Technical/Regulatory Guidance

Sustainable Resilient Remediation (SRR)

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Extreme weather events and wildfires are increasing and could impact hazardous waste sites and undermine the primary goal of cleanups, which is protecting human health and the environment. Confronted with these risks, assessing and designing remedies with decades-long time frames should be reevaluated. Sustainable resilient remediation (SRR) is an optimized solution to cleaning up and reusing a hazardous waste site that limits negative environmental impacts, maximizes social and economic benefits, and creates resilience against increasing threats.

The objective of this SRR guidance is to provide resources for regulators, stakeholders, consultants, and responsible parties to help integrate sustainability and resilience practices into remediation projects. This guidance updates the Interstate Technology and Regulatory Council's (ITRC) Technical and Regulatory Guidance: Green and Sustainable Remediation: A Practical Framework (ITRC 2011a) and includes a strong resilience component to address the increasing threat of extreme weather events and wildfires. Recommendations for careful and continuous consideration of the social and economic costs and benefits of a cleanup project are included.

In the context of cleaning up contaminated sites, sustainability and resilience can be thought of as two sides of the same coin: while sustainability considers the remedy's impact on the environment, resilience considers the environment's impact on the remedy. This distinction is not so simple. To be truly sustainable, a remedy must maintain functionality for the duration of its design life and do so by being resilient to extreme events and changing conditions. The interconnectedness of sustainability and resilience, particularly as they relate to the cleanup of contaminated sites, reemphasizes the importance of an integrated approach.

This SRR guidance presents the following lessons learned and resources:

- answers to frequently asked questions about SRR
- a summary of the state survey performed about SRR, including opportunities and barriers
- an online map with links to available state and federal resources to quickly find examples and best practices from your state or other states and federal agencies
- expanded information about and resources for the social and economic dimensions of sustainability, including state-of-the-art social and economic evaluation tools
- an updated framework that illustrates how and why sustainability and resilience should be integrated throughout the remedial project life cycle
- checklists of key sustainable best management practices to address resilience based on specific vulnerabilities at a site as well as resources for additional information
- case studies illustrating the application of SRR considerations
- a list of recommendations for the future

1. Introduction

Extreme weather events and wildfires are increasing with the potential to impact hazardous waste sites and undermine the goal of cleanup—to protect human health and the environment. Confronted with these newly realized risks, the convention of assessing and designing remedies that require years of operation or monitoring beyond initial remediation construction should be reassessed. Sustainable resilient remediation (SRR) is an optimized solution to cleaning up and reusing hazardous waste sites that limits environmental impacts, maximizes social and economic benefits, and creates resilience against the increasing threat of extreme weather events, sea-level rise, and wildfires.

This guidance is an update of ITRC's *Technical and Regulatory Guidance: Green and Sustainable Remediation: A Practical Framework* (*ITRC 2011a*) *and* includes a strong resilience component to address the increasing threat of extreme weather events, sea-level rise, and wildfires. The new guidance recommends a careful and continuous consideration of the social and economic costs and benefits of a cleanup project on equal footing with environmental costs and benefits.

This SRR document is intended to apply to any remediation program. It can be used by state regulators, federal employees, and the private sector, including consultants and industrial and commercial companies. This document can also be used by remediation industry stakeholders, including communities, local organizations, advocacy groups, and nongovernmental organizations. This SRR guidance may be used in part or in its entirety. It may be used for a particular phase of a project or applied to the entire project life cycle. It is not intended to supplant any regulatory requirement. Any user may concur with this document, but it may not comprehensively align with existing guidance due to variations in existing rules and statutes across different regulatory cleanup programs.

In the context of cleaning up contaminated sites, sustainability and resilience can be thought of as two sides of the same coin: while sustainability considers the remedy's impact on the environment, resilience considers the environment's impact on the remedy. But this distinction is not so simple. To be truly sustainable, a remedy must maintain functionality for the duration of its design life and do so by being resilient to extreme events and changing conditions. The interconnectedness of sustainability and resilience, particularly as they relate to the cleanup of contaminated sites, reemphasizes the importance of an integrated approach.

Many lessons have been learned in the nearly 10 years since ITRC's green and sustainable remediation (GSR) guidance was published. This new SRR guidance, which leverages many of these lessons learned, is organized into the following sections.

Section 2: Importance and Value of SRR – Section 2 addresses the evolution of environmental remediation to SRR, provides a brief overview of how sustainable remediation was first integrated into remediation, introduces important attributes to be considered in resiliency, summarizes case studies in SRR to provide readers context of how SRR has been implemented, and answers frequently asked questions related to the value and misperceptions of SRR. Overall, this section will help practitioners understand the benefits of implementing SRR, visualize benefits, and help convey to project stakeholders the importance and value of implementing SRR.

Section 3: Perspectives – This section assesses state survey results and is a policy developer's how-to guide, highlighting opportunities to implement SRR in state programs. It also provides insight into SRR options at private-party sites; approaches of various federal government branches and public and tribal stakeholders; and provides an overview of ASTM International's (ASTM) SRR-related guidance. Practitioners (for example, owners, consultants) planning to conduct investigation or cleanup of contaminated sites can use this resource to gain an overview of the tools available to guide their planning, design, and implementation.

Section 4: State Resource Map – This section provides fingertip access to the building blocks of SRR, climate resilience, showcasing state programs around the United States. Within each layer, state resources are categorized by type with a link to program-specific resources, including but not limited to legislation, gubernatorial actions, policy, and guidance. This resource map will quickly guide practitioners to state-specific SRR resources and relevant options in each state.

Section 5: Advancing the Practice: Social and Economic Dimensions of Sustainability and Resilience – This section focuses on the importance of considering the social and economic impacts of remediation on communities and discusses environmental justice, linking desired outcomes to metrics or progress indicators, and incorporation of resilience into brownfield sites. This section also proposes three different evaluation levels to be considered when assessing the social and economic dimensions of SRR. These topics, along with a discussion of ecosystem services, will help readers to better understand the social and economic dimensions of SRR so these attributes can be better integrated into cleanup projects.

Section 6: Integrating Resilience and Sustainability into the Remedial Project Life Cycle – The section provides an interactive view of the remediation project life cycle, the various components integral for successful completion, and recommendations on how SRR can be implemented in specific project life-cycle phases, starting with project planning and moving through site characterization; remedy planning; implementation; operation, maintenance, and monitoring (OM&M); and site closeout. Like Section 5, this section proposes use of three scalable evaluation levels when integrating SRR into the project life cycle.

Section 7: Key Sustainable Best Management Practices – This section identifies important sustainable best management practices (SBMPs), key resources, and additional considerations for evaluating, implementing, and maintaining resilience to extreme weather and wildfire events at a remediation site. Response considerations and actions are also included. SBMPs are effective and practical methods or techniques to build or adapt a sustainable and climate impact–resilient environmental remediation site. SBMPs are an integral part of SRR. SBMPs are organized by type of extreme event. SBMPs are provided for a number of weather-related events, including wind, snow and hail, fluctuating groundwater levels, flooding, bank and shoreline erosion, wildfires, sea-level rise, evapotranspiration, storm surge, and permafrost thaw. This section will help readers understand different management practices that can be implemented to make projects more resilient and sustainable. A tool is included that can be used to create a site-specific summary of SBMPs and document whether specific SBMPs are applicable, prioritize SBMPs, and track implementation.

Section 8: Recommendations for the Future – In discussion with the members of the Sustainable Resilient Remediation Team as to what areas they believed could use further research, several topics were indicated.

Qualifier for the Superfund Program – During the course of developing this guidance, several workgroup team members and stakeholders have commented on how sustainability and resiliency are included in some regulatory cleanup programs, to varying degrees. For example, the U.S. Environmental Protection Agency (USEPA) provided the following comment on the document:

Superfunds position is on the guidance: Remedy decisions need to be made in the context of the regulatory scheme within which the remedy is being conducted. For example, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, aka Superfund) program has a defined regulatory process, and consideration of sustainability is already woven into remedy selection, design, and operations. Remedies may often be implemented in ways that factor insocial, and economic, and environmental footprint perspectives. For example, remedy decisions consider remedy cost and reasonably anticipated land use as part of the alternatives development and remedy selection. Consideration of the environmental footprint was outlined in the 2016 guidance on Consideration of Greener Cleanup Activities in the Superfund Cleanup Process. Community acceptance, which is considered in remedial alternative analyses, may also contribute more expansive concepts social and economic perspectives to the remedy selection process under CERCLA, and the 2020 Superfund Community Involvement Handbook (found at: https://www.epa.gov/superfund/superfund-community-involvement-tools-and-resources) provides a robust framework to engage communities consistent with CERCLA requirements and processes.

This document will be valuable complement to USEPA's Superfund guidance, as it pertains to sustainability and resiliency. The authors of this document recognize that there are numerous regulatory cleanup programs that may not fully address the sustainability and resilience elements. This document will provide, or complement, other existing cleanup program guidance on implementing sustainability and resiliency into cleanup projects.

Nomenclature – A brief note on nomenclature used in this document: SRR is inclusive of "green remediation," "sustainable remediation," "green and sustainable remediation (GSR)," and "resilient remediation." The SRR term was developed in the course of preparing this guidance document and was developed to consolidate the above four terms. This document will use these four terms that can be considered to collectively represent SRR when citing previous documents or describing a unique component of one of the four terms. For example, the term "greener cleanup BMPs" in Table 5-3 refers to specific BMPs associated with green remediation.

2. Importance and Value of Sustainable Resilient Remediation

This section provides the following:

- background and context on evolution to and value of SRR
- brief overview of the history of hazardous waste cleanup and the importance of GSR
- climate change impacts from extreme weather events, sea-level rise, and wildfires to the integrity of environmental remediation solutions and, in turn, the public health and environment of the surrounding communities
- case study matrix that summarizes projects where SRR has been implemented
- frequently asked questions (FAQs) about misperceptions and the value of SRR that prove the case for using SRR, along with references to case studies

2.1 Evolution of Environmental Remediation to SRR

Approaches to cleaning up contaminated sites became more standardized in the United States following the establishment of transformative federal regulations (and subsequent state regulations) governing their remediation. Since the early days of site cleanup activities, the remediation industry has progressed through several cycles representing different approaches for achieving cleanup objectives (Figure 2-1).

