully understood. Efforts are underway to improve understanding of its topography so that projections of coastal interactions can more accurately account for flow regimes and change in shoreline contours over time. Improved data will allow us to remove the simplifying assumptions about a static shoreline and representativeness of Seattle area measurements in future revisions of this guidance.
- Upland areas inundated under the base elevation scenarios do not account for:
    - Whether they are hydraulically connected to marine waterbodies.
    - If water flow pathways are present since they are based on ground surface elevation.

- Therefore, inundation scenarios may be underestimates.

Flooding

Assumptions. FEMA's 100- and 500-year floodplain mapped areas are assumed to:

- Accurately represent current flood hazard conditions.
- Not have flood controls.
- Not be influenced by potential future environmental events such as sea level rise, increased extreme precipitation events, or earlier snowpack melt.
- Flood hazards will be affected by these factors, so the FEMA maps would be considered an under estimate of future flood risks.

Data Limitations

- The hydrology and topography of Washington state are not fully understood.
  - Washington state has a network of rainfall and river height gauges used to collect data to provide warnings about imminent floods (near-term), but it is insufficient for longer-term flood projections (see NOAA National Weather Service, Advanced Hydrologic Prediction Service *https://water.weather.gov/ahps/about/about.php,* NOAA 2017c).
  - Gauge data has been an effective method for projecting near-term flood risk so the use of Light Detection and Ranging (LiDAR) mapping and hydrologic modeling has been limited. Some communities have started using LiDAR which will allow for more appropriate modeling, but data is not widely available as yet.
- Models that predict the change in form and timing of precipitation do not converge.
  - Washington's complex weather system complicates climate change modeling efforts, so that even when an assumption is made regarding a scenario (for example, assuming that warming will be 2°C), the models do not yet converge on single projections. An example of this would be the ability to project global, state, or even regional averages, but not very small-scale local changes in precipitation or temperature.
  - Washington experiences a great deal of year-to-year and decade-to-decade variability in precipitation (i.e., "noise"), which – on an annual basis – is expected to continue to be much larger than the *change* in precipitation (i.e., the "signal") projected to result from climate change.

Wildfire

Assumptions

- The type and distribution of trees in forest populations are representative of future populations.
- The impacts from pests will remain constant.

Data Limitations. Applying this data at a site-specific level is challenging and may not be the most ideal representation of future fire risks due to the following limitations:

- The data used in this guidance was from vegetation and fuels from LANDFIRE, weather from the National Weather Service, and community data from the U.S. Census Bureau.
- Data collected on forest fires in this area was aggregated up to 2014 so recent fires or land disturbances are not represented.
- Data are for comparisons on a state, region, and county level and insufficient for understanding risk on a more local level (e.g., neighborhood or individual home or site level).
- Changes in pest types and occurrence for emerging threats, such as the mountain pine beetle, are being researched. An improved understanding about how climate change will affect pest incidence will allow us to remove the simplifying assumption about static pest impacts in future revisions of this guidance.
- Finally, the data are not considered suitable for climate change projections, so extrapolation will be necessary.

Landslide

Assumptions

- The data is intended to show the relative hazard of occurrence.
- Landslides are a function of site-specific geology, slope instability, and other causes.

Data Limitations

- DNR cautions that its data cannot be used to definitively predict that landslides will or will not occur and does not forecast the potential for deep-seated landslides (DNR 2022a).
- Data only accounts for present risk; it does not account for potential impacts from extreme events related to climate change.

A.5 Sediment loading

Marine water inundation into rivers and streams may affect natural recovery processes such as sedimentation. It may also impact habitat due to subsidence or sedimentation and increase the risk of flooding. Climate change is expected to exacerbate the impacts of sediment aggradation (increase in land elevation due to sediment deposition) in stream channels (from channelizing flow) that will affect flood risk and habitat, such as tidal marsh, channels, and eelgrass. In an effort to develop adaptive management strategies for increasing resilience, the Washington Coastal Resiliency Network is developing metrics and models that detect change and monitor performance of land use actions. By 2080, more precipitation falling as rain (vs. snow)—especially on steep mountain slopes exposed by retreating glaciers and snowpack—is projected to increase the intensity of floods and fluvial sediment loads in glacier-fed streams by 3- to 6-fold. The impact from tides and storm surge due to inundated coastal environments is expected to retard stream flows, which will increase and promote stream channel sedimentation further upstream.

Channelization through levees has mobilized fluvial sediments from floodplains and increased deposition in the nearshore and deeper depths of Puget Sound. This has led to ~1 meter of local subsidence in agricultural lands, which results in greater flood risk and poor drainage (Grossman 2014).

Appendix B:
Climate Resiliency Resources

B.1 Introduction

This appendix identifies resources for climate change resilience and adaptation as it relates to cleanup. Table B-1 contains a list of resources with descriptions that are subdivided into the following categories:

- Resilient technologies
- Adaptation plans
- Decision Tools
- Case studies
- Organizations and scientific data sources
- Other resources.

Each resource category is explained below, with a short summary of particularly relevant information found in each category but does not list all resources contained in Table B-1. The table also includes additional documents that may be useful for site managers who are working on projects where climate resilience should be considered and can be accessed as a separate spreadsheet. For resources on green remediation, see Appendix D of this guidance.

B.2 Resilient technologies

Documents prepared by the EPA and the United Nations Framework Convention on Climate Change (UNFCCC) are summarized below. They describe resilient technologies and potential climate change adaptation measures for various types of cleanup sites, including shoreline and coastal; landfill; sediment; groundwater; and soil cleanup sites. Ecology recognizes the EPA climate resilience guidance as valuable resources which provided significant support for development of this guidance. The below information can help during the feasibility process when screening technologies, evaluating remedial alternatives, and/or during remedial design. Full citations are found in Table B-1.

- Table of Engineered Structures Commonly Used in Adaptation Measures (EPA 2016). Describes engineered structures commonly used in adaptation measures for various types of cleanup sites, including coastal, sediment, landfill, forested, and inland sites.
- Technologies for Adaptation to Climate Change (UNFCCC 2006). Describes UNFCCC's review of possible climate change adaptation technologies for five sectors: coastal zones, water resources, agriculture, public health, and infrastructure. Figures 4

through 9 in the document describe technologies for adaptation in each of the five sectors.

- Climate Change Adaptation Technical Fact Sheets Environmental Protection Agency (EPA). EPA has a wealth of available information for site managers related to climate change adaptation for superfund, brownfields, sediment, and soil and groundwater cleanup sites. Resources include:
    1. Adaptation plans for each EPA Region 1 through 10
    2. Case studies
    3. Lists of resources organized by impact and engineered structures
    4. Decisions tool.
    5. Technical Fact Sheets.
    6. EPA prepared three technical fact sheets summarizing climate change adaptation technologies to consider for:
        - Contaminated sediment remedies (EPA 542-F-19-003);
        - Contaminated waste containment as an element of site cleanup (EPA 542-F-19-004); and
        - Groundwater remediation systems (EPA 542-F-19-005).

Tables 2 or 3 in each fact sheet give examples of potential adaptation measures for system components based on climate change impacts associated with temperature, precipitation, wind, sea level rise, and wildfires.

B.3 Adaptation plans

The adaptation plans listed in Table B-1 outline how various organizations and agencies have approached climate change impacts, adaptation design, and implementation for areas at risk, including infrastructure, water resources, ocean and coastlines, and forests. This information may be helpful during the feasibility study to understand how other agencies have developed adaptation plans. The following summaries of select adaptation plans are applicable to Washington state and EPA Region 10.

- Preparing for a Changing Climate, Washington State's Integrated Climate Response Strategy (Ecology 2012). This is Washington state's adaptation plan. It outlines a framework for protecting communities, natural resources, and the economy from climate change impacts, and incorporates methods for adapting to climate change. The plan also describes how new and existing state policies can help Washington prepare for the impacts of climate change. Seven high priority response strategies and actions are identified:

1. Protect people and communities.
2. Reduce risk of damage to buildings, transportation systems, and other infrastructure.
3. Reduce risks to ocean and coastlines.
4. Improve water management.
5. Reduce forest and agriculture vulnerability.
6. Safeguard fish, wildlife, habitat, and ecosystems.
7. Support the effort of local communities and strengthen capacity to respond and engage the public.

- EPA Region 10 Climate Change Adaptation Implementation Plan, Publication No. 910B22001 (EPA 2022). Includes a vulnerability assessment with a detailed description of vulnerabilities that exist for EPA Region 10 and adaptation goals, including:
    a. Improving air quality
    b. Protecting waters
    c. Cleaning up communities and advancing sustainable development
    d. Ensuring the safety of chemicals and preventing pollution
    e. Enforcing environmental laws

As part of this plan, the EPA has developed remedy-specific Technical Fact Sheets to assess vulnerabilities for cleanup sites within EPA Region 10 and as a resource for evaluating the performance of adaptation measures.

City of Olympia Engineered Response to Sea Level Rise Technical Report (2011). This report includes 1) an engineering analysis of potential inundations of downtown Olympia due to precipitation runoff, sea level rise, and tidal and wave effects and a proposed strategy to address flood risks. The city is currently working on a comprehensive response plan.

Department of Ecology, Shoreline Master Program Handbook Appendix A. (2017). This report includes background information on projected sea level rise in Washington state, potential impacts of sea level rise, and suggestions for local governments to address sea level rise in the Shoreline Master Plan updates.

Sound Transit Climate Risk Reduction Project Report 0075 (2018). This report includes a vulnerability assessment of Sound Transit commuter rail, light rail, and express bus services, options for strengthening the agency's resilience, and how to integrate climate change impacts into decision making.

Tacoma Climate Change Resilience Study. (2016). This report by the City of Tacoma, WA describes key climate change impacts and vulnerabilities in Tacoma's built infrastructure, natural systems, and social systems, includes adaptation actions, and data gaps to be filled in the future.

City of Seattle Climate Strategy. (2018). This is an update to the 2013 Seattle Climate Action Plan which focuses on the actions the city can do to reduce greenhouse gas emissions from transportation and building sectors and increase the city's resilience to the impacts from climate change.

King County Strategic Climate Action Plan. (2020). This plan sets out a 5-year strategy for the county to integrate climate change into all area of County operations to reduce greenhouse gas emissions, prepare for the impacts of a changing climate, and ensure the county continues to lead on climate action.

B.4 Decision tools

Many decision tools are available for evaluating climate change vulnerabilities and impacts. To supplement this guidance, a few key decision tools are available to assist site managers in determining a site's vulnerability to sea level rise and flooding. These decision tools focus mainly on the vulnerability of water resources (including stormwater, wastewater, and drinking water), sea level rise, and flooding.

- University of Washington Climate Impacts Group. A widely recognized academic institution providing scientific data, tools, and technical resources to help address climate change impacts for the Pacific Northwest. Key resources include scientific reports, guidance, and climate mapping web applications with downscaled climate projections of precipitation, air temperature, drought, sea level rise, snowpack, wildfire, and streamflow as well as tools to understand environmental trends.
- Washington Coastal Hazards Resilience Network. A comprehensive website hosted by the Washington Department of Ecology in collaboration with Washington Sea Grant, NOAA, and University of Washington Climate Impacts Group. The website is intended to guide users in the process of learning about coastal hazards, direct users to Washington-specific tools and resources, and provide examples coastal resilience projects.
- Northwest Climate Adaptation Science Center. This center is a federal-university partnership focused on produces relevant science on climate change impacts and adaptation for the Northwest (Washington, Oregon, Idaho, and surrounding river basins).
- U.S. Climate Resilience Toolkit. A comprehensive and interactive website hosted by NOAA's Climate Program Office to find and use tools, information, and subject matter expertise to understand and manage climate related risks implement climate resilience. https//www.toolkit.climate.gov.

- Sea Level Change Curve Calculator Tool (Version 2022.72; USACE 2022). Calculates three local sea level change scenarios (low, intermediate, and high curves) based on historic rates of sea level change, the modified National Research Council's projections, Intergovernmental Panel on Climate Change projections, and/or vertical land movement.
- National Stormwater Calculator - Climate Assessment Tool (EPA 2022). EPA developed this tool to evaluate future climate vulnerabilities applicable to stormwater, based on national estimates of annual rainfall and frequency of runoff. Local soil conditions, land cover, and historic rainfall are also considered.
- Climate Resilience Evaluation and Awareness Tool (EPA 2022).
  CREAT 3.0 is a valuable tool to assist site managers in understanding and assessing potential climate change impacts and risks to drinking water, wastewater, and stormwater systems.
- NOAA Sea Level Rise Viewer. NOAA Office for Coastal Management. This is a web mapping tool to visualize community-level impacts from coastal flooding or sea level rise up to six feet.

B.5 Case studies

This section provides case studies on how climate resilience was implemented for cleanup or restoration projects. Appendix C of this guidance offers Ecology-specific case studies for cleanups that incorporate climate change resilience. Table B-1 provides additional case study summaries for cleanup sites where climate change adaptation and resilience were incorporated into the cleanup and restoration designs or adaptive management plans. The case studies discuss:

1. Considering increased flooding in the remedial design at landfills and coastal soil and groundwater cleanup sites.
2. Implementing adaptive management to address flooding from increasing 100-year storm events.
3. Incorporating sea level rise into the restoration designs at a shoreline site in Puget Sound.
4. Restoring the capacity of a Puget Sound delta to buffer against sea level rise and flooding.
5. Implementing wildfire management measures within a vulnerable mountain forest to enhance adaptation.

- EPA Case Study Summary – Site Operations and Remedy Design: Hurricane Irene Flooding and Adaptation at the American Cyanamid Site (EPA 2013). After floodwaters flowed over the 100-year berm at the American Cyanamid Site in New Jersey during Hurricane Irene in 2011, flood plans and adaptation measures were developed to improve flooding resilience and response efforts. Flood mitigation measures were also incorporated into the remedial design for soil and groundwater contamination. Adaptive measures included:

a. Increasing the capacity of the groundwater extraction system.

b. Increasing the elevation of the groundwater treatment system to be more than 1-foot above the expected flood levels.

c. Installing new HDPE covers over impoundments located at the site to reduce waste mobilization during flooding.

d. Reinforcing berms for erosion control and to withstand storm surge water velocities of eight feet per second.

- EPA Case Study Summary – Remedy Performance: Remedy Resilience to Flooding at the Rocky Mountain Arsenal (EPA 2013). The Rocky Mountain Arsenal site in Denver, Colorado, was a former arsenal site with soil and groundwater contamination. The soil remedial design consisted of placing the most contaminated soil into two onsite RCRA Subtitle D landfills and less contaminated soil into six onsite RCRA-equivalent covers. The landfills and covers were constructed to withstand a 1,000-year and 100-year (respectively) 24-hour storm.

  The six RCRA-equivalent covers used evapotranspiration technology with a capillary barrier comprised from bottom to top:

  1. Crushed concrete
  2. Pea gravel
  3. Soil
  4. Deep-rooted native vegetation to increase resilience to erosion
  5. Drainage channels constructed of concrete and grass-lined swales
  6. Low slopes to prevent rills and gullies during flooding.

  The two RCRA Subtitle D landfill caps were constructed from bottom to top with:

  1. Crushed concrete
  2. Geosynthetic membranes
  3. A rock-amended soil layer
  4. Deep-rooted native vegetation to increase resilience to erosion
  5. Drainage channels constructed of concrete and grass-lined swales
  6. Low slopes to prevent rills and gullies during flooding.

  These adaptation measures are examples of approaches that can be implemented during remedy design to mitigate the effects of flooding at landfill cleanup sites.