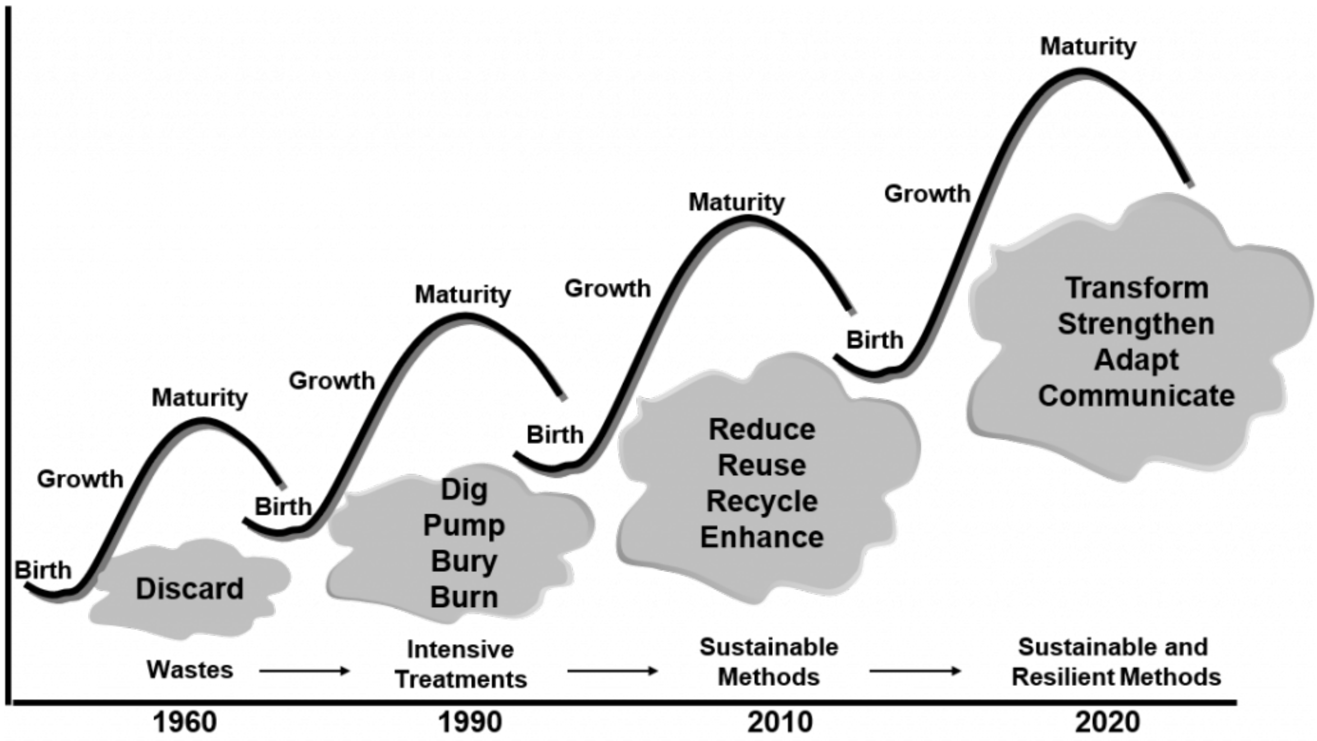


Figure 2-1. Evolution of environmental remediation to SRR.

Source: Adapted from Ellis and Hadley (2009).

Until recently, the development of remedial approaches relied mostly on a static site characterization (for example, current and historical groundwater elevations, flow directions, precipitation rates) that reflected conditions at a single point in time. Conceptualsite models (CSMs) have generally placed more emphasis on how past site activities created current site conditions, and little attention on what could happen at a site in the future.

Since 2000, cleaning up contaminated sites has generally consisted of a risk-based approach while maintaining the primary objective of protecting human health and the environment. As a result, many contaminated sites are being addressed through long-term management (for example, institutional and engineering controls, land-use restrictions, hydraulic control, source containment, passive treatment, monitoring, and natural attenuation) rather than resource-intensive, active source removal. In long-term management, protecting human health and the environment is not a static objective to be achieved, but a condition that must be maintained throughout the lifespan of the remedy.

2.1.1 Introduction of Sustainability Principles and Practices

When introduced in 2008, GSR was a fresh look at how to best manage environmental assessment and remediation to maximize the benefits of such efforts. The integration of sustainability practices into remediation was launched through a series of seminal guidance documents published between 2008 and 2011:

- USEPA published Green Remediation: Incorporating Sustainable Practices into Remediation of Contaminated Sites in 2008 (USEPA 2008).

- The Sustainable Remediation Forum (SURF) published a sustainable remediation white paper in 2009: Sustainable Remediation White Paper—Integrating Sustainable Principles, Practices, and Metrics into Remediation Projects (SURF 2009).
- ITRC published Overview Document: Green and Sustainable Remediation: State of the Science and Practice□□□ in May 2011 (ITRC 2011b) and Technical and Regulatory Guidance: Green and Sustainable Remediation: A Practical Framework in November 2011 (ITRC 2011a).

The above documents not only provided guideposts on what was considered practical for implementation based on general industry stakeholder acceptance, they provided industry with tools and practices that could be applied. These tools and practices place as much emphasis on ensuring sustainability in the *process* of cleanup as they do in the long-term impacts of the remedy. GSR is not a means of justifying a less effective remedial action, but instead a case for weighing the additional measures of environmental, social, and economic effectiveness alongside remediation potential at all stages. The *intentionality* of considering these GSR elements is its key distinguishing feature.

Many lessons have been learned about GSR (for example, the importance of stakeholder engagement), the science has advanced (social and economic impact evaluations), and new tools have emerged since the ITRC published its guidance documents in 2011. Many of these attributes are summarized in a review (Favara et al. 2019). This new ITRC guidance, Sustainable Resilient Remediation (SRR-1), presents these lessons learned as resources for state agencies and other decision makers, remediation, and resilience practitioners, and affected communities.

The evolution described above has provided a mechanism with which to address resilience in remediation. There is growing evidence that shifting short- and long-term climatic conditions will critically influence the performance of many types of infrastructure, including contaminant management and remediation measures intended to protect human health and the environment (Maco et al. 2018, O'Connell and Hou 2015, Reddy, Kumar, and Du 2019).

2.1.2 **Impact of Extreme Weather, Sea-Level Rise, and Wildfires**

In 2019, the Government Accountability Office (GAO) published a report entitled Superfund, U.S. EPA Should Take Additional Actions to Manage Risks from Climate Change, which highlights several National Priorities List (NPL) sites' vulnerability to extreme weather. The GAO reported that 60% of all nonfederal NPL sites are in areas that may be impacted by flooding, storm surge, wildfires, and/or sea-level rise. The GAO noted that their findings may not fully account for the number of nonfederal NPL sites because (1) federal data are generally based on current or past conditions; (2) data are not available for some areas; and (3) there may be other climate change effects (such salt-water intrusion, drought, precipitation, hurricanes, winds, and average and extreme temperatures) that could impact nonfederal NPL sites (GAO 2019).

A 2018 report by SURF found that:

> Extreme weather events can undermine the effectiveness of the original site remediation design and can also impact contaminant toxicity, exposure, organism sensitivity, fate and transport, and long-term operations, management, and stewardship of remediation sites. In the U.S., nearly two million people—the majority in low-income communities—live within one mile of one of 327 Superfund sites in areas prone to flooding or vulnerable to sea-level rise caused by climate change. In2017, the federal government reported that "…extreme weather events have cost the United States $1.1 trillion since 1980…" (Maco et al. 2018, page 8).

2.1.3 **Resilience Considerations**

Federal, state, and local agencies; emergency response departments; nongovernmental organizations; and private companies have led numerous planning and organizational efforts in response to increasing environmental threats (for example, intense storms, extreme drought, coastal and inland flooding, and wildfires). Efforts have focused on reducing the impacts of these adverse events and doing so efficiently by maximizing social, economic, and environmental benefits (Marchese et al. 2018). The result is an increased interest in both sustainability and resiliency.

The Shark River Marina case study (Appendix A) exemplifies a multiorganizational partnership and the benefits of an SRR project. The State of New Jersey, Federal Emergency Management Agency (FEMA), Township of Neptune, and Monmouth Conservation Foundation provided funding for site cleanup, purchase of the property, and redevelopment as a full-service marina and a disaster assistance center during emergencies. The environmental benefits included in situ treatment that reduced contaminant concentrations and limited excavations to contaminant hotspots. Solar panels provide sustainable resilient power. A new drainage system recharges groundwater, avoiding costs and disruptions that would result from extreme weather events. The full-service marina also provides the public health benefits associated with outdoor recreation.

Resilience is the capacity of a community, business, or natural environment to prevent, withstand, respond to, and recover from a disruption (USEPA 2020b). Understanding resilience requires an understanding of vulnerability, which includes both site vulnerability and social vulnerability. As discussed in Section 6.2.5.1, each of these terms is a balance of several quantifiable characteristics:

> **Site Vulnerability** = Extreme Weather & Wildfire Exposure + Site Sensitivities – Remedial System Adaptive Capacity
>
> **Social Vulnerability** = Extreme Weather & Wildfire Exposure + Community Sensitivities – Community Adaptive Capacity

The National Contingency Plan (NCP) established nine criteria for evaluating remedial alternatives to ensure that all important considerations are factored into remedy selection. While all nine criteria must be considered, two of these criteria serve as useful examples of how sustainability and resilience can be considered in remediation projects:

> **Long-term effectiveness** and permanence are criteria that address the need for reliable protection of human health and the environment over time. To effectively evaluate a remedy with respect to this criterion, vulnerabilities to extreme weather, sea-level rise, and wildfire events over the expected lifetime of the remedy should be considered. Where vulnerabilities are identified, adaptation measures can be developed and integrated into the remedial design to maintain the integrity and resilience of the remedy over time.
>
> **Short-term effectiveness** addresses the time needed to implement the remedy and potential adverse impacts to the community, workers, and the environment during construction and operation until cleanup standards are achieved. This criterion can consider the direct and indirect beneficial and unintended environmental, social, and economic impacts of remedial alternatives. Site management practices should be identified and integrated into the remedial design to maximize benefits and minimize unintended impacts.

The steadily increasing economic, environmental, and social losses from natural disasters and the awareness of the potential effects of catastrophic events on vulnerable infrastructure require policies and procedures for implementing and measuring resilience to be more consistently applied. Integrating resilience with sustainability planning and management (Section 6) is expected to minimize conflicts and maximize synergies when compared with separate implementation strategies.

2.1.4 **Managing Changing Risk Factors**

The anticipated risks of extreme weather events, wildfires, and changing climatic conditions on contaminated sites are substantial. Vulnerabilities to critical infrastructure in the vicinity of the site must also be considered. For example, upstream dams or levees with high hazard ratings could lead to different resilience and adaptation measures for contaminated sites downstream. Beyond the anticipated direct impacts to the remedy itself, indirect impacts may also need to be addressed (see Section 7, Key Sustainable Best Management Practices for Climate Change Resilience to Extreme Weather Events and Wildfires).

2.1.5 The Case for SRR

There is growing evidence that resilience measures have favorable economic returns on investment. A recent study of federal government hazard mitigation projects found that hazard mitigation funding can save the United States $6 in future disaster costs for every $1 spent on hazard mitigation (NIBS 2018).

While sustainability considers the remedy's impact on the environment, resilience considers the environment's impact on the remedy. However, this distinction is not so simple. For example, a remedy that is vulnerable to extreme weather—that is, not resilient when exposed to an extreme weather event—may fail to reach its design life, thereby causing significant adverse impacts to the surrounding environment. These environmental impacts, in turn, may have associated economic impacts (for example, the cost to clean up a release caused by extreme weather and reestablish the remedy) and social impacts (for example, the impacts to the community from the release caused by the extreme weather or the additional costs to reestablish the remedy at the expense of using those funds for another cleanup action). To be truly sustainable, a remedy must maintain functionality for the duration of its design life and do so by being resilient to extreme events and changing conditions. The interconnectedness of sustainability and resilience, particularly as they relate to the cleanup of contaminated sites, reemphasizes the importance of an integrated approach.

To help readers better recognize examples of SRR integrated into cleanup projects, Appendix A is a summary of SRR case studies. The case studies summarized in the appendix were selected from USEPA's CLU-IN "Profiles in Green Remediation," SURF's case study website, other published sources, or other work that is summarized in this document for the first time. The case study matrix outlines the following information for the case studies:

- Case study name (which may be referenced in other parts of this document)
- Location of case study
- Overview of remediation activities conducted
- Elements of SRR activities performed at site
- Examples of environmental, economic, social, and resilience benefit(s) derived from the work
- Offset/avoidance achieved
- Tools used to support SRR work
- Literature references or links to full case study
- Regulatory program work was completed under

Appendix A was designed for readers to look at each of the above components by project or to quickly scan the matrix for examples of environmental, economic, social, resilience, or avoidance/offset benefits achieved. The reader is encouraged to read the full case study (if a link is available in the matrix), as not all information from the case study could be summarized in the matrix. While the SBMPs developed for this document were not available when the case study projects were being completed, examples of how particular SBMPs might be applicable to a case study project are provided in the "tools footprint, BMPs, LCA, MCDA, surveys, etc…" column of Appendix A.

This ITRC SRR guidance is the first to integrate sustainable remediation and resilience. In summary, SRR:

- can be good business and good government (Appendix A and full case studies in this document highlight the value of SRR).
- creates trust or earns valuable trust (see 2nd Street Park; Tar Ponds and Coke Ovens; and California Gulch case studies in Appendix A).
- can focus on underserved, most vulnerable communities (see Phoenix Park case study, Section 5.10).
- helps expedite cleanup and redevelopment (see Pharmacia and Upjohn case study in Appendix A).
  decreases public health risks (see Appendix A for examples of reductions of air emissions in the "environmental" and "offset/avoidance" columns).
- creates jobs, parks, wetlands, and resilient energy sources (see Harrison Avenue Landfill/Cramer Hill Waterfront Park Project, Appendix A).

2.2 Frequently Asked Questions (FAQs)

Key messages were developed to support responses to questions about the value proposition and potential misperceptions of SRR.

2.2.1 **Why is SRR Valuable?**

Table 2-1 addresses FAQs related to the value of SRR. The table states a FAQ and provides a concise answer. The table also provides examples for how the components of the FAQ were included in a case study in Appendix A and/or Section 5.10.

Table 2-1. The value of SRR and references to case studies reflective of answers.

FAQ	Answer	Case Study Match(es)*
Do sustainable and resilient remedies improve long-term risk management?	Yes. Practitioners identify project risks not normally considered. Sustainable risk management includes emissions mitigation and community revitalization. Resilient risk management maximizes adaptive capacity to changing climatic conditions.	Santa Susana Field Laboratory, Area IV—used cost/risk reduction tools. Senator Joseph Finnegan Park used risk management in determining remedy scope that limits long-term risk.
How can stakeholder involvement benefit SRR?	Stakeholder collaboration identifies unintended impacts and perceived risks of site activities. These perspectives inform community remediation performance metrics. Integrating stakeholder values maximizes site cleanup benefits.	Tar Ponds and Coke Ovens Canada—stakeholder involvement wasdescribed as critical to completion.

What are some examples of how SRR planning maximizes the potential of local and regional benefits from cleanup and restoration activities?	Best management practices transcend site impacts. Sustainable materials management considers local waste streams and socially conscious sourcing. Resilient environmental restoration contributes to regional climate adaptation efforts.	Bellingham Bay Waterfront—started as a multiagency (including local and regional partners) pilot project. Iron Mountain Mine Superfund Site, Shasta County, California—considered regional climate impacts as part of the Remedial Investigation/Feasibility Study and worked with local and regional fire authorities to minimize potential impacts. SURF Groundwater Conservation and Reuse—Unidynamics Superfund Site, worked with local authorities to allow groundwater reinjection to support regional resources. Port Sunlight River Park, U.K.—funded long-term management and specifically funded a local social services agency (autism) to provide long-term management and educational benefits. Tar Ponds and Coke Ovens Canada—partnered with local college tocreate groups to bridge technology/staffing gaps. Elizabeth Mine—worked with local landowners and organizations to limit adverse cleanup effects on historic resources at site (eligible for National Register of Historic Places). Grove Landfill—partnered with local nonprofit group to assist land donation, and welcomed weekend volunteers for development of nature trails, small-scale farming, community garden beds, and commercial composting. Reuse of waste materials targeted educational sustainability demonstrations, leading to full conversion of property to environmental education center. Pharmacia and Upjohn—included extensive community outreach to engage local stakeholders in selection of remedy and the future of the site.

Does SRR align with corporate social responsibility and (the United Nations) sustainable development goals?	Yes. The ensemble of sites worldwide has compounding impacts. Shareholders, elected officials, and community stakeholders have sustainability and resilience goals. These initiatives can aid remedial and restoration decision making.	All case study sites reflect some aspect of corporate or global sustainable development aspects. Specific examples: Tar Ponds and Coke Ovens Canada—reflects social considerations. Frontier Fertilizer Superfund Site, focuseson documenting emissions offsets. Pharmacia and Upjohn—includes emissions offset, land management, and social/economic considerations.
Does adaptive management have a role in SRR?	Yes. Site regulatory and physical conditions continuously change. SRR practices consider mitigation and adaptation to these future events, including reuse scenarios, stakeholder concerns, flooding, wildfires, and drought.	Phoenix Goodyear Airport Superfund Site—existing and future extremes in weather conditions required adaptive planning. Iron Mountain Mine Superfund Site, Shasta County, California—responses to wildfire impacts required adaptation in engineering, planning, and maintenance.
Where is the return on investment for implementation of SRR achieved?	Cost savings occur during sustainable materials management and remedy optimization. The earlier in the process changes are made the greater the potential impact. Affected stakeholders can benefit from site cleanup and restoration. Long-term savings can be realized by adapting to projected climate vulnerabilities.	Former Nebraska Ordnance Plant—found significant energy savings in multiple processes. Frontier Fertilizer Superfund Site—produced significant energy savings, including an example of a lessthan 3-year return on investment. Havertown PCP Site—resulted in significant energy savings, including life-cycle cost analysis.
How can SRR evaluation findings inform an assessment of remedial alternatives and other site-related strategies?	SRR tools identify differences among environmental, socioeconomic, and community impacts of alternatives. Short-term effectiveness considers unintended impacts from remedial scenarios. Long-term permanence considers vulnerability to dynamic site conditions. (See Section 2.1.3 for information about SRR remedy selection and implementation within the NCP criteria.)	Santa Susana Field Laboratory, Area IV—SRR tools and process were used in evaluating remedial alternatives.
Is SRR applicable to any cleanup site within the U.S. or U.S. territories, such as Puerto Rico and the Virgin Islands?	SRR practices are applicable to all environmental hazards and physical conditions. Long-term projects likely have more opportunities. Federal and state agencies offer guidance and resources. (See State Resource Map for state guidance and resources related to GSR, climate resilience, and wildfires.)	Former St Croix Aluminum Plant, U.S. Virgin Islands – ran a solar “sipper” with on-site solar power, transferred recovered product to adjacent reclamation facility, operations remained off the grid.

Does SRR provide an opportunity to look at a project through a different lens and promote innovation?	Yes. Considering SRR facilitates innovative solutions. Setting SRR goals early in project planning provides a new path toward alternative(s) development. Subsequently, innovation is integrated in remedy planning and execution.	Santa Susana Field Laboratory, Area IV—SRR tools and process were used in evaluating remedial alternatives.

2.2.2 What Are Common Misperceptions about SRR?

Table 2-2 addresses FAQs related to common misperceptions about SRR. The table is formatted to state a FAQ and provide a concise answer. The table also provides examples for how the components of the FAQ were included in a case study in Appendix A and/or Section 5.10.

Table 2-2. Common misperceptions about SRR and references to case studies reflective of answers.

FAQ	Answers	Case Study Match(es)
Does SRR just add cost toa remediation project with little added value?	a. No. SBMPs result in short- and long-term cost savings. Sustainable risk management refines remediation footprint and unintendedimpacts. Resilient risk management minimizes effects of future vulnerabilities. (See Section 7).	Phoenix Goodyear Airport Superfund Site—used SBMPs and reuses 500K gallons of water per year.
	b. No. Refining the active remediation footprint results in immediate cost savings(for example, reduced consumption of embedded materials, energy, and water).	Frontier Fertilizer Superfund Site—significant energy savings andemissions offsets reported. Lawrence Aviation Industries—wastewaterdischarge and energy choices are featured in this example.
Is the outcome of an SRRevaluation predictable and, therefore, not worth performing?	No. Specific technologies or approaches are not necessarily preferable over another. Sitecharacteristics and stakeholder values informsustainability and resilience metrics. An evaluation of metrics informs remedial decision making.	Frontier Fertilizer Superfund Site—SRRprocesses developed identification of beneficial reuse options for treated groundwater. Santa Susana Field Laboratory, Area IV—SRR tools were used in developing remedial alternatives.
If stakeholders are engaged early to define SRR metrics, will we haveto do remedial activities above and beyond the cleanup objectives?	a. No. Early stakeholder engagement is an opportunity to set site assessment boundaries. SRR practices should be fiscallyresponsible. Rationale for inability to meet applicable practices should be communicated.	Pharmacia and Upjohn—included extensive community outreach to engagelocal stakeholders in selection of remedy and the future of the site. SURF Tar Ponds and Coke Ovens Canada—Earlier stakeholder involvementcould have diminished controversy around the project and would likely have resulted in decreases in project duration and cost.
	b. Stakeholder engagement provides an opportunity for social sustainability awareness. Practitioners are informed of site-related stakeholder concerns and needs. Cleanup can incorporate broader objectivesto maximize socioeconomic benefits.	California Gulch—engaged stakeholders ranging from landowners, local authorities, state park, natural resource trustees, and potentially responsible parties, resulting in the use of soft engineering approaches such as root wads placement and bendway weirs for bank stabilization instead of riprap.