- EPA Case Study Summary – Remedy Design: Long-Term Protective Measures against Storms and Flooding at Allen Harbor Landfill (EPA 2013). The Allen Harbor Landfill is a coastal landfill Superfund Site located on Narragansett Bay in Rhode Island. During remedy selection, it was determined that the landfill cap should be constructed to prevent erosion and transport of contaminants to sediments. This case study is an example of how to protect a landfill from flooding with specific cap construction methods,

shoreline armoring, wetland restoration, and seawalls. The cap was composed from bottom to top of:

1. A bedding/gas transmission layer
2. Geosynthetic clay liner
3. Geomembrane
4. Drainage layer
5. Geotextile
6. Barrier protection layer
7. Soil layer to support deep-rooted vegetation.

Riprap was placed along the entire shoreline to protect it from erosion during high tide and storm surges, and 1.5 acres of intertidal wetlands were restored by planting deep-rooted cord grass. An embedded seawall was also constructed that, together with the intertidal wetlands, reduced the wave energy that would reach the riprap.

- See EPA's Superfund website for additional case studies: https://www.epa.gov/superfund/superfund-climate-resilience
- Kayak Point Restoration Feasibility and Design, Phase 2 – Sea-Level Rise Assessment (Philip Williams & Associates, Ltd. 2008). This report summarizes future sea level rise projections and implications for the shoreline at Kayak Point Regional Park in Stanwood, Washington. Wave runup during storm events was also evaluated. Recommended adaptation measures include:

    a. Removal of the bulkheads; and
    b. Establishing a setback distance for the shoreline equal to the high sea level rise scenario, plus an additional 30 feet to serve as a buffer.

    These managed shoreline realignment methods can be used at most shoreline cleanup sites to adapt to sea level rise and wave runup climate change impacts.

- Nisqually National Wildlife Refuge (NWR), Estuary Restoration Project Monitoring Framework - Restoring Tidal Flow and Enhancing Shoreline Resilience in the Nisqually River Delta (Nisqually Indian Tribe and Nisqually NWR 2015). Restoration of the Nisqually River Delta commenced in 2002 as an eight-year, phased project. The first phase in the restoration process removed more than four miles of dikes to restore tidal flow to roughly 762 acres in the Nisqually NWR. Dike removal also helped to restore wildlife habitat and the delta's buffering capacity to withstand sea level rise and flooding.
- Building Wildfire Management Capacities to Enhance Adaptation of the Vulnerable Mountain Forests of Armenia (Global Environment Facility and United Nations Development Programme 2012). This case study was conducted as a pilot project to enhance the adaptive capacities of vulnerable mountain forests in Armenia on the southeastern edge of Europe. The consequences of climate change in the Armenian forests were increased wildfires due to an increasingly arid climate. Wildfire trends and

management shortcomings were identified, and the following management systems were implemented to prevent and control wildfires:

a. Enhanced forest management planning and practice to address the root causes of fires.

b. Improved forest health monitoring.

c. Improved forest connectivity by replanting with resilient mixed high diversity species.

d. Replanting with native species.

These wildfire adaptive management techniques can be applied to cleanup sites with forested areas that are projected to become more arid with climate change.

- Department of Defense (DOD). The DOD has many ongoing sites around the world. As part of DOD efforts to address climate change at their sites, they prepared a report that summarizes regional sea level rise scenarios at coastal sites for use in risk management. The DOD also developed a companion online sea level rise scenario database. The DOD has compiled global sea level rise projection data and evaluated trends and patterns that can be used for assessment of sea level rise and decision making.
- U.S. Army Corps of Engineers (USACE). The U.S. Army Corps of Engineers developed an adaptation plan in 2012, and has performed research on sea level change impacts, responses, and adaptation. In 2014, they prepared a technical letter that's available to the public and outlines sea level change adaptation elements. This sea level change adaptation information could be applied to any coastal cleanup site that is tidally influenced.
- National Oceanic and Atmospheric Administration (NOAA). NOAA is a federal agency with a Climate Program Office with the mission of "Advancing scientific understanding of climate, improving society's ability to plan and respond." NOAA provides scientific data, research, grants, and education and outreach to help prepare for climate change impacts.
- University of Washington's Climate Impacts Group (CIG). CIG is a group within the College of the Environment at the University of Washington. It focuses on working with public and private entities to assess and apply climate change risks based on information gathered from applied research projects, scientific data, decision tools, case studies, and publications.
- University of Oregon's Climate Change Research Group. This group performs climate change research, provides teaching resources, and hosts various events each year, including presentations and an annual climate change research symposium.

Appendix C:
Washington State Case Studies

Appendix C contains brief case study summaries of cleanup sites that have incorporated resilience into the cleanup design or adaptive management plans. They discuss:

- Incorporating sea level rise into the remedial design:
  - At landfill cleanup sites located along the marine waterfront.
  - At contaminated soil and groundwater site located along the marine waterfront.
  - At sediment cleanup sites in a marine embayment.
- Implementing adaptive management during post-cleanup construction at a sediment site to address damage from multiple severe storm events within 3 days of each other.
- Incorporating protection from severe storm events into the remedial design for a sediment and upland shoreline site.

C.1 Sea level rise

Sea level rise has been addressed at a number of cleanup sites in Bellingham Bay including a landfill, a contaminated soil and groundwater site, and a sediment site.

C.1.1 Landfill Cleanup Site: Cornwall Avenue, Bellingham Bay

Figure 17: Cornwall Avenue landfill site. This shows the waterfront portion at the south end of the site.

The Cornwall Avenue Landfill cleanup site is located in Whatcom County on Bellingham Bay, between Boulevard Park and the former Georgia Pacific pulp mill, on the south end of Cornwall Avenue (Figure 17). From 1888 to 2005, the site had multiple uses including sawmill operations, municipal waste landfill, and log storage and warehousing operations after the

landfill closed in 1965. The municipal landfill was created by dumping and pushing waste into the bay to form new land.

About 13 acres of the site are on land and about 13 acres have been delineated in water. Future investigations will be undertaken to define the extent of the site in deeper water. The site has approximately 1,500 feet of shoreline exposed to strong wave action. Severe erosion of the shoreline has occurred in the past and continues in the present.

The site contains an estimated 295,000 cubic yards of municipal waste and 94,000 cubic yards of wood waste. Some of the contamination associated with this waste includes:

- *Groundwater*: Tannins and lignins associated with wood waste-breakdown products, elevated nitrogen compounds such as ammonia, elevated dissolved metals such as manganese, and volatile organics such as benzene.
- *Sediment*: Mercury, phthalates, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, phenols, and diesel and oil-range petroleum hydrocarbons.
- *Soil*: Petroleum hydrocarbons, pentachlorophenol, carcinogenic PAHs, and other municipal landfill contaminants.

Cleanup Remedy

Sea level rise is currently being incorporated into the remedy during the remedial design phase. A sea level rise of 2.4 feet over 100 years is being considered as the design metric for maintaining the integrity of the cleanup into the future. The cleanup remedy will consist of an upland multi-layer cap, a shoreline stabilization system, and the use of enhanced natural recovery in deeper subtidal areas. The shoreline stabilization system includes an upper gravel blanket and a lower sand filter. Together they will be designed to prevent landfill waste from being eroded into the bay and to prevent environmental exposure. The stabilization system will be constructed throughout the intertidal zone and into the shallow subtidal zone to ensure it remains stable under high-wave action during extreme low tides. In addition, the stabilization system will serve as a cap and biotic barrier over the shallow and intertidal sediment. This sediment is most impacted by site releases, due to shoreline erosion that results from wave action.

Two shoreline protection options have been developed as part of the initial engineering design. One option consists of a conventional heavy armor rock blanket 3- to 4-feet thick, with an average rock diameter of 1.9 feet. The second option uses a large rock groin to reduce wave action, which will allow a blanket of smaller diameter sandy cobble gravel in some areas. However, additional engineering analysis of the stabilization system's thickness, gradation, and elevation limits will be required during the final remedial design. This will ensure that the system provides adequate protection from significant wave action during winter storms, and effectively contains the sand filter layer, underlying refuse, and wood debris.

Sea level rise is being factored into the remedial design by considering what aspects of the remedy would be vulnerable under higher water conditions. This evaluation shows that the

primary risk would come from overtopping of the shoreline stabilization system, with concomitant erosion of the upland cap and undermining of the shoreline stabilization system itself. Erosion of this type would expose waste materials to human contact and release waste materials directly into the bay. The primary design response will be to increase the height of the shoreline stabilization system to accommodate the anticipated sea level rise. In addition, a sloping area of upland cap will be constructed adjacent to the shoreline stabilization system to allow raising the system even higher in the future, if necessary (Figures 18 and 19).

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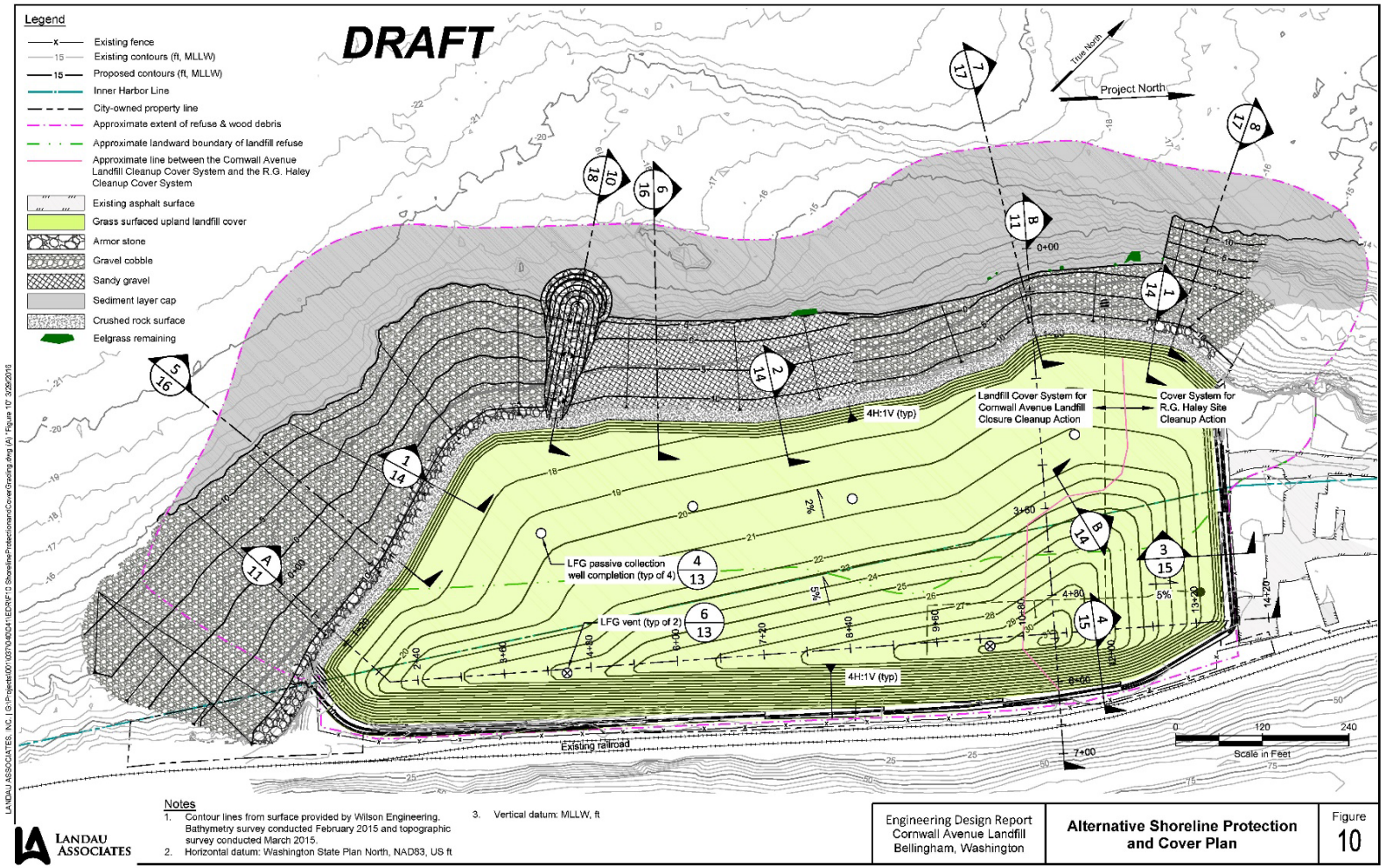

Figure 18: Cornwall Avenue landfill shoreline plan view showing the topographic tie-in between the sloping upland surface and the shoreline/subtidal area.

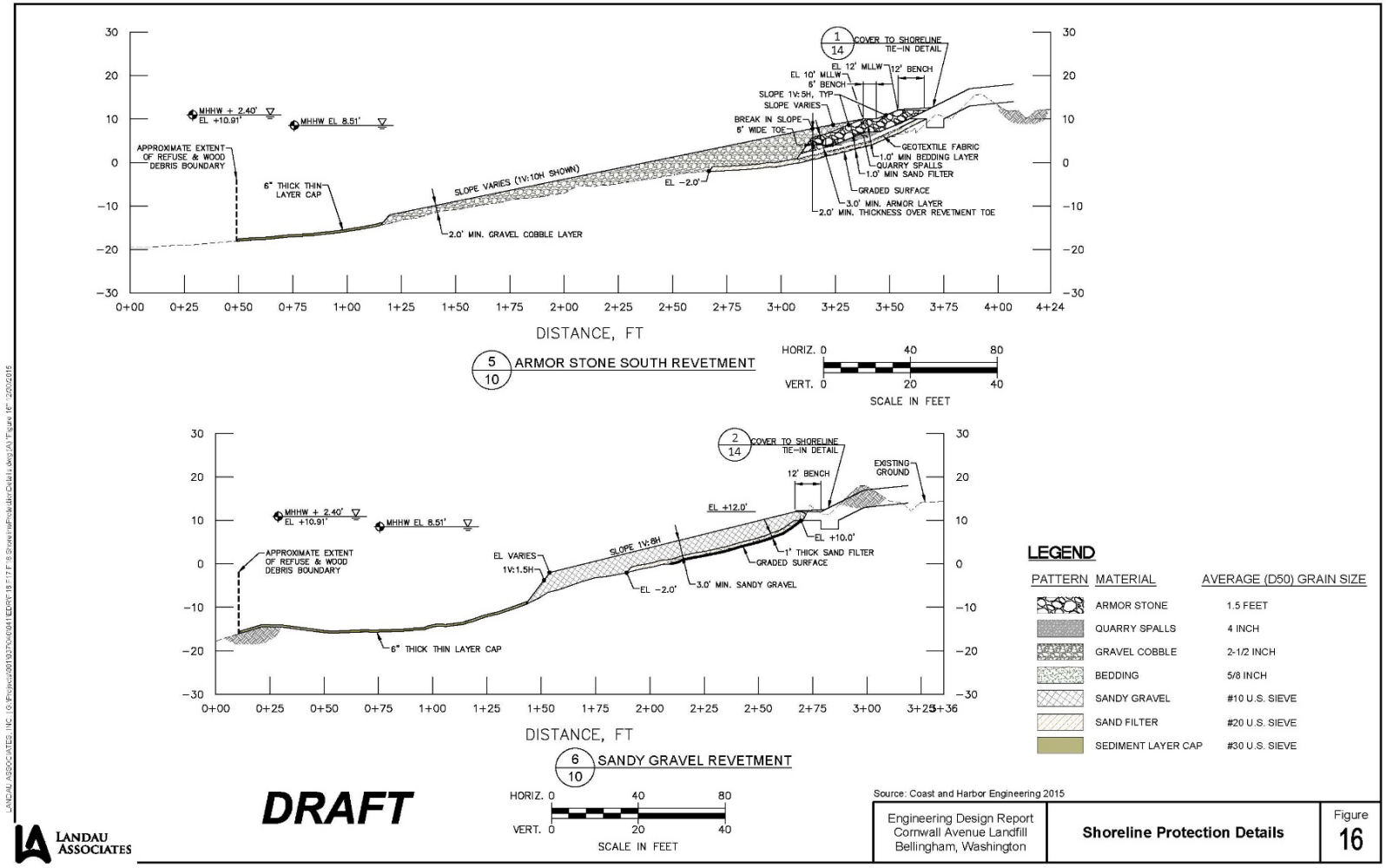

Figure 19: Cornwall Avenue landfill shoreline cross section.

C.1.2 Landfill Site: March Point, Padilla Bay

Figure 20: March Point Landfill before cleanup showing the lagoon.

The March Point Landfill site (also referred to as Whitmarsh Landfill) is located along the shoreline of Padilla Bay in Anacortes. It is situated along a lagoon connected to Padilla Bay by a 100-foot-wide channel under the Burlington Northern Santa Fe (BNSF) railroad embankment. The landfill operated for more than 20 years as an unregulated public dump, then around 1973 served as a county disposal area for household, commercial, and industrial wastes. From the late 1980s to 2011, a sawmill was operated at the site, which resulted in accumulations of wood waste up to 10-feet thick over large portions of the landfill (Figure 20).

The contaminants of concern are numerous:

- *Soil*: solid waste, wood waste, and landfill gas (methane); metals, total petroleum hydrocarbons, benzene, semi-volatile organic compounds (SVOCs), and PCBs.
- *Groundwater:* SVOCs, benzene, pesticides, PCBs, and metals.
- *Surface water:* metals, one pesticide, PCBs, SVOCs, and benzene seeping from the landfill to surface water (Ecology 2017b).

Cleanup Remedy

The cleanup remedy consists of:

- A design to address impacts from 100-year storm events and sea level rise of 7.6 feet above MHHW due to tsunamis (short-term impact) or climate change (long-term impact) (Figures 21-23).
- Moving solid waste from the edges of the landfill inward.
- Grading the waste to a mound.
- Installing a passive landfill gas collection system to vent gases to the atmosphere.
- Installing an engineered cap over the landfill with standard geosynthetic clay laminated liner (GCLL) above 16 feet mean lower low water (MLLW) to minimize or eliminate infiltration into the landfill.
- Placement of an enhanced geosynthetic clay liner over the landfill along the shoreline up to 16 feet MLLW to minimize or eliminate discharge of groundwater to surface water (Figures 21-23).
- Constructing a perimeter access road around the landfill.
- Requiring 30 years of operation and maintenance.

A tidal study, and geotechnical and hydrogeological evaluations, showed that a) the shallow nature of Padilla Bay, b) the BNSF rail embankment, c) nearby hillside, and d) Highway 20 protected the lagoon and shoreline from increased wave heights that might result from sea level rise, as well as wave and current actions during 100-year storm events (Ecology 2017b).

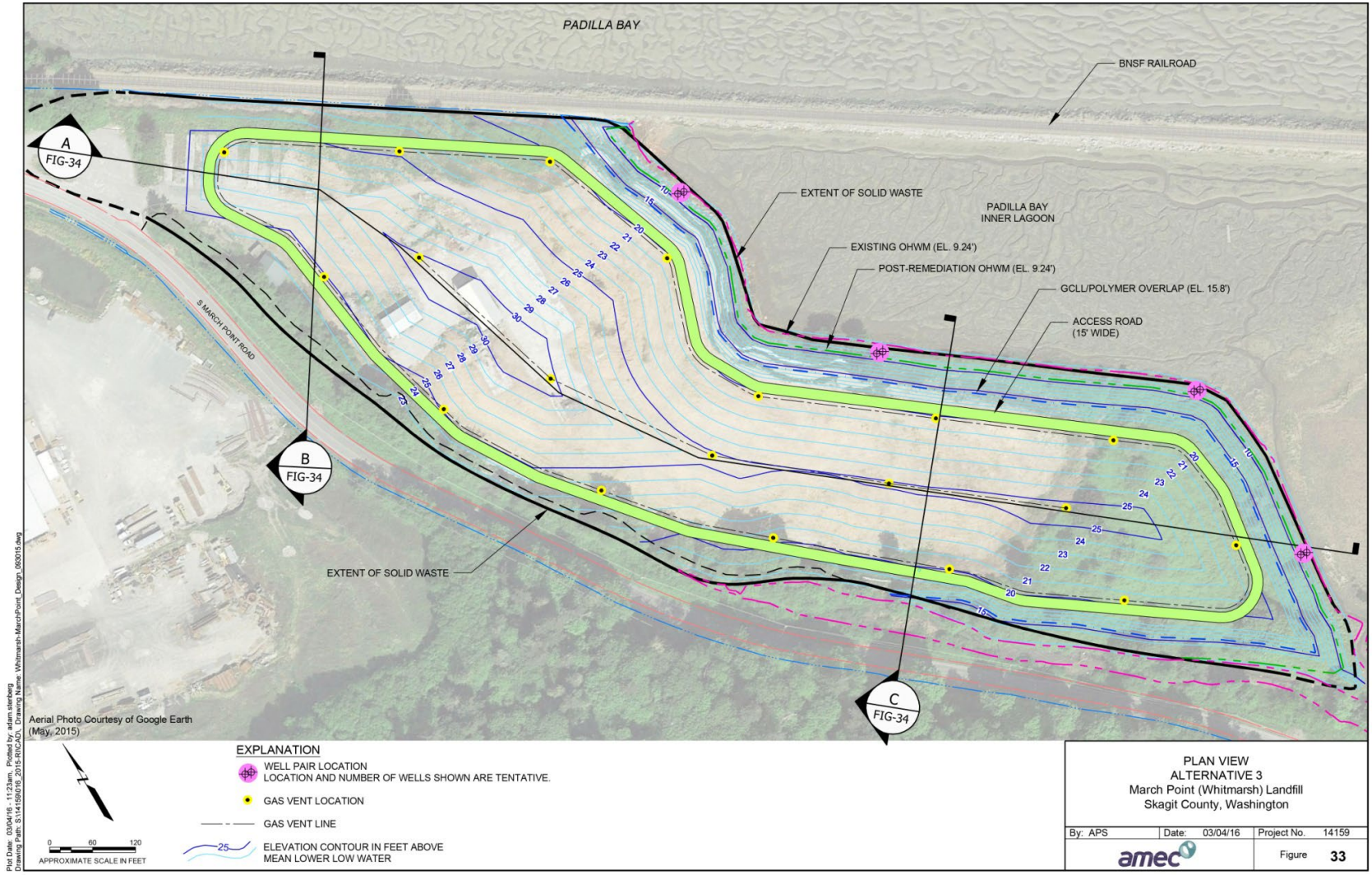

Figure 21: March Point Landfill plan view of extent of GCL liner and waste.

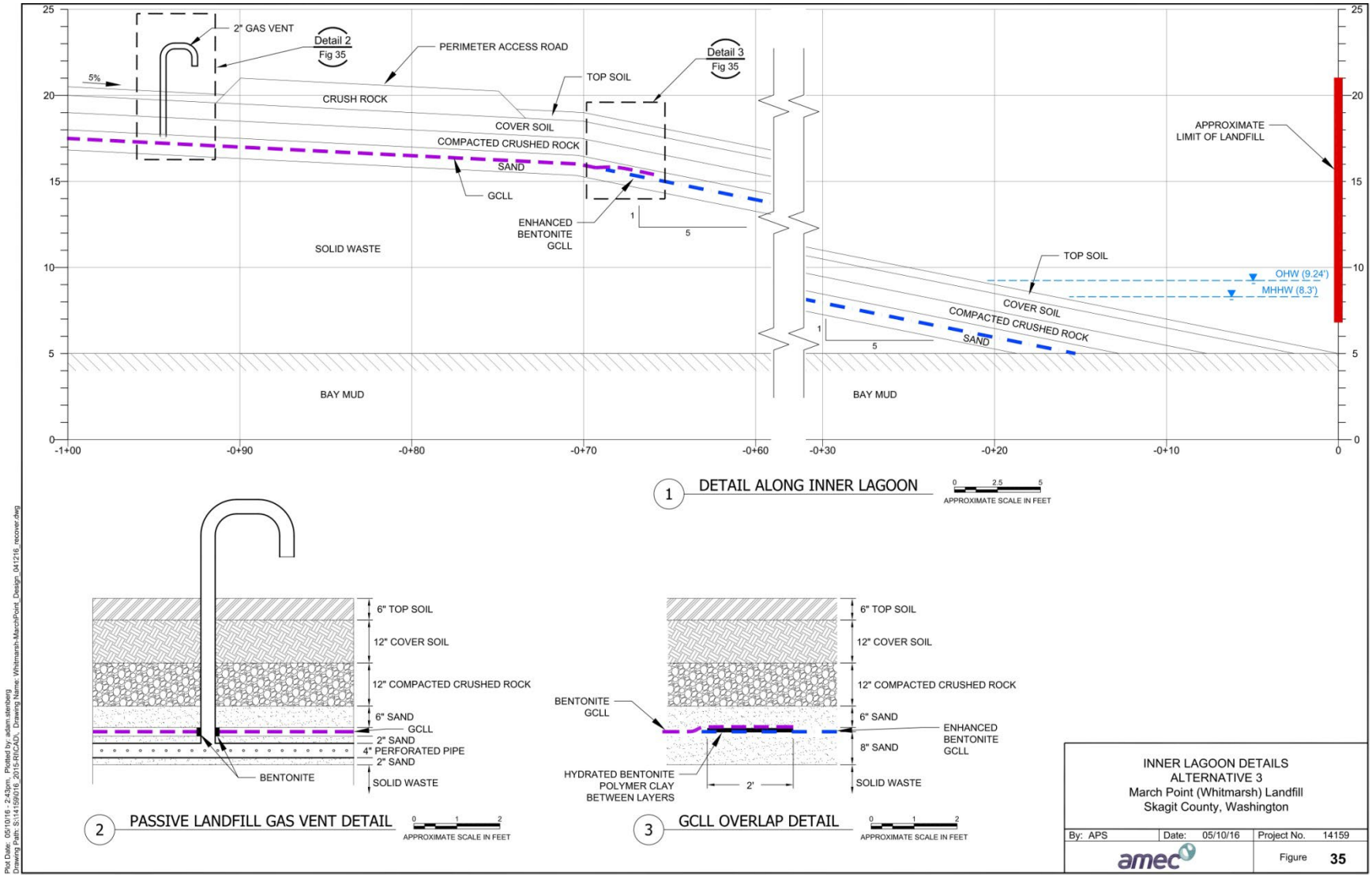

Figure 22: March Point Landfill details of enhanced GCL liner.

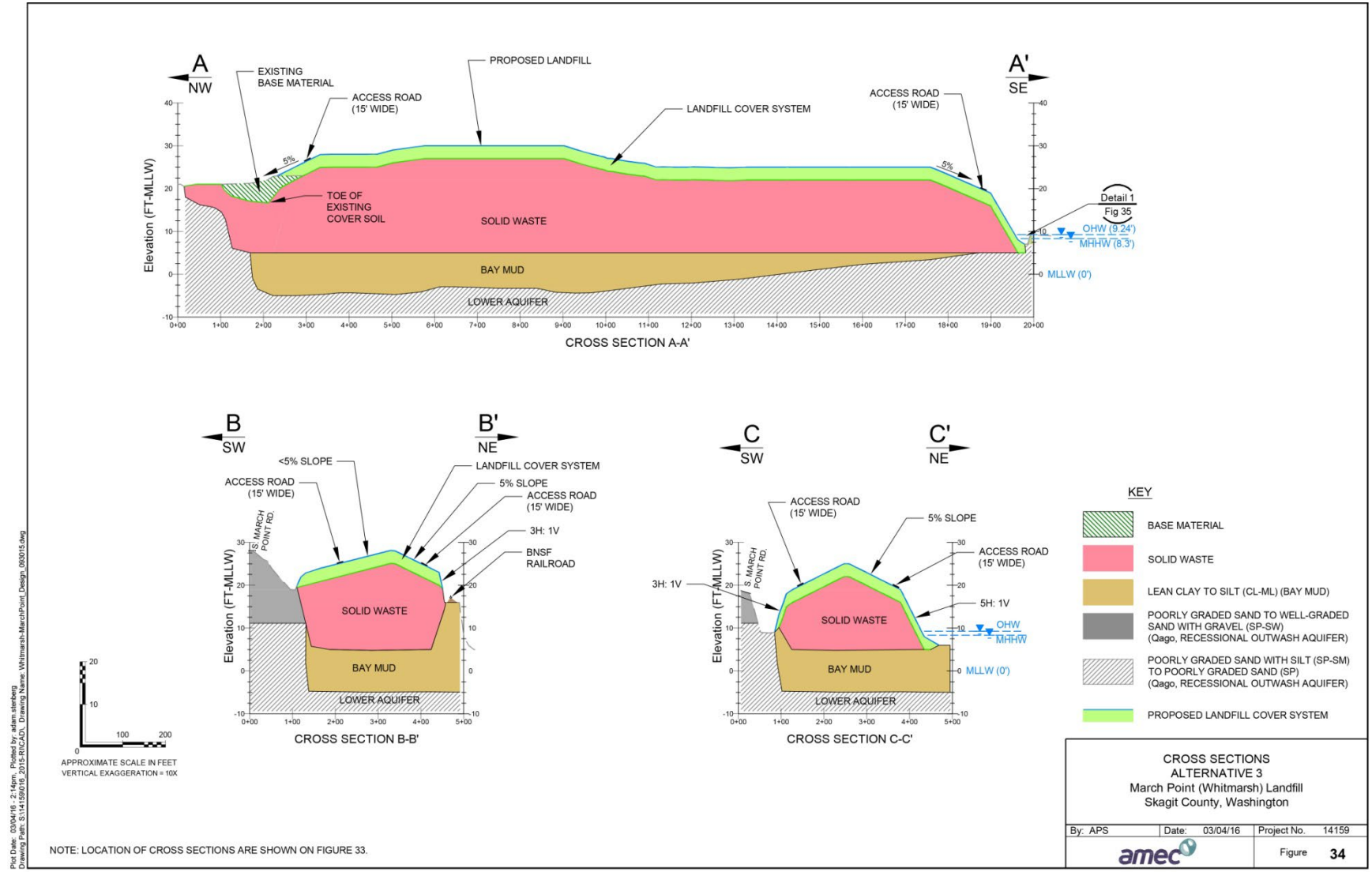

Figure 23: March Point Landfill details of enhanced GCL liner.

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C.2 Sea level rise and extreme storm events

Sea level rise combined with extreme storm events has been addressed at a number of sediment and soil sites in Port Gamble and Fidalgo Bays.

C.2.1 Sediment Site: Port Gamble Bay Mill

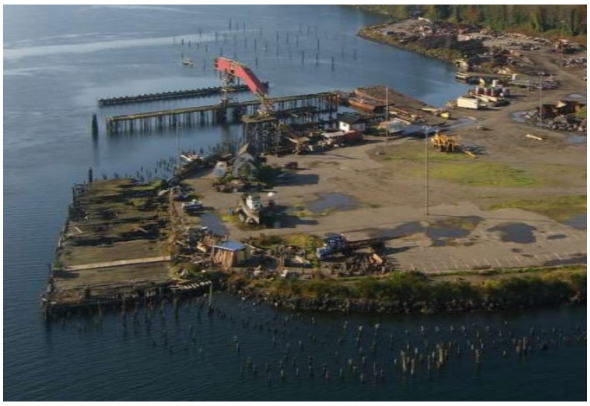

Figure 24 at left: Port Gamble Bay site before cleanup construction.

Figure 25 at right: Port Gamble site after cleanup construction.

Port Gamble Bay in Kitsap County south of the Strait of Juan de Fuca includes > two square miles of subtidal and shallow intertidal habitat. The Port Gamble Bay Mill site manufactured forest products for 142 years until 1995. Sediment contamination included woodwaste, creosote, cadmium, mercury, PAHs, and dioxins/furans (Figure 24; Ecology 2014).