The regulator did not accept our SRR assessment submittal. What best practices can we implement to avoid this in the future?	Collaborate with regulators early to formulate site objectives, including identifying values, metrics, and evaluation tools, and format to integrate findings in remedial decision making. Educating the regulators about the SRR process at the start of the project, up front and transparently, reduces the possibility of objections that may cause delays.	Harrison Avenue Landfill/Cramer Hill Waterfront Park—illustrates success when bringing in state regulators as early as possible into the SRR process.
Are cleanup sites that were resilient to recent severe weather events still vulnerable to future events?	Yes. The frequency and severity of climate change impacts is dynamic. Future precipitation, temperature, and sea-level rise projections evolve with new data. Changes in land use also occur.	Iron Mountain Mine Superfund Site, Shasta County, California—impacts from current wildfire threats informed the evaluation of climate change potential impacts in the Remedial Investigation/Feasibility Study. Port Sunlight River Park, U.K.—the sustainability assessment included climate change projected impacts.
Is a technical and quality review by a "subject matter expert" required for an SRR evaluation?	Yes. Experts advise on site practices, tools, and guidance. Data inventory, assumptions, and evaluation findings are reviewed for consistency and accuracy. Support also includes outreach and goal setting. SRR experts have the experience and long-term perspective necessary for successful SRR implementation.	BP Site, Busy Bee's Laundry, and California Gulch—are all case study sites that noted good engineering judgment as being important to the success of SRR implementation.
Is an SRR evaluation labor-intensive?	It depends. Required labor is tailored to meet site-specific SRR goals. Identifying SBMPs and performing a qualitative assessment is less intensive. Assessing SRR return on investment (ROI) highlights value of labor-intensive evaluations. Refer to value-added aspects of SRR implementation presented in Table 2-1 FAQ #6 (Where is the return on investment for implementation of SRR achieved?) and Table 2-2 FAQ#1 (Does SRR just add cost to a remediation project with little added value?).	Jet Propulsion Laboratory—example of a complex SRR evaluation. Phoenix Goodyear Airport Superfund Site, example of a best management practice (BMP) evaluation site.
Can social metrics be quantified with existing methods and tools?	Yes. Social metrics can be quantified using economic valuation tools. Quantifying social metrics is not always necessary. Semiqualitative tools include rating systems, surveys, and community input sessions.	Port Sunlight River Park, U.K.—part of the remedy was establishing a set-aside to ensure that stakeholders had contract opportunities that provide jobs and long-term engagement with the remedy.

Are there metrics, methods, or tools to evaluate social impacts of cleanup sites in a technically sound manner?	Yes. Integrating environmental economics and social science methodologies builds technical integrity in an assessment. Sustainability experts advise on metrics and tools. These should represent beneficial and unintended impacts.	Port Sunlight River Park, U.K.—social impact considerations were a major part of this remedy. Tar Ponds and Coke Ovens Canada—this is *the* social impacts case study. A single example for this case study includes: “annual community surveys, annual accountability reports and tracking documents, partnered with local college to create groups to bridge technology/staffing gaps.”
Is tracking SRR metrics and SBMP performance during implementation a costly, labor-intensive process? What tools are readily available regardless of those identified during project planning?	No. SRR can be considered at any phase of a cleanup project. SBMPs align with value engineering. Cost-effective tracking tools are available.	Elizabeth Mine—is currently using value engineering hand in hand with SRR. Havertown PCP Site—used life-cycle cost analysis.
Are there benefits to starting SRR early in the development of the remediation project?	Yes. Early Conceptual Site Model (CSM) development can consider potential risk to climate and other extreme event impacts. Early SBMP implementation maximizes SRR opportunities and outcomes. Early stakeholder engagement facilitates collaboration.	Whitney Young Branch Library—an example of a site that saw time and cost savings through early use of SRR tools. Port Sunlight River Park, U.K.—used SRR tools during development of the CSM.
What is the point of transitioning to an SRR approach if traditional remedial efforts are known to work effectively?	Additional benefits can be realized when SRR approaches are integrated. Traditional approaches may overlook stakeholder values, which can cause project delays, especially at the end of the project. Anticipating stakeholder needs and concerns up front can result in a project more people support and limits project risk. Transitioning to SRR maximizes benefits and minimizes unintended impacts of cleanup and also factors in resilience considerations that may not have been previously considered.	Pharmacia and Upjohn—extensive community outreach to engage local stakeholders in selection of remedy and the future of the site. Tar Ponds and Coke Ovens Canada—“Earlier stakeholder involvementcould have diminished controversy around the project and would likely have resulted in decreases in project duration and cost.” Santa Susana Field Laboratory, Area IV, included use of benefit/cost analysis, cost/risk reduction analysis, to anticipate unintended impacts by the remediation and to the remediation.

* Harrison Ave Landfill and Senator Joseph Finnegan Park appear in both Appendix A and Section 5.10. Phoenix Park, Camden and Bellingham Waterfront only appear in Section 5.10. The rest of the sites only appear in Appendix A.

3. Perspectives

This section uses the results of a survey of environmental state agencies to identify challenges and opportunities related to implementing SRR in state programs. This section also provides insight into SRR options at private-party sites, approaches of various federal government branches and public and tribal stakeholders, and provides an overview of ASTM International's SRR-related guidance.

3.1 State Survey Summary

In 2019, a survey was distributed to state environmental agencies (Appendix B). The survey consisted of 16 questions pertaining to the availability, use, and value of different mechanisms to state governments that incentivize or require use of SRR at contaminated sites. Fifty-two individuals from various state agencies responded. Most (74%) of the state representatives surveyed agreed that a sustainable remediation guidance or framework that also addresses extreme weather events and wildfire impacts related to climate change at contaminated sites would be useful for their states. The survey results also indicated a state-led cleanup or a brownfield site as the type of site on which SRR would most likely be used. State or federal grant incentives were most likely to move a cleanup toward SRR, with mandates being the second most likely over local permits, land-use controls, or private certification. The respondents placed a high value on economic metrics (for example, job creation or job preservation) when evaluating whether SRR should be used at a site. Social impacts (for example, future use as parkland or open space) were of medium value to the respondents. The data gathered from this survey were factored into the development of the content provided in this SRR guidance document.

3.1.1 **Challenges**

The state survey identified three primary challenges that can impede implementation of SRR in site remediation: lack of regulations and/or policies, perceived higher cost, and lack of knowledge. These challenges are summarized in the following sections.

3.1.1.1 ***Lack of Regulations or Policies***

Many states have no regulations or laws requiring SRR considerations during remedy selection. Even in those states that have policies, SRR may be treated as optional rather than an enforceable requirement. This makes it difficult to implement SRR with any consistency or reliability. Specific state regulations and policies are accessible through the State Resource Map. Section 3.1.2 presents strategies on how to overcome this barrier.

3.1.1.2 ***Perceived Higher Cost***

Oftentimes, sustainable assessments and SRR evaluations and technologies are perceived as too expensive to incorporate into the remedy or redevelopment when, in fact, SBMPs can result in short- and long-term cost savings. For example, using SBMPs (Section 7) can lower material, energy, and water use, as well as reduce processing, transportation, and labor costs.

Factoring life-cycle costs into a decision-making process that includes SRR remedial alternatives and long-term protectiveness or resilient alternatives will provide a comparison of overall anticipated costs (ITRC 2006). It is possible that a remedial alternative that is more expensive in the short term will save money over the long term, especially if the site is vulnerable to climate change impacts such as sea-level rise, flooding, wildfires, or other extreme weather events.

In addition, some states provide monetary incentives (see Section 3.1.2.4) to further encourage the incorporation of sustainable and resilient considerations into the remedial process.

3.1.1.3 ***Lack of Knowledge***

Lack of knowledge on behalf of the regulators and regulated community is problematic, and gaps in knowledge should be discussed between both parties. This may include a lack of understanding of the environmental footprint of the cleanup actions; the potential risks of climate change to the selected remedy; applicable regulations; and the technical aspects of SRR.

For example, in relation to resilience, very few research studies have addressed the issues of residual contaminants and potential hydrological shifts (Libera et al. 2019). There are few guidelines on how to model hydrological systems in changing climate conditions or how to implement climate resilient remediation and monitoring systems. In addition, such assessments require modelers to choose the range of climate-forcing parameters in the future (for example, precipitation and recharge values), even if these parameters may be highly uncertain. Although there are several climate assessments available on the national scale—for example, U.S. Global Change Research Program (USGCRP 2018)—they are mostly qualitative and less specific at each location. More guidelines and tools are needed to select the appropriate range of future climate conditionsfor each assessment and how to quantify the future climate conditions at the local site scale.

This lack of knowledge often leads to SRR not even being considered during remedial selection and implementation. To address this lack of knowledge, a few states and organizations are developing resources and tools, such as an assessment tool to evaluate climate change risks at state-led sites:

- Massachusetts Climate Change and Hazardous Waste Site Screening is a research study in which a simple model was developed and geographic information system (GIS) tools were used to evaluate the potential vulnerability of a subset of 6,001 high-interest state-listed sites based on their locations and remediation status (Mielbrecht and Tarrio 2019).
- The State of Washington Department of Ecology has published a written procedure entitled Adaptation Strategies for Resilient Cleanup Remedies: A Guide for Cleanup Project Managers to Increase the Resilience of Toxic Cleanup Sites to the Impacts from Climate Change (Ecology 2017).

3.1.2 **Opportunities**

This section presents various drivers for integrating SRR into remediation projects. This ranges from strong legally binding statutes, regulations, executive orders, and contracts to nonbinding guidance and policy, to opportunities to voluntarily incorporate into procurements or remedial planning. Even in states without existing legally binding statutes and regulations, opportunities exist to incorporate SRR into remedial selection and implementation decisions. Specific state regulations, executive orders, and policy are accessible through the State Resource Map.

Since the 2011 release of the ITRC GSR guidance (ITRC 2011b, ITRC 2011a), some states have taken steps to incorporate GSR into their programs. In response to the threat of extreme weather events and wildfires, nearly all states have started resilience planning and adaptation initiatives. Three states—California, Massachusetts, and New Jersey—have also begun to include resilience considerations in site remediation and redevelopment programs as follows:

- California – California has several programs, regulations, and policies in place for wildfires, climate resilience, and green remediation. The Tech Sheet: California SRR Resources in Appendix C summarizes these efforts. Of note are the following hazardous waste management resilience initiatives:
    - DTSC Interim Summary Report of Woolsey Fire – The California Department of Toxic Substances Control (DTSC) and a team of federal, state, and local agencies evaluated impacts of the Woolsey Fire on conditions at the Santa Susana Field Laboratory site (state-led cleanup) and in nearby communities. The interim report summarizes work done to address concerns about the impact of theWoolsey Fire on the site and surrounding communities (DTSC 2018).
    - Los Angeles Region Framework for Climate Change Adaptation and Mitigation: Potential Regulatory Adaptation and Mitigation Measures – This framework looks at the effects of climate change on contaminated sites and underground storage tanks and how these effects can be considered in the agency's actions (LARWQCB 2019).
    - Existing Conditions and Stressors Report—Contaminated Lands
    - The San Francisco Bay Conservation and Development Commission's Adapting to Rising Tides project evaluated the current condition of shoreline and community assets and the stressors affecting them.
- Massachusetts – Massachusetts has established programs and enacted laws with ambitious goals to combat climate change and incorporate resilience in infrastructure and remediation. The Massachusetts Climate Change Clearinghouse is the primary gateway to data and information relevant to climate change

adaptation and mitigation across the state. It provides the most up-to-date climate change science and decision support toolsfor the commonwealth to support scientifically sound and cost-effective decision making for policy makers, practitioners, and the public. The state also maintains a climate action website with links to supporting programs, policies, and laws. The Tech Sheet: Massachusetts SRR Resources in Appendix C summarizes some of these efforts.

- New Jersey – New Jersey has developed policies and passed regulations, statutes, and executive orders, taking specific actions to address sustainability and resilience at contaminated sites. The Tech Sheet: New Jersey SRR Resources in Appendix C summarizes the information available.

3.1.2.1 ***Laws and Regulations***

This section provides examples where implementation of sustainability or resilient remediation is required through state **statutes** (legislative action) or **regulations/rules** (agency action) to be legally enforceable as laws. This is generally the strongest and longest lasting driver for implementation of SRR.

In response to the state's 2008 Global Warming Solutions Act (GWSA), the Massachusetts Department of Environmental Protection (MassDEP) amended the Massachusetts Contingency Plan (MCP) to include the consideration of green approaches for the assessment and remediation of regulated sites. In response to the governor's 2016 Executive Order 569, MassDEP again amended the MCP in 2019 to require those conducting cleanups to (1) identify and assess foreseeable climate impacts that may affect the permanency and protectiveness of the cleanup at vulnerable sites; and (2) take reasonable measures to reduce vulnerabilities. These changes are expected to become final by 2021. For more information see the Tech Sheet: Massachusetts SRR Resources.

In 2018, the New Jersey Department of Environmental Protection (NJDEP) addressed sustainability at contaminated sites in the state's Technical Requirements for Site Remediation, which states that the NJDEP "encourages the use of green and sustainable practices during the remediation of contaminated sites" (N.J. Admin. Code § 7:26E-1.9, NJDEP 2018). Although not a strong directive, it incorporated green and sustainable practices into the lexicon of site remediation in New Jersey and encouraged their consideration at contaminated sites during the remediation process. A year later, the state incorporated GSR into its statutes when the Site Remediation Reform Act was amended. More detail about these laws is provided in the Tech Sheet: New Jersey SRR Resources.

3.1.2.2 ***State Contract Language***

Incorporating SRR into state-funded response actions is beneficial for many reasons, including:

- contributing toward state-mandated climate and sustainability goals reducing emissions and waste generation
- planning for extreme weather events that pose a risk of compromising the remedy

Depending on how state contracts are secured, this can be accomplished in various phases of project planning.

- State employees can work with project engineers and contract specialists to develop model language to include in design specifications and contracts with trade contractors
- If the state has a bid specification model, incorporate this language into the template. This will make SRR an automatic consideration for project managers as they evaluate approaches for remedial actions.
    - Consider beginning with a pilot study prior to implementing statewide.
    - Develop measurement and tracking mechanism to evaluate the costs and benefits.

3.1.2.3 *State Executive Orders*

This section provides examples in California, New Jersey, and Oregon, where the implementation of SRR is mandated through executive orders (EOs). At the state level, an EO is a mandate issued by the governor. EOs direct action and have the rule of law, but can be overturned by the legislature or the courts.

- In 2015, then California Governor Jerry Brown established EO B-30-15, which aims to reduce greenhouse gas (GHG) emissions and incorporate climate change impacts into planning and investment decisions. This order also requires the state Natural Resources Agency to update the state's climate adaptation strategy every 3 years. For more information, see the Tech Sheet: California SRR Resources.
- New Jersey Governor Philip Murphy signed EO No. 89 on October 29, 2019, on the seventh anniversary of Superstorm Sandy. It directed the state, through the NJDEP, to develop a statewide climate change strategy to guide decisions and policies across state government. The EO also ordered the formation of a Climate and Flood Resilience Program within the NJDEP and created the Interagency Council on Climate Resilience to promote the long-term mitigation, adaptation, and resilience of New Jersey's economy, communities, infrastructure, and natural resources. For more information on SRR efforts in New Jersey, see the Tech Sheet: New Jersey SRR Resources.
- In March 2020, Oregon passed EO 20-04, Directing State Agencies to Take Actions to Reduce and Regulate Greenhouse Gas Emissions. The EO requires the state to reduce its GHG emissions at least 45% below 1990 levels by 2035 and 80% below 1990 levels by 2050. Agencies are directed to consider and integrate climate change and climate change impacts into their planning, budgets, investments, and policy-making decisions and to prioritize actions that will help vulnerable populations and impacted communities adapt to climate change impacts. The state's Environmental Justice Task Force must be consulted when evaluating climate change mitigation and adaptation priorities and actions.

3.1.2.4 *Policy and Voluntary Guidance*

Strategies for implementing SRR can take the form of policy and voluntary guidance. The state agency may strongly encourage implementation of SRR at private-party and state-funded sites through policy or through guidance developed by the state agency or adopted from another entity such as ITRC, ASTM, or the USEPA. Vulnerability assessment resources (Section 6.2.3) and key SBMPs (Section 7) can help states identify if a contaminated site is vulnerable to direct or secondary impacts from climate change. Some ways to disseminate this information and build support for a state SRR voluntary program include:

- providing information on the state agency website
- sharing information and offering encouragement in state agency list serve distributions
- management encouraging and supporting staff to implement at state-funded sites
- encouraging SRR verbally in meetings with private parties
- providing or sponsoring training to agency staff, consultants, and the regulated community
- offering a good corporate citizen program that includes SRR in the point system for consideration

In addition to providing technical information to the regulated community, it is helpful to build a case for the benefits of SRR and how sustainability and resilience reduce long-term costs and liability at contaminated sites. Referencing state case studies is recommended to illustrate the potential for life-cycle cost reduction and resources saved when SRR practices are used. Numerous case studies are provided in Appendix A.

Sometimes states provide financial assistance to incentivize incorporating SRR into the remedial process. For example, Delaware incorporated SRR evaluations and technologies into brownfield reimbursement guidance, most recently updated in July 2020 (DNREC 2020). Other states, such as Washington State (Ecology 2017), simply provide guidance.

3.2 Private-Party Sites

Where explicit regulations requiring SRR do not exist or where guidance is lacking, private parties may still incorporate SRR components by looking to the broader requirements of existing regulation and policy. For example, if a state or federal cleanup program has a regulation or policy with the statements below, the potential risks of future changes in climate and extreme weather can be considered for a cleanup site.

- that the cleanup conducted not pose an unreasonable risk of injury to health or the environment
- that the subject property be returned to maximum beneficial use for the community
- that the cleanup decisions be protective of human health and the environment

Ask the question, *"Is this remedy vulnerable?"* See Section 6 to learn how to integrate resilience into site plans and other phases of the project life cycle.

Owners can also voluntarily include contract language to require their contractors to evaluate or implement SRR remedial SBMPs. Such contract language and actions reduce the potential of climate impacts from remedial actions and increase resilience. As a result, owners demonstrate their commitment to corporate responsibility and reduce their long-term liability (Section 2.1.4).

3.3 Federal Perspectives

3.3.1 **Executive Orders**

There are no specific laws or regulations that mandate the implementation of SRR; however, federal EOs that require federal agencies to incorporate sustainability practices and climate change adaptation in agency operations were signed from 2013 to 2015. Some were revoked in 2017 and 2018, as noted below.

- *Efficient Federal Operations (EO 13834)* affirmed "that agencies shall meet such statutory requirements in a manner that increases efficiency, optimizes performance, eliminates unnecessary use of resources, and protects the environment." In implementing this policy, agencies are tasked to prioritize actions that reduce waste, cut costs, enhance the resilience of federal infrastructure and operations, and enable more effective accomplishment of the federal government's mission. Section 8 of the new EO **revokes** EO 13693 of 19 March 2015 (*Planning for Federal Sustainability in the Next Decade*), which incorporated sustainability principles and federal leadership in environmental, energy, and economic performance (NARA 2015). EO 13834, *Efficient Federal Operations*, **revoked** EO 13693 (NARA 2018).
- *Preparing the United States for the Impacts of Climate Change* (EO 13653) directed federal agencies to promote engaged and strong partnerships and information sharing, risk-informed decision making, adaptive learning, and preparedness planning (National Archives and Records Administration 2013). *Promoting Energy Independence and Economic Growth* (EO 13783) **revoked** EO 13653 (NARA 2017).

3.3.2 **U.S. Environmental Protection Agency**

3.3.2.1 ***Office of Superfund***

The USEPA's Superfund Climate Resilience website provides comprehensive guidance on climate resilience at Superfund sites and has developed an approach that raises awareness about the vulnerabilities that result from climate change. Superfund applies climate change and weather science as a standard operating practice in cleanup projects. In June 2014, the USEPA released its agencywide Climate Change Adaptation Plan, which includes actions to be taken through the Superfund program (USEPA 2014). The climate resilience strategies involve three elements: vulnerability assessment, resilience measures, and adaptive capacity.

3.3.2.2 ***Brownfields Program***

The USEPA's Climate Smart Brownfields Manual provides a comprehensive approach for communities on climate mitigation, adaptation, and resilience for redeveloping these sites. Topics include the role of local communities in land-use planning, zoning, and building codes; green building techniques, practices, and adaptation strategies (USEPA 2016b). Further, incorporating sustainable and resilient BMPs in an application for a USEPA brownfields grant is considered favorably over an application that lacks those types of concepts.

3.3.2.3 ***Office of Research and Development***

The USEPA Office of Research and Development is the scientific research portion of the organization. Specific efforts related to SRR include the following:

- Sustainable and Healthy Communities is a national research program that is focused on promoting and building sustainability and resilience at a community level. The program's research aims to answer the question, "How do we meet today's needs without compromising the ability of future generations to meet their needs in ways that are economically viable, beneficial to human health and well-being, and socially just?" A robust portfolio of intramural research projects is aligned with the main goals of SRR:
    - studying the benefits of sustainable remediation, restoration, and revitalization in terms of a community's total (that is, environmental, social, and economic) health and well-being with special focus on vulnerable groups
    - developing and providing practical tools and solutions
    - measuring the beneficial health and ecological impacts for communities

Under this program, the USEPA developed the Sustainable and Healthy Communities Strategic Research Action Plan for 2019–2022 (USEPA 2020b). The purpose of this plan is to inform agency partners (program and regional offices) and external stakeholders of the program's strategic direction over the next 4 years. The plan focuses on remediation solutions for contaminated sites as well as revitalizing and protecting communities at risk from contamination and natural disasters. The 2019 plan concludes with nine priority topics, three of which address the importance of investigating the resilience to extreme weather events and other climate events, including the remobilization of contaminants.