Cleanup Remedy

The cleanup remedy (Figure 25) included:

- A design for 100-year storm events.
- Removal of ~8,592 creosote pilings and overwater structures.
- Dredging or excavation of ~120,000 cubic yards of contaminated sediments.
- Removal and recycling of 6,620 tons of steel, concrete, asphalt, and creosoted pilings.
- Capping or thin-layer capping of 79 acres.
- Active cleanup of 5.4 acres and 3,485 linear feet of shoreline.
- 224,091 tons of cleanup capping material placed including sand, habitat mix, filter, backfill, and armoring material (Ecology 2014).

The intertidal excavation and capping was done during low tide in the dry. Subsequent tidal elevations were up to 2.5 feet above projections due to warmer than normal ocean temperatures, known as the Pacific Coast Blob, and low-pressure systems over western

Washington (Jacox 2016). These high tides prevented working in the dry any further, so construction was completed during inundation from the water side. Contingencies and scheduling buffers were developed prior to construction, in order to prevent delays during the limited work windows (such as anticipated environmental factors or equipment breakdown, etc.). These extra buffers of time, and the flexibility to adapt to changes in conditions, proved critical for staying on schedule.

Figure 26 at left: Damage to the site after two severe storm events.

Figure 27 at right: Port Gamble Bay Mill site damage repaired.

Adaptive Management Strategy

Frequency and intensity of storms and tidal surge informed designing the shoreline cap to withstand a 100-year storm event, using the historical record for wind events and modeling wave analysis. In March 2016, two severe storm events within a period of three days occurred, which eroded the fines and habitat mix layers of the cap (Figure 26).

Damaged portions of the intertidal cap was redesigned and repaired to improve on protectiveness and long-term effectiveness against more frequent severe storm events (Figure 27). This entailed reconstructing or overlaying the armor layer of the cap with larger sized rock capable of resisting the storm energy that caused the damage. The augmented armor material, originally sized at 9-inch minus, went to 1-to-1.5-foot minus and in the most exposed areas, included protection using 2-to-3-man rock (Ecology 2015).

C.2.2 Sediment and Soil Site: Scott Paper Mill, Fidalgo Bay

Figure 28: Scott Paper mill before cleanup.

Scott Paper Mill is a waterfront site in Anacortes that was used as a lumber mill, then pulp mill, from the late 1800s through the late 1970s. It then served as a log yard, staging area for oil field equipment, a boat manufacturing site, storage, and a modular home assembly area. The pulp mill used waste from the lumber mill and discharged waste water directly to Fidalgo Bay. Soil, sediment, and groundwater were contaminated with metals; diesel- and motor oil-range polycyclic aromatic hydrocarbons; polychlorinated biphenyls; and dioxins/furans (Figure 28). The former mill site now features a public waterfront park that provides unprecedented public access to the shores of Fidalgo Bay (Figure 29; Ecology 2009).

Cleanup Remedy

Figure 29: Scott Paper Mill after cleanup construction showing structures to attenuate waves and lessen impacts of 100-year storms (as currently defined by FEMA) projected to occur every 25 years.

The cleanup remedy included:

- Design for 100-year storm events projected to occur every 25 years in the future and 2 feet of sea level rise.
- Dredge and/or excavation of ~30,200 cubic yards of contaminated sediment from the intertidal and subtidal areas to a minimum depth of 2 feet (Figure 29).
- Removal of wood waste, brick, and creosote pilings.
- Backfill of dredged areas with clean sand and gravel.
- Placement of a minimum 2-foot-thick capping layer of clean sand, gravel, and armor stone along the shoreline where contaminants will remain in sediment at depth where:
    - The intertidal area connects to the shoreline, intertidal excavation was done to a sufficient elevation for the armor layer to be placed. This minimized the potential for erosion at the edge of the cap, caused by breaking waves on the slope.
    - The transitional intertidal slope cap had a minimum 2-foot thickness, with a lower 1-foot layer of quarry spalls that were covered with a 1-foot layer of surficial sand and gravel mixture.

Figure 30: Scott Paper Mill site wave attenuation structures.

- To protect the upland soil remedy along the shoreline and the sediment remedy from storm-generated wave and current wave action, attenuation structures were placed offshore of the north portion of the site (Figure 30). These are intended to protect the softened shoreline and shoreline habitat, control erosion of upland contaminated soils that remain at depth, and prevent them from being a source of down-drift sediment contamination.

- The wave attenuation structures were designed for what is currently a 100-year storm event but projected to occur every 25 years.

- The modeling results showed that the structures will effectively dissipate the wave energy along the uplands area shoreline by breaking incoming storm-generated waves and preventing wave reflection from the existing breakwater (Figure 31).
    - The structure was constructed of imported rock with crest elevations ranging up to +12 feet MLLW.

    - To further protect against future erosion of shoreline soils and release of contaminants remaining at depth, an armored cap was placed. A minimum 0.5-foot-thick top dressing of sand and gravel was placed in the interstices of the cap armor stone.

    - To further protect the confined underlying sediment from direct wave-break action when exposed by tides, the lower portion of the transition slope cap was constructed of a quarry spall armor layer with a minimum thickness of 1 foot. The armor layer was then covered by a minimum of 1 foot of sand and gravel material (Ecology 2009).

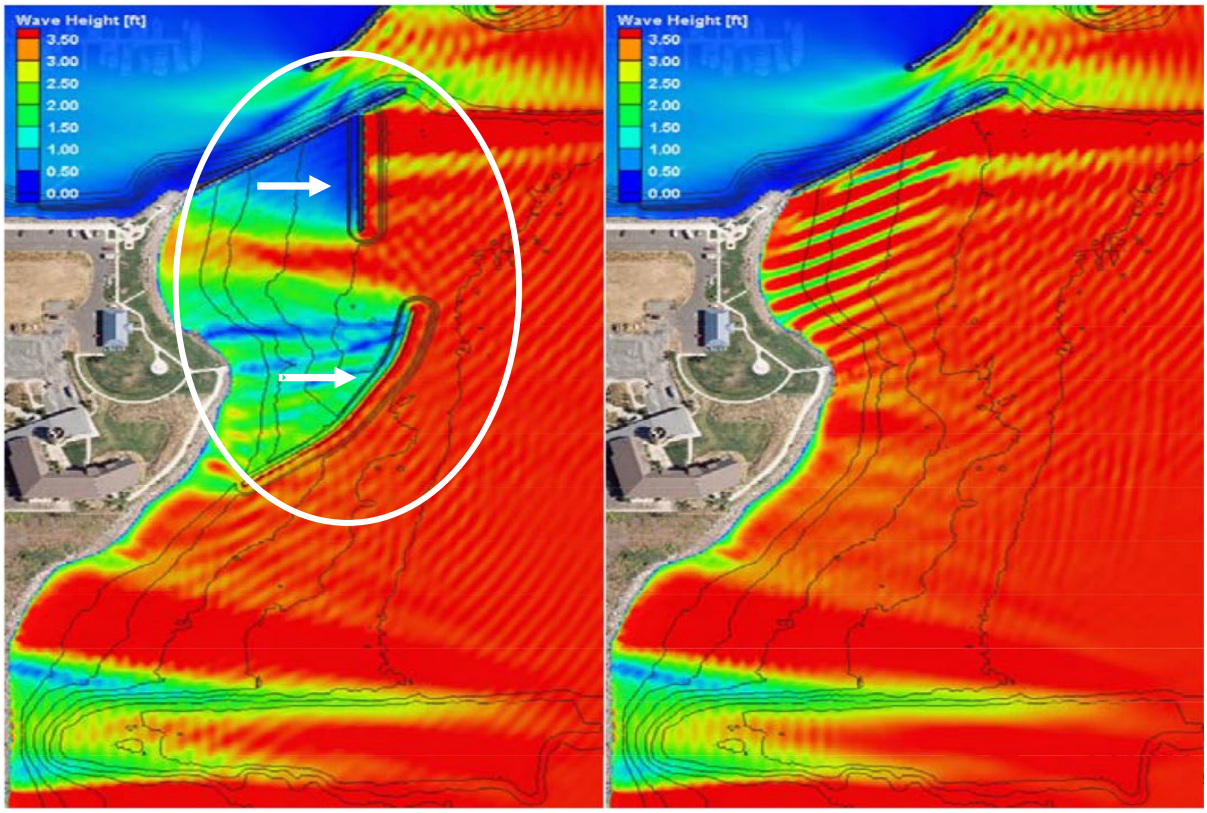

Figure 31: Scott Paper Mill site wave modeling shows reduced wave height, and increased shoreline protection, with additional structures (white arrows).

Adaptive Management Strategy

Since at least 1962, storm-generated wave and current action has resulted in considerable erosion along the filled shoreline. To address this, the Port of Anacortes completed a bank stabilization interim action along the Seafarers' Memorial Park shoreline. Protection of the shoreline has required routine maintenance. The wave attenuation structures and shoreline armoring for the Scott Paper Mill site are expected to minimize erosion. However, due to its history, continued maintenance and adaptive management are a necessary part of the Scott Paper Mill site remedy.

It is possible that the cleanup along the shoreline may create soil disturbances that mobilize contaminants in soil at depth. Post-construction monitoring of groundwater and sediment is planned to ensure that deeper contaminated soils left in place do not migrate to surface water and sediment and pose a risk to the marine area. If groundwater or sediment results show exceedances of cleanup levels without abating, or show that the shoreline protection, cap and backfill stability, substrate suitability, or habitat is compromised, additional actions will be considered.

C.2.3 Sediment Site: Custom Plywood, Fidalgo Bay

Custom Plywood is a waterfront site in Anacortes that was used as a mill and box factory beginning in the early 1900s. Custom Plywood operated the site from 1984 until 1991, but all operations ceased following a fire in 1992. Wood waste and chemical contaminants were found in upland soil, groundwater, and sediment in the intertidal and subtidal areas, as well as in a wetland (Figure 32; Ecology 2011a & b).

Cleanup Remedy

Figure 32: Custom Plywood site before cleanup construction.

The cleanup consisted of the following (Figure 32):

- Designed for what is a current 100-year storm event but projected to occur every 25 years, and 2 feet of sea level rise.
- Excavation of contaminated soil.
- Hydro seeding with grasses and construction of a bioswale to treat stormwater.
- Construction of a 12,000 square foot wetland mitigation area connected to the marine environment and vegetated buffer.
- Removal of in-water construction debris and creosote pilings.
- Excavation of 60,000 cubic yards of wood waste contaminated with dioxins/furans.

- Construction of a spit and extension of a jetty to protect the shoreline and wetland by attenuating storm-generated wave and current actions from severe storm events projected to occur every 25 years (Figure 33).
- Wave modeling was conducted to determine the most appropriate design (Figure 34; Ecology 2013).

Figure 33: Custom Plywood site after cleanup construction.

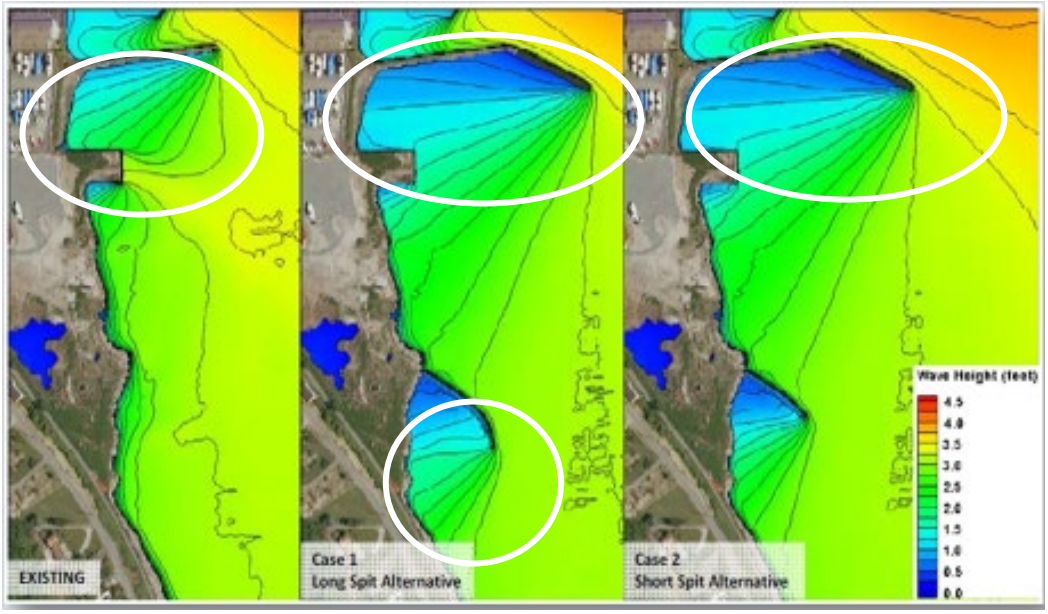

Figure 34: Wave modeling to determine most appropriate wave attenuation structure design.

Adaptive Management Strategy

- As a result of wave action and natural sediment transport processes, the fine-grained sediment in the bank of the wetland eroded into the water portion. Since this resulted in habitat improvement, no additional action was taken (Figure 35).

- This site will require continued monitoring to confirm success of the remedy; performance and integrity of the wave attenuation structure; and protection of the wetland.
- Long-term protection of the upland area from sea level rise was considered. Since upland surface elevations range down to about 8 feet elevation (NAVD 88), it was determined that portions of the site may be vulnerable to inundation.

    - The Operations Monitoring and Maintenance Plan includes an adaptive management approach to identify and evaluate additional surface protection features that may be needed to protect against wave erosion.

    - Supplemental surface vegetation, paving, or other armoring may be needed to provide further protection from soil erosion, as well as contaminant transport to surface water and sediment.

    - Backfilled excavation and dredging areas provide a protective layer to prevent exposure of the residual contaminated sediment that remains at depth.

Figure 35: Custom Plywood site with erosion of the wetland bank during a storm event.

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Appendix D:
Green Remediation Guidance

D.1 Introduction

The purpose of this Appendix is to provide guidance to incorporate Green Remediation best management practices (BMPs) into the cleanup process. The goals of Green Remediation are to increase the environmental benefit and reduce the environmental impacts during the cleanup process. Sustainable Remediation can be accomplished by using both Climate Change Adaptation (Chapters 1-9 and Appendices A-C) and Green Remediation (Appendix D) concepts in this guidance. This appendix is organized by the following metrics and goals:

Table D-1: Green Remediation metrics and goals for cleanup.

Green Remediation Metrics	Green Remediation Goals
Energy	• Minimize use of non-renewable fuels. • Maximize use of renewable energy. • Use local goods and services. • Use chemicals and materials produced with less energy. • Avoid double handling of materials. • Minimize overall energy use.
Air	• Minimize emissions of greenhouse gases. • Minimize emissions of other air pollutants. • Use clean fuels and engine technologies. • Use materials and chemicals that are produced with less air emissions.
Materials and Waste	• Minimize waste materials generated for disposal. • Minimize consumption of raw and virgin materials. • Recycle or re-use equipment and materials. • Use local facilities for waste recycling, reuse, disposal, and treatment.
Water	• Minimize freshwater consumption. • Recycle water or use reclaimed water. • Use low impact development to manage stormwater. • Use native, drought-resistant plants for landscaping and habitat restoration. • Minimize impacts to water quality.
Land and Ecosystems	• Create and restore functional habitat. • Maintain and protect existing functional habitat. • Minimize nuisances to the community such as noise, odor, emissions, and light.

D.1.1 Benefits of implementing Green Remediation

Implementing Green Remediation BMPs can result in:

- Benefits to human health and the environment. For example, reducing nitrogen oxides, sulfur oxides and diesel particulate matter emissions benefits air quality; and reducing greenhouse gas emissions decreases contributions to carbon in the atmosphere.
- Cost savings. For example, conserving energy reduces fuel and electricity costs, minimizing waste material reduces transportation costs and landfill tipping fees, and identifying ways to avoid or reduce material use saves in material costs.
- Benefits to the local economy. For example, using local goods and services can generate revenue and jobs for the community and limits the mileage from transporting people and materials. This, in turn, conserves energy and fuel and reduces air pollutant emissions.