- In 2020, as part of its Science to Achieve Results (STAR) Program, the USEPA funded six 3-year research projects under the 2019 request for applications entitled Contaminated Sites, Natural Disasters, Changing Environmental Conditions and Vulnerable Communities: Research to Build Resilience.
- The USEPA has developed the Climate Resilience Screening Index (CRSI), which is designed to capture the sensitivity of five domains (natural environment, built environment, governance, social structure, and vulnerability or risk) to climate events. CRSI is a county-level score for climate resilience (scalable both upward and downward spatially) that is also defined by various indicators/metrics to quantify, for example, climate and demographic conditions. The "exposure" indicator includes the probability of a technological hazard being in the proximity of contaminated sites, including nuclear sites, toxic release sites, Superfund sites, and Resource Conservation Recovery Act (RCRA) sites (USEPA 2017a).
- USEPA's Science Inventory is a searchable repository of USEPA reports, currently showing seven results on "sustainable remediation."

3.3.3 **U.S. Department of Defense**

The Department of Defense [DOD] manual Defense Environmental Restoration Program Management instructs DOD to evaluate remedial alternatives to ensure that they are efficient; are environmentally, economically, and fiscally sound; consider sustainable practices; reduce the footprint of remediation systems on the environment; and "consider and implement green and sustainable remediation opportunities in current and future remedial activities when feasible" (DOD 2012, page 48). The manual notes that opportunities to increase sustainability considerations exist throughout all phases of remediation. Section 6 of this guidance, Integrating Resilience and Sustainability into the Remedial Project Life Cycle, provides information about how to integrate these considerations during a remediation project.

3.3.3.1 *U.S. Department of Navy*

In 2012, the U.S. Department of the Navy (DON) announced a policy that requires continual optimization of remedies in each phase of the remedial process. The DON's Guidance on Green and Sustainable Remediation (USN 2012) provides remediation program managers and consultants with a clear approach to incorporating GSR considerations in all phases of the environmental restoration process. A GSR analysis of each of the alternatives evaluated in the remedy evaluation documents is included, and the SiteWise tool is used to conduct a remedy footprint analysis of each alternative (Bhargava and Sirabian 2013). Additional remedy footprint analysis tools can also be used, but only in conjunction with or after an analysis using the SiteWise tool.

3.3.3.2 *U.S. Air Force*

In 2019, the U.S. Air Force issued contracting policy to incorporate GSR into environmental cleanup contracts (USAF 2020). The Environmental Restoration Technical Support Branch of the Air Force Civil Engineer Center has led efforts to implement environmentally friendly and effective technologies to restore contaminated sites. The Sustainable Remediation Tool (Claypool and Rogers 2012) evaluates remediation projects from a carbon-footprint perspective, and CleanSWEEP helps evaluate renewable energy sources. In collaboration with other federal agencies and intergovernmental organizations, the branch has also participated in establishing GSR guidelines and standards. More detailed information is available on the Air Force Civil Engineer Center's website.

3.3.3.3 *U.S. Army Corps of Engineers*

In 2010, the U.S. Army Corps of Engineers (USACE) finalized its interim guidance, Decision Framework for Incorporation of Green and Sustainable Practices into Environmental Remediation Projects (USACE 2010). The guidance provides a process for incorporating GSR practices into environmental remediation consistent with DOD policy and the Army Environmental Cleanup Strategic Plan during USACE execution of the Formerly Used Defense Site program. The scope of the document is to provide these processes for the entire environmental remediation life cycle, from project inception through site closeout (Section 6).

In addition, the USACE Regional Sediment Management and Engineering with Nature programs can complement and be coordinated with SRR activities.

3.3.4 **U.S. Department of Energy**

The U.S. Department of Energy (DOE) has been managing more than 100 sites with soil and groundwater contamination and radioactive waste associated with nuclear weapons production and government-sponsored nuclear energy research. Following EO 13653 *Preparing the United States for the Impacts of Climate Change*, DOE has been developing strategies to enhance climate preparedness and resilience (Moore et al. 2016). DOE released a series of DOE Climate Change Adaptation Plans (USDOE 2014, USDOE 2016), as well as the DOE Climate Change Vulnerability Screening Guidance (USDOE 2017), to ensure inclusion of climate change adaptation as part of its planning and operations. Moore et al. (2016) investigated three sites that were impacted by wildfire, flooding, and groundwater changes. DOE also required the incorporation of contract language encouraging the incorporation of sustainability principles in its remediation efforts. Currently, DOE requires each of its sites to develop an annual Site Sustainability Plan that includes promoting resilience to disturbances from a variety of sources (USDOE 2018).

3.3.5 **Federal Emergency Management Agency (FEMA)**

The impacts of natural disasters are diminished with the right planning and preparation, which incorporates resilience. FEMA has numerous publications and resources to help with resilience preparation. For example, flood and wind map tools are available. FEMA has a program through which communities that prove resilience against impacts through wide-scale efforts (such as improving drainage basins and floodplain management) can be certified in a way that gives individuals and local businesses reductions in rates from insurers.

3.3.6 **Government Accountability Office (GAO)**

In a report published in 2019, the GAO reviewed various potential issues related to the impact of climate change on nonfederal National Priorities List (NPL) sites, which include some of the most seriously contaminated sites. The analysis was focused on flooding, storm surge, wildfires, and sea-level rise, based on federal data, including from the USEPA, FEMA, National Oceanic and Atmospheric Administration, and U.S. Forest Service. In addition, the GAO reviewed laws, regulations, and documents and interviewed federal officials and stakeholders. Among other objectives, they examined the following: (1) what available federal data suggest about the number of nonfederal NPL sites located in areas that may be impacted by selected climate change effects and (2) the extent to which USEPA has managed risks to human health and the environment from the potential impacts of climate change effects at such sites (GAO 2019).

The report suggests that climate change may result in more frequent or intense extreme events, such as flooding, storm surge, and wildfires, among other effects, which could damage remedies at nonfederal NPL sites and lead to releases of contaminants that could pose risks to human health and the environment. About 60% of all nonfederal NPL sites are in areas that may be impacted by these potential climate change effects. The GAO recommends broadly incorporating climate resilience into the site-level decision-making process to ensure long-term protection of human health and the environment (GAO 2019).

3.4 Public and Tribal Stakeholders

ITRC defines stakeholders as members of environmental organizations, community advocacy groups, or other citizens' groups that deal with environmental issues (ITRC 2011a). Likewise, tribal stakeholders are affiliated with, or are employees of, tribal nations, or are Native American, Alaska Native, or Native Hawaiian. These public and tribal stakeholders, other interested individuals, are the voices of the communities and tribes that are affected by environmental problems.

Stakeholders' perspectives for contaminated sites undergoing cleanup incorporate cultural, historical, and other community-based values. Contamination at sites can damage resources that belong to both current and future generations. This obligation to future generations is particularly strong among tribal stakeholders. While tribal stakeholders share many of the same concerns as other public stakeholders, they have additional concerns as custodians of ancestral lands and shared resources with federal, state, and local agencies. USEPA's policy is to consult on a government-to-government basis with federally recognized tribal governments when USEPA actions and decisions may affect tribal interests. Consultation is a process of meaningful communication and coordination between USEPA and tribal officials prior to USEPA taking actions or implementing decisions that may affect tribes.

Tribes have accumulated knowledge about the plants, animals, natural phenomena, landscapes, and timing of events at specific places, often referred to as traditional ecological knowledge (TEK). TEK continues to evolve and identify changes in the environment. TEK is an important part of the tribal consultation process and decision making. Section 7.1.2 provides information on how to incorporate TEK into resiliency planning at the remediation site.

Remediation sites often contain hazardous substances that pose a risk to health, a threat to property, and a danger to resources. As individuals, members of environmental or community advocacy groups, and participants in official advisory bodies, stakeholders are the ultimate beneficiaries of environmental remediation activities and usually believe that contamination should be cleaned up to the extent practicable. While it may be impractical to remove or destroy all hazardous substances at a remediation site, stakeholders generally expect the following:

- Responsible parties, regulators, and others who engage in the investigation and remediation of hazardous waste have an obligation to reduce the toxicity, mobility, and volume of waste to the extent practicable and in the most environmentally responsible manner, considering sustainable and resilient options.
- All exposure pathways to hazardous substances that have been released into the environment should be eliminated, and innovative remedial technologies should be considered in all phases of the remediation process.
- Decision makers should include active SRR components in every remedy. Remedies that operate for long time frames require a robust system of long-term management, and the cost and other SRR challenges of long-term activity should be evaluated when considering initial remedies.
- Regulators who make remediation decisions should view public stakeholders and tribal representatives as partners in site remediation from the beginning to end of cleanup.
- Sites should be evaluated to determine whether the remedial design and objectives were based on an adequate characterization and a valid CSM. Finding and controlling sources reduces remediation time frames, cost of remediation, and overall ecological burden on public resources.
- The remediation of complex sites should use sustainable and energy- and resource-efficient remedial technologies except when doing so avoids restoring resources or delays remedial goals. Restoring resources is the priority value.
- Long-term management strategies at remediation sites should remove institutional controls as remediation reduces risks and return land and resources to community use. SRR may become more important and applicable as the cleanup progresses.

The SRR guidance builds on the 2011 ITRC GSR framework by recommending a careful and continuous consideration of the social and economic costs and benefits of a cleanup project on equal footing with environmental costs and benefits (ITRC 2011a). Robust and transparent stakeholder engagement is almost always required to identify specific and meaningful social and economic goals for a remediation project and must be continued to ensure that community expectations are met as the project progresses (see Favara et al. 2019). Stakeholder engagement resources in Section 5.9.1.5 provide essential guidance for structuring these processes (Figure 5-5 and Table 5-7). Stakeholder engagement is addressed at each stage of the cleanup process in Section 6.

3.5 ASTM International

ASTM International has produced several standard guides related to SRR, including the following:

- Standard Guide for Integrating Sustainable Objectives into Cleanup (ASTM E2876-13) presents a framework that allows and encourages practitioners to address sustainable aspects within cleanup projects (ASTM 2013a).
- Practitioners may implement this guide to integrate sustainable objectives into cleanup while working within applicable regulatory criteria.
- Standard Guide for Climate Resiliency Planning and Strategy (ASTM E3032-15e1) presents a generalized, systematic approach to the voluntary assessment and risk management of extreme climate-related events and conditions (ASTM 2015). It helps practitioners structure their understanding of the climate-related vulnerabilities and consequences they seek to manage and identify adaptive actions of both an institutional (legal) and engineering (physical) nature.
- ASTM E2893-16e1 Standard Guide for Greener Cleanups provides a process for identifying, prioritizing, selecting, implementing, documenting, and reporting activities to reduce the environmental footprint of a cleanup (ASTM 2016). The USEPA provides a free webinar.
- New Guide for Remedial Action Resiliency to Climate Impacts (ASTM WK66522) is an additional document about remediation resilience that is currently in development. The guide will include sections on climate evaluation for remediation stages, potential climate impacts on remedies and adaptation, potential climate impacts on contaminants and contaminant migration, potential societal impacts, and appendices with examples of impacts of disasters on cleanup sites.

4. State Resource Map

The state resources map provides a way to locate information specific to each state. This section provides fingertip access to the building blocks of SRR, showcasing state and federal programs from around the United States.

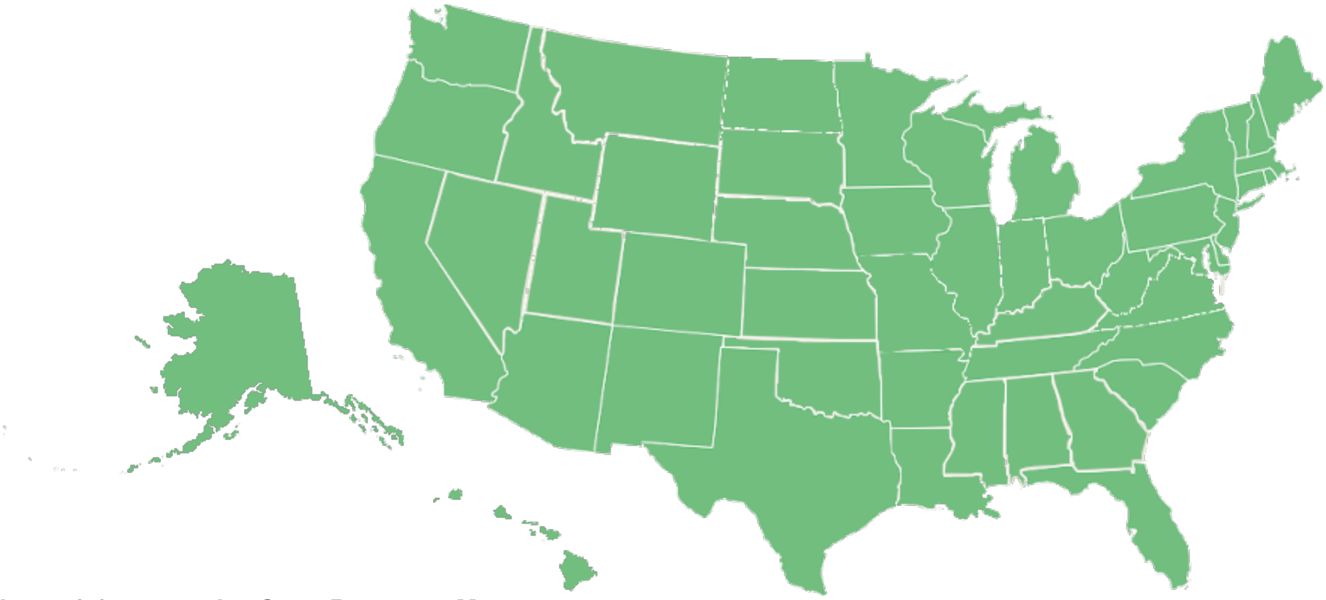


Figure 4-1. Interactive State Resource Map
Source: ITRC SRR Team

How to use the Interactive State Resource Map Online

To use the state resources map tool, select a state, and information on state-specific SRR or other climate resilience and wildfire resources will appear. These resources are categorized by:

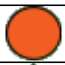
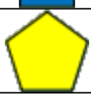
- Laws and regulations (statutes, laws, and regulations)
- Gubernatorial EOs
- Policy and guidance
- Other resources provided by that state
- State case studies

Simply click on the state you are interested in and a screen will pop up to show you which resources are available. Then click on the state name in the pop up and that will bring you available resources. The link to the federal resources are available within the state link.

Federal agency, stakeholder, and academic resources are also presented. These resources, some of which are state-specific, are on topics that can impact site remediation projects or help prevent adverse impacts to these projects. Click **here** to view Federal Resources.

There is also a button to select if you are aware of updates to a state's listed SRR resources. Comments about the map are also welcome; use the update button above.

Key to State Resources

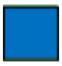
	Laws and Regulations(Statutes, Regulations, Rules)
	Executive Order
	Policy/Guidance
	Resources(Plans and Strategies, Reports, Websites
	Case Study

Washington

Washington

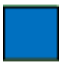
(Click here for information and links)

GSR



Climate Resilience

Wildfire Resilience



Federal Resources

Oregon

Oregon

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GSR

Climate Resilience

Wildfire Resilience

Federal Resources

California

California

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GSR

Climate Resilience

Wildfire Resilience

[Federal Resources]

Idaho

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Climate Resilience

Wildfire Resilience

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Nevada

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Climate Resilience

Wildfire Resilience

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Montana

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Climate Resilience

Wildfire Resilience

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Utah

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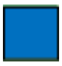
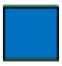
Climate Resilience



Wildfire Resilience



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Arizona

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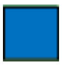

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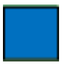

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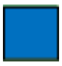

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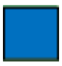

Wildfire Resilience

Federal Resources

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South Carolina

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Maryland

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Delaware

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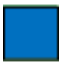

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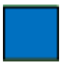

Federal Resources

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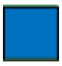

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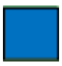

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Massachusetts

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Rhode Island

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Climate Resilience

Wildfire Resilience

5. Advancing the Practice: Social and Economic Dimensions of Sustainability and Resilience

This section provides examples and tools to help incorporate social and economic factors that will help promote sustainable projects and inform stakeholders. Unlike the environmental prong of sustainability (sometimes referred to as “greening”), regulators, cleanup professionals, and parties responsible for the cleanup often need to convince their stakeholders that these considerations matter. Likewise, community advocates often need to convince regulators or the responsible party that communities need a seat at the decision-making table due to the perception that economic and social concerns are external to cleanup. While this narrow view may have been understandable if not desirable, there are new technologies and sources of information that make it possible to deliver fully sustainable projects. Our intention is to bring these often-overlooked aspects of sustainability onto even footing with the traditional environmental optimization process that dominated early sustainable cleanup planning.

This section is intended for a broad audience:

- regulators or the party responsible for cleanup who may need to convince project proponents of the need to consider these factors or who may need to educate themselves about why these factors matter
- community leaders and advocates who know their concerns matter but may not be able to articulate why or lack the technical expertise necessary to identify cobenefits in the technical language that regulators use
- planners who might appreciate both of those views but lack a holistic framework that reconciles them.

Some of the material in this section may seem repetitious—this is intentional to allow nontechnical audiences and others who do not have the time to read a traditional technical guidance to engage with the subject and become effective participants in cleanup decision making.

5.1 Sustainability Is More Than a Footprint

Sustainability is more than an environmental concept that asks us to be efficient with resources—it requires that projects also consider the communities a cleanup serves and impacts. Sustainable planning and project management involve gathering community data, considering how a site or its cleanup might differently affect different communities, and strikinga balance between the three pillars of sustainability -environmental, social, and economic (Purvis, Mao, and Robinson 2019). Meeting this “triple bottom line” seems like it is asking a lot, but doing so can also help you deliver better projects at lowertotal costs by increasing overall community benefit and ownership.

5.1.1 **Sustainability Is Good Business and Good Government**

Sustainable design lowers lifetime costs and delivers efficient and optimized projects. While reduced operation and maintenance costs are easy to factor into traditional design, we often struggle to think of the economic context and the social factors in the same way. Holistic planning can lead to direct cost savings and unlock more project options. For example, if mobilization can be coordinated or the need for expensive and time-consuming ground-disturbing operations can be shared to accomplish different goals (cleanup and stormwater improvements, cleanup and utility tunneling, cleanup and creation of green spaces, etc.), then it can be easier to justify those expenses. This document presents case studies that show that authentic community involvement and creative thinking about local needs increase both resources available for completing cleanups and the trust that communities place in you, your company, and your government (see Section 5.4.3).

5.1.2 **Sustainability Earns You Valuable Trust**

Businesses or industries that act with consideration and respect to local communities typically receive more trust in return. Conversely, cleanups that proceed without considering local communities are more likely to face court challenges, receive negative press attention, or generate political headwinds. Dealing with conflicts after they arise costs money and time and can erode trust. Sustainable projects that account for community needs make it easier for communities to engage with future projects and place their trust in what you say. Investing to earn social license pays dividends on future work.

5.2 Special Considerations for Low-Income and Minority Communities

Project planning and execution do not happen in a vacuum. There are strong and well-known correlations between the locations of environmental contamination and the neighborhoods of people of color and/or low-income residents. Living near environmental contamination creates and perpetuates public health and socioeconomic disparities among these groups. Toxic Wastes and Race in the United States (UCCCRJ 1987) is a seminal work that documented this relationship almost 30 years ago. Minority, low-income, and indigenous communities are often the most vulnerable and the most overburdened by environmental and public health stressors (USEPA 2016c), and therefore deserve special consideration in this guidance. Even the most well-intentioned cleanup projects can perpetuate these systemic disparities if they fail to address these issues in project planning, execution, or operation.

For more information, consider reading the Environmental Justice Working Group's appendix to the Minneapolis Climate Action Plan. The appendix was written by local communities and contains their perspectives and suggestions on how to approach climate justice in a proactive manner (MSO 2013).

Project managers must work proactively to overcome these challenges, and the pursuit of environmental justice should be considered an overarching goal for a cleanup project. Robust stakeholder engagement is crucial for achieving meaningful outcomes in environmental justice communities. Project managers should aim to create ongoing, multiple opportunities for two-way dialog and collaboration with stakeholders throughout the project life cycle and beyond. In particular, involving stakeholders in the development and definition of project goals can help to overcome systemic biases and improve the overall sustainability of a given cleanup. The stakeholder engagement resources discussed in Section 5.10.4 provide essential guidance for structuring these processes.

A number of additional tools and resources, such as USEPA's EJ Screen, have been created to support project managers seeking to assess whether or not minority or low-income communities are likely to be impacted by contaminated sites or cleanup decisions. See Section 5.11 for further guidance on identifying vulnerable populations.

5.3 Road Map of Economic and Social Resources

5.3.1 **Cleanup Put in Context**

In general, Section 5 contextualizes social and economic sustainability as part of the cleanup process (1) in cleanups that are integrated with a larger redevelopment project (such as a brownfields revitalization) and (2) in cleanups that are driven primarily by regulatory responsibilities under a federal or state cleanup program (such as CERCLA or RCRA). Section 6.2.3 explains the role that vulnerability assessments can play in capturing economic and social threats to sites and help you find leverage points for communities and their needs to enter the cleanup process.

5.3.1.1 ***Cleanup as Part of a Larger Development Project: Integrated Cleanups***

Section 5.5 will be familiar to practitioners who work regularly in brownfields development. They bring the brownfield mindset, which combines consideration of social and economic benefits to local communities and the environmental benefits of reusing contaminated spaces.