D.1.2 How to use this appendix

This appendix includes the following information:

1. A stepwise process to determine the most appropriate approach for implementing Green Remediation at your site (see below).
2. Three options (Tiers 1 – 3) to identify and evaluate Green Remediation BMPs based on site-specific needs and complexity of your site (Section D.2).
3. Recommended BMPs to achieve Green Remediation goals outlined in Section D.2.
4. The GREEN Tool (**G**reen **R**emediation **E**nvironmental **E**valuation **N**umeric Tool) to evaluate the efficacy of Green Remediation BMPs (Section D.3).
5. Environmental footprint analytical tools that can be used instead of the GREEN Tool for complex sites (Section D.4).
6. Green remediation resources that include more detail on specific BMPs than this appendix provides (Section D.5).

To implement this appendix, the following steps are recommended (Figure D-1):

Step 1. Identify which Tier is most appropriate for your site.

- **Tier 1** can be used for relatively routine sites with straightforward sampling, limited remedies that are energy and fuel intensive and have low material usage and does not include contaminated sediment as part of the site. For example, a leaking underground storage tank site with a small plume (e.g., less than 5 acres) and a relatively straight-forward excavation remedy (e.g., complete removal - dig and haul).

- **Tier 2** is designed for intermediate sites that involve multi-phase sampling, multiple media types, technologies, and remedies. They are typically more complex than Tier 1 sites, have relatively nominal use of materials but can be energy and fuel intensive. For example, a 20-acre waterfront site with contaminated soil, groundwater, and sediment.

- **Tier 3** may be appropriate for complex sites with multi-phase sampling requirements, multiple media, and remedies that are materially, energy, and fuel intensive (e.g., large volumes of cement, chemical reagents), and span a very large area. For example, an embayment or complex landfill. Most state cleanup sites will not fall under this tier.

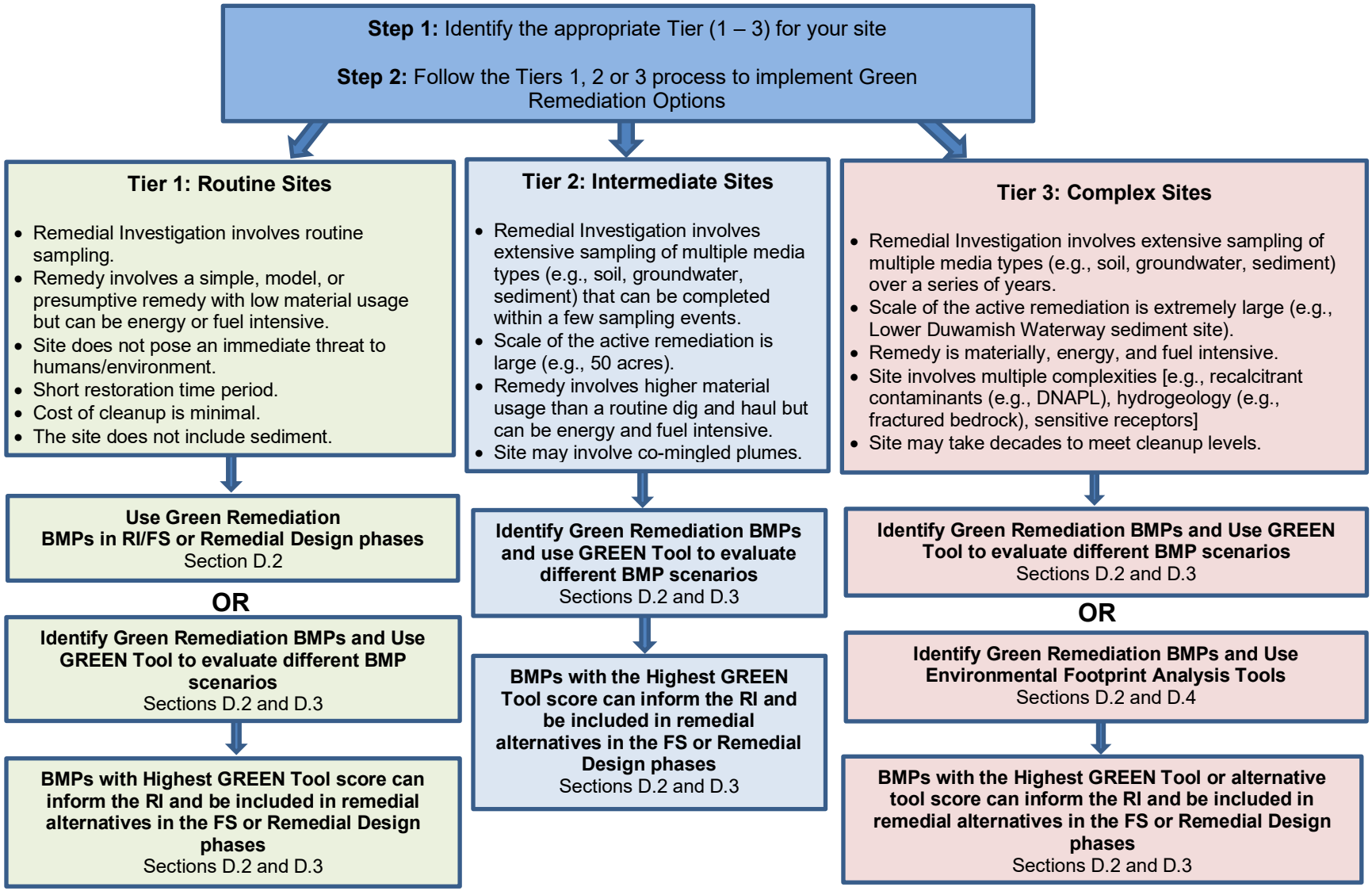
Step 2. Follow the appropriate process for the Tier selected in Step 1:

- **Tier 1:** Use Section D.2 to identify and directly implement Green Remediation BMPs that are best suited to the site. Using the GREEN Tool to evaluate BMPs is optional.

- **Tier 2:**
  a. Use Section D.2 to identify Green Remediation BMPs that could be used at the site.
  b. Use the GREEN Tool in Section D.3 to evaluate and compare the efficacy of the identified BMPs for various technologies or remedial design options.
- **Tier 3:**
  a. Use Section D.2 to identify Green Remediation BMPs that could be used at the site.
  b. Use either the GREEN Tool in Section D.3 to evaluate and compare the efficacy of BMPs or an alternate and more complex tool in Section D.4 to analyze the environmental footprint—or life cycle—of the various technologies or remedial design options.

For both Steps 1 and 2, resiliency to climate change impacts should also be considered when identifying and evaluating Green Remediation BMPs. Chapters 1-9 and Appendices A-C of this guidance can be used to 1) determine specific vulnerabilities to climate change for your site, and 2) incorporate resiliency into remedies.

Figure D-1: Determining the appropriate approach. The examples are intentionally general in nature to provide flexibility when determining if a site is Tier 1, 2, or 3. The variables for Tiers 2 and 3 are similar but can differ in size or scale of the site and usage of materials. The decision to classify a site Tier 2 or 3 can be based on the site manager's best professional judgement and unique knowledge of the site.



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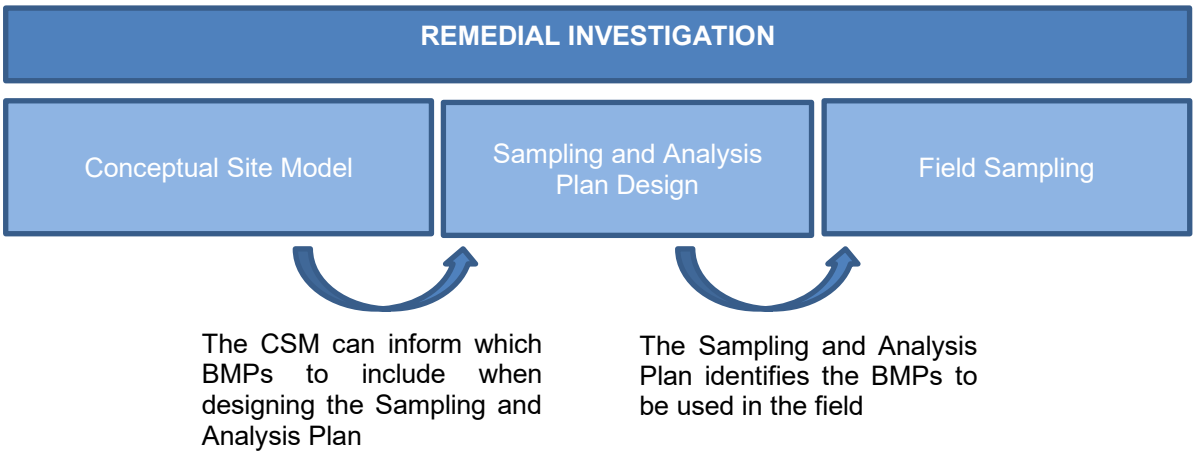
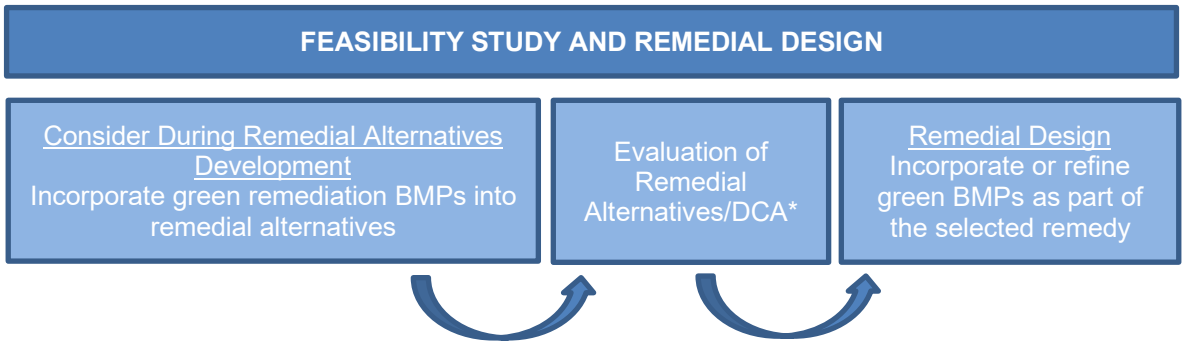
D.1.3 Incorporating BMPs at different cleanup phases

Green Remediation BMPs can be applied to all phases of cleanup (Figure D-2):

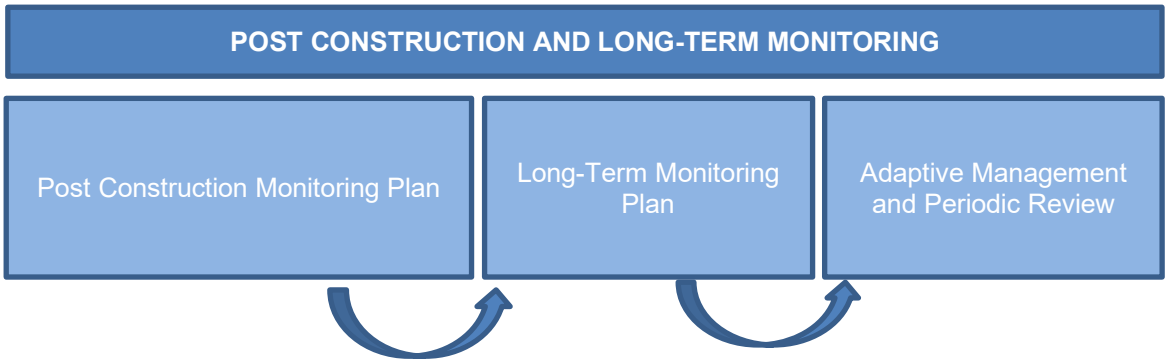
- Remedial Investigation. BMPs can be incorporated during development of the conceptual site model and the sampling design phases.
    - Conceptual Site Model. Considering Green Remediation BMPs as the conceptual site model is developed will inform how to incorporate BMPs into all phases of cleanup and allow the cleanup project manager to adaptively manage the process. The CSM can be used to identify the Green Remediation BMPs that can most easily be incorporated into the cleanup, as well as identifying approaches that may be most important to use at the site due to resource limitations or vulnerabilities. This information could be documented in the remedial investigation work plan or report.
    - Sampling Design. Based on the conceptual site model, Green Remediation BMPs can influence the design of the sampling and analysis plan and logistics of fieldwork. And the remedial investigation results can provide information to evaluate the feasibility of these BMPs during the feasibility study and remedial design phases. This information could be documented as a list of Green Remediation BMPs in the work plan and/or sampling and analysis plan.
- Development of Remedial Alternatives. This phase provides the most flexibility to incorporate Green Remediation BMPs. During the feasibility study, remedial alternatives can be developed that include BMPs that meet the Green Remediation goals (Section D.1, Table D-1). To inform this process, these remedial alternatives can be evaluated using the GREEN Tool (Section D.3). However, the disproportionate cost analysis process is not designed to score Green Remediation BMPs. This information can be documented in the Feasibility Study as a list of Green Remediation BMPs, and the GREEN Tool scoring captured as a screen shot or in table format.
- Remedial Design. Green Remediation BMPs can be developed at this phase regardless of whether they have been included previously. For example, the BMPs can be used to inform selection of materials and equipment used during construction, logistics for staging construction, use of local goods and services, effective management of waste material, and water conservation. For Tier 2 and 3 sites (Section D.1.2), evaluating BMPs using the GREEN Tool is highly recommended. This information can be documented in the Feasibility Study as a list of Green Remediation BMPs, and the GREEN Tool scoring (if applicable) captured as a screen shot or in table format.
- Monitoring. Green Remediation BMPs incorporated into the remedial investigation and remedial design phases can greatly influence development of the post-construction maintenance and monitoring plans. Many of the Green Remediation BMPs that are applicable to the remedial investigation are also applicable to field work conducted as part of post-construction monitoring. This information can be documented in the Operations and Maintenance Monitoring Plan as a list of Green Remediation BMPs.

Figure D-2: Process for implementing green remediation at different phases of cleanup.





***** Since the current cleanup rules are not clearly written to score Green Remediation BMPs as a separate category in the DCA, BMPs do not influence scoring of remedial alternatives. When scoring during the DCA, alternatives must meet MTCA/SMS criteria (protectiveness, permanence, long-term effectiveness) and should be scored based on the criteria in the MTCA and SMS cleanup rules (WAC 173-204-360 and WAC 173-204-570).



D.1.4 Policy statement

Ecology will implement Green Remediation BMPs where appropriate to maximize the environmental benefit and minimize the environmental impact from the process of cleaning up contaminated sites. Table D-2 details how Ecology plans to implement this guidance depending on the type of cleanup.

Green Remediation BMPs will be considered for all phases of cleanup and should be incorporated into remedial alternatives consistent with the protectiveness, permanence, and long-term effectiveness provisions in the cleanup rules [Model Toxics Control Act (WAC 173-340-360) and Sediment Management Standards (WAC 173-204-570)]. Currently, the cleanup rules are not clearly written to score Green Remediation BMPs as a separate category in the disproportionate cost analysis (DCA). Therefore, alternatives scored in the DCA can include Green Remediation BMPs, but they will not be separately scored based on using these BMPs.

Table D-2: How Ecology will implement or require the use of Green Remediation BMPs for specific types of cleanups.

Type of Cleanup	Type of Funding	Examples	Use of Green Remediation BMPs
Ecology Led	Ecology funded	Orphaned sites Abandoned sites	Required
Ecology Supervised	Ecology funded or partially funded	Remedial Action Grant sites	Required
Ecology Supervised	Privately funded	Formal cleanup sites	Encouraged and may receive recognition from Ecology
Independent	Privately funded	Independent cleanups	Encouraged and may receive recognition from Ecology
Independent	Privately funded	Voluntary cleanup sites	Encouraged and may receive recognition from Ecology

D.2 Green remediation best management practices

This section explains Step 2 (Subsection D.1.2) and includes Green Remediation best management practices (BMPs) that can be implemented for Tier 1, 2, and 3 sites. After identifying the Tier most appropriate for your site (Step 1, Subsection D.1.2), the following BMPs should be reviewed to determine which are best suited for your site. The Green Remediation BMPs in this section are categorized into five Green Remediation metrics:

- Energy
- Air
- Waste and Materials
- Water
- Land and Ecosystems

Each Green Remediation metric is further categorized into the phase of cleanup where it can be implemented. Some BMPs are identified as general enough to be applicable to all types of sites, while others are tailored to specific media (e.g., sediment) or type of site (e.g., landfill).

For Tier 1 sites, after BMPs are identified they can be directly implemented depending on the phase of cleanup the site is currently in. For Tier 2 sites, BMPs should be identified and can be further evaluated and compared using the GREEN Tool (Section D.3). For Tier 3 sites, BMPs should be identified then either a) evaluated and compared using the GREEN Tool, or b) an environmental footprint analysis conducted using more complex tools (Section D.4).

Green Remediation BMPs should also be resilient to climate change impacts (e.g., extreme weather events). Decisions about the most appropriate Green Remediation BMPs for your site should also factor in climate change adaptation and remedy resilience using Chapters 1-9 and Appendices A-C of this guidance.

D.2.1 Energy Best Management Practices

The goals of the Energy BMPs are to:

1) Minimize use of non-renewable fuels.
2) Maximize use of green, renewable energy sources.
3) Use local goods and services.
4) Use chemicals and material produced with less energy.
5) Avoid double handling of materials.
6) Minimize overall energy use.

All cleanup activities (i.e., site investigation, construction, and monitoring) use power and fuel, regardless of the type of site. Automobiles, construction vehicles, and vessels are necessary in all phases of cleanup and are typically powered by fossil fuels (e.g., gasoline and diesel). Electricity may be used to power onsite equipment and in energy-intensive remedies such as thermal desorption. Each of these areas provides opportunities to reduce energy use and maximize the use of green energy sources, resulting in cost savings.

Because most electricity in Washington state is produced by hydropower, wind, or solar, it is generally preferred over fossil fuels such as gasoline, diesel, or propane whenever possible. Due to concerns about the impacts of hydroelectric dams on river ecosystems and fish populations, solar and wind power are preferred where available.

D.2.1.1 Best Management Practices - Energy

Remedial Investigations and Monitoring. There are several options for minimizing fossil fuel use and maximizing use of green energy alternatives during remedial investigations and post-remediation monitoring:

- Reduce multiple follow-on investigations to completely characterize a site by using field characterization techniques that efficiently provide sufficient data to develop a comprehensive conceptual site model. For example:
    - Portable field analysis methods for real-time characterization of media.
    - High resolution site characterization tools (e.g., geophysical techniques) and direct push-deployed direct sensing tools (e.g., membrane interface probe, laser-induced fluorescence) to provide better understanding of contaminant distribution.
    - Sediment profile imaging to rapidly identify physical and habitat characteristics of sediments and identify potential areas for chemical and biological testing.
    - Collecting and archiving additional field samples or extra volume for later chemical analysis or biological testing if warranted by first-round results.
    - Feasible alternatives should be determined prior to field activities to inform appropriate data collection. Collect data needed to adequately evaluate the range of alternatives with varying energy intensities, including innovative approaches.
- Reduce the number of trips by conducting multiple activities at the site for each trip.
- Reduce vehicle miles traveled by efficiently staging equipment, carpooling, and using local contractors, goods, and services.
- Avoid traffic congestion.
- Use high-fuel efficient, hybrid, or electric vehicles for trips to and from the site.
- Purchase or rent small solar panels (rather than using fossil fuels) to power electronics, larger equipment, and monitoring devices.

- Transmit data remotely via satellite or data loggers and telemetry, reducing both power requirements and trips to the site.
- Use autonomous devices (e.g., drones) that have a battery source.
- Install dedicated sampling devices to reduce disposable waste generated during each sampling event.
- Use Energy Star-rated equipment.
- To reduce vehicle miles, where appropriate use virtual- or tele-conferencing for meetings and texting or calling for communication with field personnel instead of driving to the site.

Incorporating Green Remediation BMPs into Remedial Alternatives. Evaluate energy availability, including green energy providers, as part of the conceptual site model and consider energy requirements when identifying technologies and developing alternatives. When developing alternatives, consider including technologies that range from energy-intensive to passive treatment systems or other low energy technologies, along with a variety of energy sources that could be used to meet the project needs. Considerations for use of green energy technologies may include:

- Is a long-term remedial action likely to be necessary?
- Do some of the alternatives require high energy consumption?
- Is the site remote or is it otherwise challenging to provide electricity?
- Does the site have the environmental conditions to support solar or wind energy?
- Are there providers of green energy in the vicinity, including alternative sources such as geothermal or biomass (e.g., landfill cogeneration)?
- Does the scale and cost of the cleanup warrant use of alternative energy sources?

Remedial Design. The greater the energy requirements of the selected remedy, the more important it is to optimize the efficiency of the remedial technology to avoid over-use of fuel or energy. Pump-and-treat systems, thermal desorption, air sparging, soil vapor extraction, and multi-component treatment trains are examples of technologies that typically use large amounts of energy.

- For long-term energy-intensive remedies, purchase green energy from electricity providers through programs such as Puget Sound Energy's Solar Choice and Green Energy programs.
- Consider installation of small-scale solar energy at the site to power monitoring or remediation equipment (e.g., pumps, small treatment systems) through purchase or rental of solar energy equipment, whichever is more cost-effective.

- Include energy efficiency requirements in project solicitations and request a detailed plan to reduce energy use from bidders.
- Evaluate treatment system efficiency during the pilot phase and at intervals during operation. For example:
    - Ensure that components of the system are sized properly, and that temperatures and production rates are optimized.
    - Make effective use of insulation, weatherproofing, and energy recovery technologies.
    - For complex, long-term treatment technologies, control systems that automatically respond to changes in environmental or operational conditions may be appropriate.
    - Adjust the operation and/or configuration of the system periodically to reflect changes over time, such as the size of the plume, concentrations of chemicals in soil or groundwater, flow rates, etc.
    - Inspect equipment frequently and ensure that it is in good repair and functioning at specifications.

- Employ pulsed operation and operations during off peak hours.
- Materials required in quantity for construction (such as rock, wood, soil, or riprap) should be obtained as locally as possible to reduce costs, fuel for transportation, and to support the local community.
- Use remotely controlled or monitored systems to address small issues or collect routine reading and reduce trips to the site.
- Use organic fertilizers, instead of synthetic, and organic or re-used soil when planting vegetation.
- Minimize use of plastics—particularly single use—and materials made from ammonia, methanol (e.g., formaldehyde), and petrochemicals; and encourage the use of materials made from chemicals produced with CO_2 as a feedstock (carbon capture).
- Identify a point of diminishing returns at which the energy expenditure is no longer justified by the reduction in area or concentration achieved and consider other alternatives for meeting cleanup standards at that point.

D.2.1.2 GREEN Tool Scoring – Energy

If you are using the GREEN Tool for Tier 2 or 3 sites as described in Subsection D.1.2. and Table D-2, the below table provides suggestions for assigning scores using the GREEN Tool. Scoring of BMPs should be based relative to each other. The site manager may adjust these scoring definitions and the weights given to each category on a site-specific basis.

Score	Definition
1-2	**Very Low:** Incorporates no project or design elements to reduce energy use; uses no green energy sources
3-4	**Low:** Incorporates minor energy savings or green energy use elements into the project or remedial design
5-6	**Moderate:** Incorporates a moderate level of energy reduction or green energy substitution into the project or remedial design
7-8	**High:** Substitutes green energy for most or all fossil fuel energy needs OR includes comprehensive measures to reduce energy use throughout the life of the project
9-10	**Very High:** Substitutes green energy for most or all fossil fuel energy needs AND includes comprehensive measures to reduce energy use throughout the life of the project

D.2.1.3 Environmental Footprint Analytical Tool Scoring - Energy

More complex tools for evaluating technologies and design alternatives with an environmental footprint analysis are available and discussed in Section D.4. For these tools, it should be noted that the scoring and weighting factors for Energy Use can reflect an assumption that the major source of electric power is from coal, natural gas, or other fossil fuels, as is true in much of the United States, although the SiteWise tool (Section D.4) uses statewide averages to represent geographic diversity in emissions related to energy. If you choose to use one of these tools, scoring of the Energy Use category may need to be adjusted positively to reflect the relatively green use of hydroelectric power in Washington state. In addition, the local utility may have information on location-specific emissions.

D.2.2 Air Best Management Practices

The goals of the Air BMPs include:

- Minimize emissions of greenhouse gases.
- Minimize emissions of other air pollutants.
- Use clean fuels and engine technologies.
- Use materials and chemicals that are produced with less air emissions.

The Air BMPs are closely related to energy use—and will have some overlap in practice—so reviewing the Energy BMPs is recommended (Subsection D.2.1). These BMPs address the overall impact of the project on air quality and climate change, which may not always be related to the amount of energy and sources of energy used. For example, these Air BMPs include reducing releases of other air pollutants, such as nitrogen oxides, sulfur oxides, PAHs, volatile organic chemicals, and diesel particulate matter.

Emissions of greenhouse gases (e.g., carbon dioxide, methane) and other air pollutants (nitrous and sulfur oxides, particulate matter) are common at cleanup sites, resulting from trips to the site for monitoring, sampling, and field oversight; construction equipment, vehicles, and generators; dust and particles tracked onto roadways; dredges, tugs, and support vessels; and barge, truck, and rail transportation of import materials to disposal sites. Cleanup of volatile organic compounds in soil or groundwater may also result in emissions of these chemicals to the air. All of these activities provide opportunities to reduce emissions. The minimizing air emissions elements of these BMPs will be most important to consider if the site is located in a community of concern with a vulnerable population(s).

D.2.2.1 Best Management Practices - Air

Remedial Investigations and Monitoring. There are several options for minimizing emissions during remedial investigations and post-remediation monitoring:

- Reduce multiple follow-on investigations to completely characterize a site by using field characterization techniques that efficiently provide large amounts of data. For example:
  - Where soil types and site conditions are appropriate, direct push (e.g., geoprobe) sampling of soil and groundwater and portable field analysis methods for real-time characterization of environmental media.
  - Sediment profile imaging to rapidly identify physical and habitat characteristics of sediment and identify potential areas to sample for chemical and biological testing.
  - Collection and archiving of additional field samples or extra volume for later chemical analysis or biological testing if warranted by first-round results.
- Reduce the number of trips by conducting multiple activities at the site during each trip.
- Reduce vehicle miles traveled, by efficiently staging equipment, carpooling, using local contractors, goods, and services.

- Avoid traffic congestion.
- Use electric, hybrid-electric, or other low-emission vehicles for trips to and from the site.
- Ensure accurate delineation of plumes for design of energy-intensive or emission generating remedies for soil and groundwater volatile organic compounds, ideally using real-time field equipment to detect vapors or target compounds in media at the site. Periodically re-characterize the plume as needed to optimize and adjust the treatment system.

Incorporating Green Remediation BMPs into Remedial Alternatives. When developing alternatives, identify lower-emissions technologies or emissions reduction strategies for remedial alternatives:

- For landfill sites, consider modifications or alternatives to landfill gas flaring, which produces large amounts of methane. BMPs include emissions controls, landfill gas capture and reuse for heat, leachate evaporation, or cogeneration of electricity.
- For upland sites where excavation and landfilling or for sediment sites where dredging and upland disposal are likely to be among the alternatives considered, evaluate whether transportation by barge, truck, or train is likely to result in the least emissions. In general, rail transportation tends to have lower emissions and impacts on the surrounding communities than trucking large volumes of contaminated soil or sediment.
- For sites where clean fill, capping, or bank stabilization materials must be brought to the site, identify local source material to reduce emissions. Plan far enough ahead to coordinate with other projects that may be able to provide clean soil or sediment, such as navigational dredging or development projects.

Remedial Design. To reduce greenhouse gases and other air pollutant emissions during construction:

- Include greenhouse gases and air emissions reduction requirements in project solicitations and request a detailed plan to reduce emissions from bidders which could include performance standards for contractors to meet.
- Plan transportation routes and times to avoid congestion and unnecessary trip miles.
- Transfer only full loads with appropriately size vehicles to conserve fuel.
- Use Energy Star-rated equipment and alternative fuel vehicles. Replace older high-emissions vehicles with electric, hybrid-electric, or other clean fuel vehicles, including dredges and other vessels if available.
- Use appropriately sized equipment (e.g., excavator) to conserve fuel and minimize emissions.
- Use well-maintained vehicles and equipment with exhaust emissions controls and advanced technology. Periodically conduct tire inflation and engine tune-ups, including

cleanliness, lubrication, replacement of filters, and other maintenance that affects fuel efficiency or emissions.

- If using diesel fuel, use clean diesel technologies (see EPA National Clean Diesel Campaign) such as:
    - Ultra-low sulfur diesel (e.g., 15 ppm or less sulfur content), biodiesel, or biodiesel blend (e.g., B20 blend) for all engine types (e.g., trucks, generators).
    - Use vehicles that meet EPA Tier 4 standards (e.g., use advanced diesel technologies such as retrofitting older vehicles with a diesel oxidation catalyst, diesel particulate filter, or selective catalytic reduction).
    - Retrofit non-mobile diesel engines (e.g., air compressors, pumps).
    - Consider other fuel additives that reduce emissions, such as emulsified diesel, cetane enhancers, and fuel-borne catalysts.
- Follow a no-idle or idle-reduction policy during construction activities.
- Use alternative energy sources such as batteries or small solar panels for climate control and to power small appliances (e.g., radio) in vehicles.
- Locate diesel equipment away from the general public and sensitive wildlife or habitat.
- Ensure adequate dust suppression onsite and take measures to avoid tracking contaminated particles offsite (e.g., covering excavated areas with fabric—biodegradable to leave as fertilizer or synthetic for reuse—and spraying limited areas with water.
- Cover all open trucks for hauling and re-use covers to reduce dust from escaping.
- Periodically review the design of volatile organic compound extraction and treatment remedies to avoid release of vapors from the treatment system or vadose zone. The system must be appropriately sized, located, and adapted over time to changes in the location and concentration of the plume, and maintained in good condition to avoid inadvertent loss of vapors.
- Periodically review treatment system efficiency to determine when to switch from high-intensity VOC remedies such as soil vapor extraction or thermal desorption to a passive or “polishing” remedy. Ensure that treatment elements that are no longer needed are appropriately decommissioned to avoid becoming a conduit for VOC release.
- Use other disposal methods instead of incineration.

D.2.2.2 GREEN Tool Scoring - Air

If you are using the GREEN Tool for Tier 2 or 3 sites as described in Subsection D.1.2. and Table D-2, the below table provides suggestions for assigning scores using the GREEN tool. Scoring of BMPs should be based relative to each other. The site manager may adjust these scoring definitions and the weights given to each category on a site-specific basis.

Score	Definition
1-2	**Very Low:** Incorporates no project or design elements to reduce greenhouse gas or air pollutant emissions
3-4	**Low:** Incorporates minor reductions in greenhouse gas or air pollutant emissions
5-6	**Moderate:** Incorporates a moderate level of greenhouse gas and/or air pollutant emissions reductions
7-8	**High:** Minimizes or eliminates most greenhouse gas and air pollutant emissions
9-10	**Very High:** Uses the best available technology and project design to minimize or eliminate greenhouse gas and air pollutant emissions

D.2.2.3 Environmental Footprint Analytical Tool Scoring - Air

More complex tools for evaluating technologies and design alternatives with an environmental footprint analysis are available and discussed in Section D.4. For these tools, it should be noted that the scoring and weighting factors for the Air metric often reflect an assumption that the major source of electric power is from coal, natural gas, or other fossil fuels, as is true in much of the United States. If you choose to use one of these tools, scoring of the Air metric may need to be adjusted positively to reflect the relatively green use of hydroelectric power in Washington state.

D.2.3 Waste and Materials Best Management Practices

The goals of the Waste and Materials BMPs are to:

1. Minimize waste materials generated for disposal.
2. Minimize consumption of raw and virgin materials and use green materials.
3. Recycle or re-use equipment and materials.
4. Use local facilities for waste recycling, reuse, disposal, and treatment.

These BMPs are designed to reduce or eliminate consumption of raw and newly manufactured materials, conserving energy and resources and reducing project costs. In addition, they describe ways to reduce waste—particularly waste destined for disposal—during the remedial investigation, construction, and monitoring phases.

D.2.3.1 Best Management Practices – Waste and Materials

Remedial Investigations and Monitoring. There are several options for minimizing waste and maximizing use of low material production alternatives during remedial investigations and post-remediation monitoring:

- Plan to conduct remedial investigations and monitoring in the fewest field days by combining activities, using real-time field monitoring devices to rapidly characterize the site, and using remote data collection devices. This reduces the amount of personal protective equipment and other non-reusable waste that must be collected and disposed of each day.
- Use steam or non-toxic cleaning fluids to decontaminate field equipment, and sequence activities to prevent cross-contamination and reduce the amount of decontamination required.
- For appropriate soil types and site conditions, use direct-push coring devices rather than drill rigs to collect samples, reducing time spent in the field and eliminating drilling fluids and cuttings.
- Where possible, use passive sampling devices for groundwater to avoid generating contaminated purge water.

Incorporating Green Remediation BMPs into Remedial Alternatives. When developing alternatives, identify waste and material reduction strategies for remedial alternatives:

- For soil or sediment excavation, consider techniques for characterizing and segregating clean material for reuse at the site. Reuse of this material will minimize the amount of imported fill materials required.
- Under Washington State's solid waste and hazardous waste laws, one of the highest priorities for managing waste is to recycle or reuse waste materials. When developing a conceptual site model, identify moderately or lightly contaminated soils that may be eligible for beneficial reuse. For petroleum-impacted soils, consider utilizing the soil reuse categories provided in Ecology's Guidance for Petroleum Contaminated Sites (Publication No. 10-09-057, revised June 2016). For other moderately to lightly contaminated soils, consult with Ecology and local health departments to evaluate acceptable reuse options.
- Consider use of in-situ treatment technologies to minimize the amount of material removed (e.g., contaminated soil, groundwater) during cleanup or imported as part of site restoration. Ensure that a plan is in place to adequately maintain and evaluate the performance of the in-situ treatment system.

Remedial Design. Use of recycled and green materials and waste reduction during cleanup are particularly beneficial, because they minimize the environmental impacts from the cleanup, conserve resources, and can substantially reduce the cost of materials and disposal.

- When deconstructing and/or removing materials from a site, all efforts should be made to recycle or reuse any uncontaminated materials, for example:
    - When buildings, docks, or other structures are to be demolished, identify materials that can be recycled or reused before deconstruction begins. Concrete, rock, wood, brick, metal, and glass materials can often be donated or sold for reuse. For example, clean excavated soil can be sold as fill material or re-used on site or fill or habitat restoration.
    - Clean plant material that is excavated along with soil may be used as soil amendments, recycled at a commercial composting facility, or chipped and staged for reuse.
    - Some cleanups may require removal of organic matter—such as wood waste in sediment—that is relatively clean but problematic in its current environment. This material can be dredged or excavated and reused as mulch or soil amendments.
    - Use plants for restoration that come in recyclable, reusable, or compostable containers.

- Reuse clean materials from another property or obtain local materials at a lower cost, for example:
    - Organic waste materials from a local facility may be useful as mulch, soil amendments, or a substrate for passive treatment.
    - Clean fill or cover material from local construction activities.
    - Beneficially re-using clean dredged material for sediment capping or filling.

- Use recycled materials rather than virgin materials to the extent possible that meet the specified performance requirements for manufactured components of the cleanup or for general use materials such as paper and plastic.
- Use of green materials reduces waste and greenhouse gases during material production (e.g., use concrete with natural pozzolans to reduce the amount of Portland cement)
- Carefully examine the cleanup plan to identify any opportunities to minimize generating and disposing of waste materials, for example:
    - Adaptively manage and frequently review treatment remedies to ensure that they are optimized (e.g., sized properly, to determine when elements of the treatment process can be reduced or eliminated) to save energy and reduce waste.
    - Use filters that can be backwashed or regenerated to avoid disposable filters.

- Use dedicated groundwater pumps, passive samplers, or other sampling technologies that reduce investigation derived waste or disposable sampling equipment.
- Consider natural treatment alternatives (e.g., coconut husks, organic ash, and bioremediation using microorganisms, fungi, or plants).
- Evaluate all chemical reagents to determine whether a less toxic alternative could be used.
- Take all appropriate measures to avoid spills, seepage, or other loss of chemicals to the environment, including frequent inspections of equipment, drums, tanks, and bulk storage areas.
- Recycle general-use materials, such as paper, cardboard, or electronics.
- Minimize the use of plastic or other single-use materials.
- Retain or remodel existing structures to the extent possible.

D.2.3.2 GREEN Tool Scoring – Waste and Materials

If you are using the GREEN Tool for Tier 2 or 3 sites as described in Subsection D.1.2. and Table D-2, the below table provides suggestions for assigning scores using the GREEN Tool. Scoring of BMPs should be based relative to each other. The site manager may adjust these scoring definitions and the weights given to each category on a site-specific basis.

Score	Definition
1-2	**Very Low:** Incorporates no project or design elements to reduce materials consumption or waste generation
3-4	**Low:** Incorporates minor reuse or recycling of materials and waste reduction
5-6	**Moderate:** Includes specific elements designed to reduce the use of raw and virgin materials and minimize wastes
7-8	**High:** Substantially minimizes use of raw and virgin materials compared to other alternatives, and substantially minimizes waste
9-10	**Very High:** Avoids use of virgin products, recycles/reuses all possible materials, produces minimal waste

D.2.4 Water Best Management Practices

The goals of the Water BMPs are to:

1. Minimize freshwater consumption.
2. Recycle water or use reclaimed water.
3. Use low-impact development (LID) to manage stormwater.
4. Use native, drought-resistant plants for landscaping and habitat restoration.
5. Minimize impacts to water quality.

The water conservation elements of these BMPs will be most important to consider in areas experiencing drought conditions, where local water resources are limited, or where water is only available from sources that won't replenish in a reasonable amount of time. Water quality impacts will be important to consider at any site with significant water resources such as surface water bodies, shallow aquifers, or wetlands, particularly sites with natural areas and sensitive aquatic species or impaired water bodies (e.g., 303(d) listed under the Clean Water Act, Section 303(d)). Low-impact development and landscaping considerations are designed to reduce water use, protect water quality, and reduce maintenance costs over the long-term once the site has been remediated.

D.2.4.1 Best Management Practices - Water

Remedial Investigations and Monitoring. There are several options for conserving water and reducing water quality impacts during remedial investigations and post-remediation monitoring:

- For groundwater sampling approaches use passive or low-flow sampling devices to minimize the amount of purge water generated and discharged. Use small-scale field treatment (e.g., activated carbon) to treat contaminated purge water prior to discharge.
- Collect sufficient data on groundwater contamination to appropriately size active treatment remedies, isolate the plume, and/or design passive treatment remedies. Develop an understanding of water availability and water uses in the area and consult with local governments and other water stakeholders to ensure that alternatives can be developed that support groundwater and surface water uses and flows.
- For large sites that may impact local water resources, consider the length of time that may be needed for groundwater remedies and develop a conceptual site model that incorporates a changing water table due to climate change, increased population growth, and local water needs.
- Minimize damage to or removal of vegetation to reach sampling locations, particularly along riparian zones, and shoreline areas. Use portable sampling and coring devices to reach these areas, sample shoreline areas from small boats, or by foot during low tide.

- If vegetation must be removed near streams or water bodies, ensure that erosion control is in place, avoid introducing invasive species, and replant the area once the investigation and/or cleanup is complete.
- Sediment or shoreline soil sampling in areas with petroleum contamination can result in releases to the water. Follow BMPs during sampling to minimize releases to the extent possible and have appropriate containment or cleanup equipment available, such as oil booms and absorbent pads. Immediately report any releases to the appropriate agencies, suspend work, and respond to the release.
- Minimize the use of organic solvents or acids to decontaminate sampling equipment that may come into contact with surface water or groundwater, or where decontamination water may be discharged onsite. Use phosphate-free detergents if decontamination additives are required.

Incorporating Green Remediation BMPs into Remedial Alternatives. When developing alternatives, identify strategies for remedial alternatives that reduce the amount of water used and reduces potential to impact water quality:

- For groundwater or soil VOC treatment processes that result in clean effluent, consider reinjection of groundwater into aquifers, recharging through wetlands, or supplementing stream flows rather than discharges to sewer or stormwater systems. Alternatively, treated water may be used for applications such as landscape watering, dust suppression, or other graywater uses.
- Ensure that the chemistry, temperature, pH, and redox conditions of the treated effluent are appropriate for the intended use or discharge. If discharged into groundwater, ensure that effects of the reinjection on the water table, vadose zone, and groundwater plume are understood and appropriate.
- Consider passive treatment systems to modify the pH and metals availability in waters derived from mining or metals impacted areas. Ensure that a plan is in place to adequately maintain and evaluate the performance of these treatment systems.
- If stormwater management will be a long-term feature of the final design for cleanup, consider alternatives that incorporate low impact development features such as swales, ponds, rain gardens, wetlands, and pervious concrete and roadway materials for stormwater capture, treatment, and recharge.

Remedial Design. Use of water conservation and water quality measures during cleanup are particularly beneficial, because they minimize the potential water quality impacts from the cleanup and protect water resources:

- In areas with limited water resources and sole source aquifers, evaluate the potential impacts of groundwater pump-and-treat systems on local aquifers, water supply, and

adjacent stream flows. Have adequate contingency plans if any of these water uses are impacted over the short- or long-term. Consider potential population increases over the anticipated lifetime of the project and increased water needs for municipal, agricultural, or industrial uses during periods of drought.

- Where water resources are limited in particular, consider additional polishing steps to allow treated effluent to be used for a variety of applications or recharged into the environment.
- Use periodic groundwater treatment system evaluations and an adaptive management approach to ensure the remedy is optimized to reflect the current size, location, and groundwater concentrations. Identify a point at which diminishing returns are being reached to determine whether a passive treatment approach or natural attenuation may be appropriate to reach cleanup standards.
- When working in or near water bodies, carefully follow all BMPs and permit conditions designed to prevent releases and excessive turbidity to the water. Use oil booms, silt curtains, or other containment devices as needed to minimize the area of impact. Follow an appropriate, ideally real-time water quality monitoring plan during construction and stop work if unanticipated impacts to water or aquatic life are observed.
- Apply the BMPs described in the remedial investigation part of this section regarding vegetation removal/restoration. Use native and drought-resistant plantings and landscaping and ensure maintenance is conducted annually until the restored habitat is fully established.
- To conserve water resources, use non-potable water (e.g., rainwater, gray water) for landscape maintenance, dust suppression, etc. Additionally, use biodegradable fabrics to cover excavated or bare soil which can remain and act as slow-release fertilizer post-construction.

D.2.4.2 GREEN Tool Scoring - Water

If you are using the GREEN Tool for Tier 2 or 3 sites as described in Subsection D.1.2. and Table D-2, the below table provides suggestions for assigning scores using the GREEN Tool. Scoring of BMPs should be based relative to each other. The site manager may adjust these scoring definitions and the weights given to each category on a site-specific basis.

Score	Definition
1-2	**Very Low:** Incorporates no project or design elements to conserve water or protect water resources
3-4	**Low:** Incorporates minor water conservation measures and minimum BMPs for protecting water resources
5-6	**Moderate:** Includes specific elements designed to reduce water use and prevent impacts to water resources
7-8	**High:** Substantially reduces water use compared to other alternatives, minimizes discharges to water resources, and includes appropriate landscaping/LID elements
9-10	**Very High:** Avoids significant water use, recycles/reuses all water used, prevents discharges to water resources, and includes appropriate landscaping/LID elements

D.2.5 Land and Ecosystems Best Management Practices

The goals of the Land and Ecosystems BMPs are to:

1. Create and restore functional habitat.
2. Maintain and protect existing functional habitat.
3. Minimize disturbances to the community such as noise, odor, emissions, and light.

The Land and Ecosystems BMPs are designed to minimize the impacts of cleanups on natural habitats and functioning ecosystems, to integrate habitat restoration considerations into the design of cleanups, and lessen the impact on the community from construction activities. These activities are considered independent of mitigation required by permit conditions or restoration associated with natural resources damages, although they may be integrated with any such activities. The resulting natural landscape provides improved habitat and benefits to wildlife and natural resources and may increase property values and provide amenities to the surrounding community. Natural habitat can also serve in a functional capacity to filter stormwater, sequester carbon, promote passive remediation, stabilize soils and constructed caps and banks, and reduce long-term maintenance costs. The habitat restoration and minimizing disturbances

elements of these BMPs will be most important to consider if the site is located in a community of concern with a vulnerable population(s).

D.2.5.1 Best Management Practices – Land and Ecosystems

Remedial Investigations and Monitoring. Remedial investigations can further this BMP by developing a conceptual site model that provides a clear understanding of the current and potential future ecological amenities of the site:

- Identify areas that have functional habitat such as streams, riparian zones, wetlands, forested areas, shellfish or eelgrass beds, feeder bluffs, and natural grasslands. If present, identify the ecological and human services these habitats provide, their current degree of impairment, and their potential to sequester carbon (e.g., blue carbon habitat such as a saltwater marsh).
- Identify the risks that existing contaminants pose to species at or near the site and impacts that may be associated with remedial actions, which can inform development of remedial alternatives, remedial design, and construction.
- Identify disturbed areas that could be restored consistent with future land use plans. This is important if there are high-value functioning habitats at or near the site that could be connected or increased in size.
- Identify ecological amenities that the community may wish to see at the site as a result of or following cleanup and take them into consideration during remedial design.
- Prior to beginning field work, identify sensitive or natural areas of the site and plan investigations to avoid damaging them. For example:
    - Consider the timing of field investigations to avoid when species may be particularly vulnerable, such as nesting, fish migration, or spawning periods.
    - Avoid destruction of functional habitat to conduct sampling. Use less invasive field methods where possible, such as using hand coring devices rather than drill rigs.
    - If an area is free of invasive species and represents high-quality habitat, take measures to avoid introducing invasive species to the area during sampling.
    - Use already disturbed areas for staging and storage areas and confine vehicular traffic to these areas to the extent possible.
    - Obtain all required permits for work in wetlands, streams, and other aquatic areas and consult with the appropriate agencies to determine best practices.
- In high-value habitats, collect information needed to evaluate whether passive or less invasive alternatives are likely to be successful at the site. This information will vary with the types of alternatives that could be considered, but may include geochemical information, accurate delineation of plumes and low- vs. high-concentration areas, and

any environmental variables that may affect the rate of degradation or attenuation in the environment.

Incorporating Green Remediation BMPs into Remedial Alternatives. For sites with high concentrations of contaminants in otherwise functional habitats, there may be no alternative but to remove or contain highly contaminated soil and sediment that poses a substantial risk to the environment and human health. In these cases, remedial alternatives may include elements to reestablish habitat onsite or compensatory habitat offsite following remediation, depending on the future use of the property.

For natural areas with lower levels of contamination, less invasive remedies may be appropriate and may be considered among the alternatives evaluated. For example:

- Removal of hot spots and source materials, followed by natural attenuation.
- In situ remediation alternatives, such as thermal desorption, soil vapor extraction, bioremediation, reactive barriers, or other passive remediation systems.
- Monitored natural recovery or enhanced monitored natural recovery for sediments.

In each of these cases, the potentially longer timeframe to reach cleanup standards is considered alongside the benefits of limiting short-term damage to existing habitat, and the degree of difficulty in restoring or replacing the habitat following an invasive remedy. For example, if the site is currently disturbed and contains invasive species and can be remediated over a short timeframe followed by establishing native, drought-resistant plantings, there may be little benefit to retaining the existing habitat during construction. Similarly, if future plans include permitted development, habitat considerations may not be important. However, if a sensitive, high-value, functional habitat is present at or near the site and there is an opportunity to preserve or enhance it, less invasive remedial alternatives would be appropriate to include among the options.

Remedial Design. BMPs for remedial design and construction may include:

- Similar to field investigations, develop a construction plan to avoid damaging sensitive habitat areas that will remain intact or will be minimally disturbed as part of the remedy. This may include:
    - Establishing zones at the site for vehicular traffic, storage, and staging away from sensitive areas.
    - A plan to avoid introduction of invasive species to natural habitats.
    - Stormwater and dust control BMPs.
    - Awareness of and planning around sensitive habitats and seasonal issues.
    - Minimization of light, noise, and general disturbance of sensitive species or habitats.

  - Remedial design sampling to update concentrations and spatial information prior to final design to minimize the footprint of construction activities or hydraulic containment.

- Use low impact development approaches to minimize impervious areas and runoff.
- If areas of the site will include landscaping or habitat restoration following cleanup:
  - Use native and drought-resistant plants appropriate to the area that will provide natural and resilient habitat and not require excessive watering, fertilization, or other interventions to maintain long-term.
  - Use species that will provide functional benefits, such as erosion control, to the selected remedy and surrounding areas.
  - Avoid species that may compromise constructed remedy elements (e.g., caps).
  - Design and build habitat that will sequester carbon (e.g., wetlands, estuaries, forests, grasslands).
  - To the extent possible, select landscaping or habitat that integrates with surrounding areas to provide habitat corridors and rapid recolonization of the site.
  - Use soil or sediment types that will best support native plants and wildlife, such as soil amendments to promote plant growth or appropriate grain size for aquatic habitat. Avoid overly compacting the soil in areas that will be planted.
  - Implement a maintenance plan until the plantings or habitat are well-established and resilient, and include monitoring, measures of success, and contingencies.

- To minimize disturbance to the community, consider the following:
  - Design a traffic pattern for efficient on-site movement of large equipment and passenger vehicles that reduces traffic congestion and access to throughways or businesses for vehicles or pedestrians.
  - Follow local noise and light ordinances and minimize after hours on-site activities that require use of light or make noise.
  - If night-time lighting is necessary, install shields that direct light downwards.
  - For above ground longer term housing of equipment (e.g., vapor extraction), install sound proofing to minimize noise.
  - Install mufflers on loud equipment.
  - It is important to maximize use of these BMPs if the site is located in a community of concern with a vulnerable population(s).

D.2.5.2 GREEN Tool Scoring - Land and Ecosystems

If you are using the GREEN Tool for Tier 2 or 3 sites as described in Subsection D.1.2. and Table D-2, the below table provides suggestions for assigning scores using the GREEN Tool. Scoring of BMPs should be based relative to each other. The site manager may adjust these scoring definitions and the weights given to each category on a site-specific basis.

Score	Definition
1-2	**Very Low:** Results in significant disturbance of soil, water, or habitat and incorporates no restoration activities.
3-4	**Low:** Incorporates BMPs to prevent unnecessary disturbance and meets minimum permit requirements for mitigation.
5-6	**Moderate:** Includes specific elements designed to reduce disturbance of environmental media and restores natural elements of the site to at least their pre-existing condition.
7-8	**High:** Prevents disturbance of natural habitat during remediation compared to other alternatives and includes restoration of disturbed areas to at least their pre-existing condition.
9-10	**Very High:** Prevents disturbance of existing habitat to the greatest extent possible and includes restoration or creation of new habitat that provides significant amenities beyond the original condition of the site.

D.3 GREEN Tool for intermediate or complex sites

This section explains Step 2 for Tier 2 or 3 sites (Section D.1.2), which allows the user to site-specifically evaluate the efficacy of different Green Remediation BMP scenarios using the GREEN Tool. Different scenarios may be developed for a remedial alternative—which includes different Green Remediation BMPs—then evaluated using the GREEN Tool to narrow down the most effective or appropriate BMPs for the site. The GREEN Tool can be used for any site but is recommended for either Tier 2 or 3 sites. It can be used at different stages of cleanup. For example, after the applicable BMPs have been identified, while remedial alternatives are first being developed, and/or after the preferred remedy is selected during remedial design. The GREEN Tool allows the user to tailor the BMPs site-specifically to:

1. Score the identified BMPs (Section D.2) based on their environmental benefits.

2. Site-specifically fine-tune BMPs to achieve the highest environmental benefits score.

3. Develop Green Remediation BMP scenarios (such as remedial investigation approaches, remedial alternatives, or remedial designs) that mix and match BMPs for use at your site.

4. Compare different Green Remediation BMP scenarios to determine the most appropriate one for your site.

5. Compare Green Remediation BMP scenarios to those without BMPs to understand the relative benefits.

The GREEN Tool is a series of spreadsheets organized by the Green Remediation metrics in Section D.1 (e.g., Energy). For each metric, BMPs are listed as broad categories and specific BMPs can be selected. The user has the option of completing a spreadsheet for different Green Remediation BMP scenarios for relative comparison and to one or more scenarios that do not include these BMPs. This may make the decision-making process more effective and efficient and provide the cleanup project manager information to justify the chosen scenario. Once the Green Remediation BMP scenarios are added to the spreadsheet, they can be scored as follows:

1. The goals under each metric are scored from 1 to 10:
    a. 1 to 2 = Very low environmental benefits
    b. 3 to 4 = Low environmental benefits
    c. 5 to 6 = Moderate environmental benefits
    d. 7 to 8 = High environmental benefits
    e. 9 to 10 = Exceptional environmental benefits

    Notes can be entered to provide support for the assigned scores. More information to assist in assigning GREEN Tool scores is provided in Sections D.2.1 – D.2.5 for the Green Remediation metrics (e.g., Energy).

2. Each metric is weighted (1 – 100) based on the cleanup project manager's best professional judgement. For example, if a site is in an area prone to severe drought, water conservation BMPs may be weighted more heavily than others. Default weights are provided for the metrics but may be revised by the site manager.

3. The weighted scores for the individual metrics are automatically added together to provide a total score for each scenario.

4. The scores for the various scenarios are then automatically compiled and presented on a summary worksheet for review.

In addition, the GREEN Tool provides information to help identify the "greenest" BMP scenarios when comparing scenarios with similar costs and can show differences in costs. For example, using BMPs to improve fuel efficiency will save fuel costs and minimizing production of waste

materials and recycling/reusing waste materials will save landfill tipping fees and fuel costs for transport to landfills.

When evaluating Green Remediation BMPs using the GREEN Tool, resiliency to climate change impacts should also be considered. Chapters 1-9 and Appendices A-C of this guidance can be used to 1) determine specific vulnerabilities to climate change for your site and 2) incorporate resiliency into remedies.

To access the GREEN Tool, go to Ecology's publication page www.fortress.wa.gov/ecy/publications and search for publication no 17-09-052.

D.4 Environmental footprint analytical tools for Tier 3 sites

This Section explains Step 4 in Section D.1 and includes references to other tools that allow the user to conduct an in-depth environmental footprint analysis. These tools are highly detailed and are most appropriate for very large and complex sites on the scale of a large Superfund site (e.g., Lower Duwamish Waterway or Hanford). To effectively use these tools, the user needs to be experienced, have extensive time to learn the technical details and how to interpret the results, or hire an experienced user. They include the following:

- Spreadsheets for Environmental Footprint Analysis (SEFA). SEFA was developed by the EPA for use at large and complex Superfund sites. It is a sophisticated and highly effective tool that allows the user to fully analyze each BMP to quantify and understand all aspects of Green Remediation (e.g., CO_2 emissions, NOx/SOx emissions, energy conserved). It includes detailed instructions, and a number of instructional PowerPoint presentations are available on EPA's CLU-In website.
- SiteWise. This tool was developed by the U.S. Navy and U.S. Army Corps of Engineers. The tool is a series of Excel spreadsheets that can be used to conduct a baseline assessment of several quantifiable sustainability metrics (energy, greenhouse gas emissions). It also includes the ability to calculate incremental cost due to environmental footprint reduction activities.

D.5 Additional green remediation resources and references

This section contains additional resources for green and sustainable remediation prepared by federal agencies, consultants, and technical groups. They may be useful if a site manager needs to understand a specific Green Remediation BMP in greater detail or is interested in a wider variety of BMPs than this appendix provides.

- Superfund Green Remediation Strategy (EPA 2010). This guidance was developed by EPA to summarize green remediation goals and key actions for the Superfund Remedial Program. It provides policy and guidance for site managers to ensure that green cleanup strategies are considered during cleanup of Superfund sites. It can be

implemented in all phases of the cleanup process, including preliminary assessment, remedial investigation, remedial design, remedial action, short- and long-term remedy monitoring and operations, and periodic reviews.

- Clean and Green Policy for Superfund, RCRA, LUST, and Brownfields Sites (EPA 2009). This policy aims to promote green practices for federal cleanup programs by encouraging their use in state-authorized cleanup programs. Green remediation practices outlined in this policy are:
    a. Using renewable energy
    b. Conserving water
    c. Using cleaner fuels
    d. Reusing and recycling materials
    e. Recovering methane from landfills
    f. Reducing greenhouse gas emissions
    g. Implementing waste reduction programs at all work sites.

- EPA Green Remediation Fact Sheets. These provide valuable and more detailed recommendations related to specific types of cleanup sites and technologies:
    a. Bioremediation. Green Remediation BMPs for Bioremediation. Publication No. 542-F-10-006, March 2010.
    b. Clean Fuels. Green Remediation BMPs for Cleanup Fuel and Emission Technologies for Site Cleanup. Publication No. 542-F-10-008, August 2010.
    c. Excavation. Green Remediation BMPs for Excavation and Surface Restoration. Publication No. 542-F-08-012, August 2019 (updated).
    d. In Situ Thermal. Green Remediation BMPs for Implementing In Situ Thermal Technologies. Publication No. 542-F-12-029, October 2012.
    e. Landfills. Green Remediation BMPs for Landfill Cover Systems and Energy Production. Publication No. 542-F-11-024, December 2011.
    f. Mining. Green Remediation BMPs for Mining Sites. Publication No. 542-F-12-028, September 2012.
    g. Monitoring. Green Remediation BMPs for Site Investigation and Environmental Monitoring. Publication No. 542-F-16-002, September 2016 (update).
    h. Pump and Treat. Green Remediation BMPs for Pump and Treat Technologies. Publication No. 542-F-09-005, December 2009.
    i. Renewables. Green Remediation BMPs for Integrating Renewable Energy into Site Cleanup. Publication No. 542-F-11-003, April 2011.

j. Soil Vapor Extraction. Green Remediation BMPs for Soil Vapor Extraction and Air Sparging. Publication No. 542-F-10-007, March 2010.

k. Underground Storage Tanks. Green Remediation BMPs for Underground Storage Tanks. Publication No. 542-F-11-008, August 2019 (updated).

l. Waste Management. Green Remediation BMPs for Materials and Waste Management. Publication No. 542-F-12-003, December 2013.

- Encouraging Greener Cleanup Practices through Use of ASTM's International's Standard Guide for Greener Cleanups (EPA Memorandum December 23, 2013).
- American Society for Testing and Materials (ASTM) Publications:
  - Standard Guide for Incorporating Sustainable Objectives into Cleanup, E2876 (2013). This guidance presents a broad framework for incorporating social, economic, and environmental aspects into a cleanup to make it more sustainable.
  - Standard Guide for Greener Cleanups, E2893 (2016a, b). This guidance is more widely used and outlines a process for evaluating and implementing green cleanup activities at cleanup sites in the United States and reduce a cleanup's environmental footprint. The Greener Cleanups guide describes how to evaluate and implement best management practices and perform a quantitative assessment of the cleanup.
- GSR-2: Technical/Regulatory Guidance, Green and Sustainable Remediation: A Practical Framework (Interstate Technology and Regulatory Council (ITRC 2011). This guidance was prepared to help integrate green and sustainable cleanup into existing investigation and cleanup projects. The guidance presents a framework for performing green and sustainable cleanup applicable to any cleanup site, and includes particularly informative case studies, decision tools, resources, and contacts.
- Greener Cleanups Guidance WAC #14-150 (2014). This is the state of Massachusetts' green remediation guidance. It includes a discussion of the state's regulations which provide the regulatory authority to implement green remediation. It also includes detailed recommendations on how to use applicable parts of the ASTM Standard Guide for Greener Cleanups to meet state-specific remediation needs.
- Greener Practices for Business Site Development and Site Cleanups: A Toolkit. This is the state of Minnesota's green remediation guidance. It includes 15 options to implement greener practices in the remediation process, development and renovation, and business practices in the form of a decision tree.
- Green Remediation Practices (2018). This is the state of Arizona's green remediation guidance. It is web-based guidance and includes recommendations at different stages of cleanup and types of remedies.

- Interim Advisory for Green Remediation (2009). This is the state of California's guidance on how to implement green remediation and includes a green remediation evaluation matrix to evaluate options and conduct a life cycle analysis.
- Greener Cleanups. This is a web-based guidance for the state of Illinois to implement green remediation. It includes a matrix of best management practices that focus on air, land, water, and energy impacts.
- Sustainable Remediation Forum (SURF). This is a non-profit organization that promotes using sustainable practices to clean up contaminated sites with the objective of maximizing environment, societal, and economic benefits. The SURF website (www.sustainableremediation.org) includes information on case studies and guidance resources.

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Importantly, Ecology recognizes the EPA, ASTM, and ITRC guidance as valuable resources on green remediation. These resources were significantly relied upon to develop this Appendix.

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Appendix E:
Summary of Guidance Revisions

This appendix provides a record of revisions made to this Sustainable Remediation guidance since the 2017 publication, which was originally titled *Adaptation Strategies for Resilient Cleanup Remedies*. In January 2023 the guidance was revised to include green remediation which is included as Appendix D. The title then changed to *Sustainable Remediation: Climate Change Resilience and Green Remediation. A guide for cleanup project managers to 1) assess vulnerabilities and increase resiliency of cleanup remedies to climate change impacts and 2) reduce environmental impacts from the cleanup process*.

Table E-1: Summary of the revisions made to this Sustainable Remediation guidance in 2023.

Chapter	Brief Summary of Revisions
Title	Changed the title of the guidance to *Sustainable Remediation: Climate Change Resilience and Green Remediation. A guide for cleanup project managers to 1) assess vulnerabilities and increase resiliency of cleanup remedies to climate change impacts and 2) reduce environmental impacts from the cleanup process*.
Executive Summary	Incorporated the green remediation concept. Defined sustainable remediation as climate change resilience and green remediation.
Introduction	Incorporated the concept of green remediation and defined sustainable remediation to include climate change resilience (vulnerability assessment and adaptation strategy) and green remediation (best management practices).
Figures	Updated figures added in Chapter 2. A separate section for figures was removed. Figures are embedded with the appropriate chapters.
Acknowledgements	For this Sustainable Remediation guidance, the Climate Change Resilience part includes Chapters 1 – 9, and Appendices A – C. While the primary author is the same, some of the contributing authors and reviewers differ from the Green Remediation part in Appendix D.
Glossary	Added definitions for sustainable remediation and green remediation specific to Washington state and this guidance.
Chapter 2	Updated the environmental trends and climate change projections based on best available science published after 2017.
Appendix D	Added green remediation guidance.
Appendix E	Added this appendix to record revisions to the original 2017 guidance.

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