5.3.2 **Promoting a More Sustainable Cleanup**

Convincing stakeholders, the public, and project backers to include sustainable and resilient features can be a challenge, but this guidance will help you promote a more sustainable cleanup as a worthwhile investment. This guidance will help you identify and explain the hidden benefits (or hidden costs avoided) associated with taking a greener and more sustainable approach and provide you with the tools and examples you need to streamline these benefits as part of the cleanup process.

5.3.2.1 ***Planning, Identifying, and Capturing Hidden Benefits of a Sustainable Cleanup***

Section 5.4 will cover how to identify and capture the hidden social and economic benefits and possible costs of sustainable and resilient cleanup action. In these pages we demonstrate the importance of stakeholder engagement for eliciting costs and benefits and provide examples of metrics that can be used to capture these additional benefits.

5.3.2.2 ***Do-It-Yourself: Examples of Green Infrastructure Options, Ecosystem Services, and Co-uses***

Sections 5.6 and 5.7 provide background on ecosystem services and green infrastructure, respectively important concepts that support finding co-uses and overlooked benefits beyond the cleanup itself. In addition to the background, you can find information on specific types of green infrastructure that can support sustainable cleanups and deliver cobenefits. These technologies are included for their ability to significantly shift understanding and characterization of a projects' costs and benefits. These technologies and practices can serve remedial needs (for example, management of stormwater runoff from a cleanup construction site) while providing long-term public benefits (for example, infiltration on nonsite runoff and green spaces for bioswales). These technologies could allow regulators or project proponents to justify more costly alternatives that meet cleanup needs by making clear the additional benefits and offering ways to quantify those benefits.

5.3.2.3 ***Social and Economic Impact Evaluation***

Section 5.9 provides metrics and tools for use in measuring and documenting how economic and social considerations factor into a cleanup project. Evaluation methods and resources include commercial and academic aides that support identification and integration of SRR objectives into decision making. In addition, you can find advice on communications, stakeholder identification, and outreach to make local communities authentic participants in project development.

5.4 Social and Economic Sustainability Through Constructive Change andProtective Remedies

5.4.1 Understanding SRR and Where Additional Environmental, Social, and Economic Benefits Are Derived

Like all remediation and cleanup activities, SRR can deliver easily or commonly recognized public health and environmental benefits associated with cleaning up contaminated land, water, or air (see Jenkins, Kopits, and Simpson 2006). These benefits are primarily associated with the protectiveness of the remedy. But the SRR approach goes a step further, considering additional social, economic, and environmental costs and benefits both within the boundaries of the site or cleanup project, and to surrounding communities or environments. Despite recent attention and guidance (ITRC 2011a), many of these additional benefits remain poorly defined and only vaguely understood by both project managers and stakeholders. This is especially true for benefits that accrue beyond the fence line of a site or cleanup project (such as an improvement in property values in surrounding neighborhoods), or where environmental, economic, and social benefits are derived more from choices made in the process of a cleanup project as distinct from the overall protectiveness of the remedy itself.

These “hidden benefits” of sustainable remediation are the subject of Section 5. Improving understanding of these hidden benefits also offers a basis of support for SRR practices, encouraging project managers and stakeholders to seek solutions that reduce social and economic determinants of risk and vulnerability in nearby communities that are also relevant to social and economic sustainability. This is particularly relevant when SRR planning and project activities move beyond site boundaries to consider wider, cascading impacts, such as when cleanup is part of a wider, transformative, or revitalization-based effort, or when broader consideration of social impacts and ongoing community interaction with sites is included in site assessment and remedy selection processes.

Robust and transparent stakeholder engagement is almost always required to identify specific and meaningful social, environmental, and economic goals for a remediation project, and must be continued to ensure that community expectations are met as cleanup progresses (see Favara et al. 2019). In this way, SRR places as much emphasis on ensuring sustainability in the process of land cleanup as it does in the immediate and long-term impacts or effectiveness of the remedy. This should not be interpreted as a means of justifying a less protective remedial action, but instead as an indication that additional measures of environmental, social, and economic effectiveness should be weighed and pursued at all stages of cleanup and as end-state goals. Some of the additional benefits discussed here could accrue naturally or as a positive externality of standard remediation or cleanup practices, but unless they are intentionally pursued, they do not represent SRR. The intentionality of the SRR approach is its key distinguishing feature, and the approach highlights the need for further guidance on how and where to look for its sometimes-hidden benefits.

More reading on this topic:

- The Sustainable Resilient Remediation Evaluation Framework in Section 6 provides an easy visual guide to the full SRR evaluation process.
- The Social and Economic Impact Evaluations section contains detailed information about performing economic and social evaluations under each of the SRR pathways described in Figure 6-1.

5.4.1.1 *Linking Benefits to Steps in SRR*

In 2011, the ITRC produced a GSR document that contains step-by-step guidance for project managers and decision makers involved in SRR (ITRC 2011a). Many of these steps are directly relevant to achieving and documenting the hidden benefits of SRR and reducing unexpected costs. We encourage practitioners to review the steps in SRR and to consider how their project plans can be used to protect and enhance the social and economic benefits of SRR in particular. Stakeholder engagement activities in the remedy evaluation and selection stages can represent especially important keys to unlocking additional benefits.

5.4.2 **Hidden Environmental Benefits of SRR**

The hidden environmental benefits of SRR accrue primarily at site level and are sometimes referred to as “collateral benefits” of sustainable remediation practices. This term is somewhat unhelpful for SRR, because SRR intentionally pursues as many of these benefits as possible, and therefore treats them not as collateral impacts, but rather as central goals. Characterizing benefits in this goal-based manner also makes it easier for project managers and stakeholders to understand how hidden benefits accrue with the SRR approach, which focuses as much on the sustainability of key components or phases of the cleanup process as the effectiveness of the eventual remedy. Some possible goals that will deliver additional environmental benefits are listed below.

- reduced particulate and GHG emissions through use of cleaner technology and vehicular route planning
- reduced consumables or use of materials with a smaller environmental footprint (such as recycled material)
- reduced energy consumption through use of efficient technology/use of renewable energy
- reduced water use through activities such as reuse of treated water and protection of surface water
- reduced waste by reusing on-site materials where possible or recycling materials back into the site
- reduced truck and traffic noise through vehicular route planning
- reduction in greenfield development (if performed in an urban area) and preservation of land, habitat, and green space
- use of minimally invasive technologies that reduce disturbance to wildlife and wildlife habits
- creation of new habitat
- flood control and flood storage
- environmental renewal (for example, soil and groundwater quality improvements that accrue later)
- helping/promoting novel and effective green remediation technologies become mainstream

Please note that the boundaries between these benefits can overlap; many of these examples could also lead to improvements in other areas (for example, public health or livability). Sections 5.5 (brownfields) and 5.10 (case studies) also delve into many of these concepts in more detail for brownfields cleanup projects.

5.4.3 **Hidden Social and Economic Benefits of SRR**

As with environmental benefits, the additional social and economic benefits of SRR and potential links to improved community resilience accrue most often through identifying and intentionally pursuing social and economic benefits linked to key components or phases of the cleanup process, although there is potential for longer term impacts as well. As stated previously, many of the benefits discussed here have also been confirmed in prior studies of environmental cleanup, but with SRR they are pursued intentionally as outcomes and/or project process goals where practical. Table 5-1 provides a summary of some of the key benefits and goals that could be pursued in this context. More information on how to pursue and measure progress toward these benefits and goals can be found in Section 5.9. For more specific discussion on how social and economic benefits accrue in an SRR project, see Harclerode et al. (2016).

Table 5-1. Main social and economic goals and broad indicators.

Source: after CL:AIRE (2020), Harclerode et al. (2016)

Health and Safety
• of site workers and the surrounding community including, but not limited to, the alleviation, prevention, or mitigation of contamination risks on site, generation of emissions and dust, and hazards of construction and operation of remedial systems • remediation and restoration options may vary in addition to wider public health benefits., such as public health and well-being benefits that might accrue from exercise and well-being as the surrounding community are more encouraged to be outside in restored/improved environments

Economic Vitality
• by contracting local vendors and resources, developing, and investing in new skilled training and education, and incorporating redevelopment into the remediation strategy selection • internal to the site owner, such as the impacts of remediation costs on debt financing and its ability to allocate resources to its other interests. Other concerns might relate to reputational or brand value, and in some cases fines or punitive damages.
Stakeholder Collaboration
• record the transparency of decisions to local communities and their degree of engagement to identify beneficial and undesirable impacts, to discuss perceived risks, to develop future land use and design, and to aid in assessment goals and indicators to maximize buy-in for the eventually implemented remediation strategy • consideration of the range of interactions, including how remediation might affect local services, community functions and amenities such as improvement of the local landscape and other renovations, including the consequential development of infrastructure such as pathways or roads, and public open space
Benefits to Community at Large
• by promoting the community's quality of life, including increased property value, social and human capital, reuse of treated media/materials to meet community needs, and redevelopment of the property • improvements in the livability of a local area, including removal of invasive vegetation, clearance of vermin, mitigation of odor, or reduction in the informal or antisocial use of the site. Also worthy of consideration is the potential removal of wider risks from sites such as fire or windblown litter
Alleviation of Undesirable Community Impact
• at the neighborhood and locality scale, including noise, traffic, odor, congestion, business disruptions, and compromising local heritage and cultural concerns • integrate resilient adaptation measures to mitigate mobilization of contaminants to receptors during a severe weather event or climate-related impacts and prevent exacerbation of community impacts if such an event were to occur
Social Justice
• consideration of ethics and intergenerational equity and whether the nature or duration of remedial works results in the transfer of contamination impacts and/or their mitigation to future generations; and/or a disproportionate distribution of site revitalization benefits resulting in a greater proportion of adverse impacts to ethnic, vulnerable, disadvantaged (etc.) groups • during urban revitalization, through increased housing availability for all community members, widened access to employment opportunities, and reused brownfields for equitable use throughout the community
Value of Ecosystem Services and Natural Resources Capital
• altered by site activities and consumption, reuse of treated media, and restoration of ecosystems, hydrologic functions, fauna, and indigenous flora habitat, in ways that enhance local quality of life and otherwise address societal challenges • restoration or enhancement of ecosystem services in cleanup and restoration activities, such as green infrastructure and carbon sequestration benefits, as well as mitigation of local and regional impacts to severe weather events and other climate-related impacts

Risk-Based Land Management and Remedial Solutions
• to distribute additional resources (for example, energy, raw materials) in a manner to effectively address the site-specific human health, environmental justice, and community issues associated with contaminated sites • remedial solutions compared with the value of benefit, such as mitigation of liabilities by the risk management achieved, redevelopment potential released for the site, land value enhancement *for the site*

Regional and Global Societal Impacts
• such as long-term, chronic public health impacts and financial implications (for example, mitigating effects of climate change and limited water resources) due to the generation of emissions and consumption of nonrenewable resources • project life span and flexibility via integration of resilience and long-term effectiveness of engineering and institutional controls operating under normal and severe weather event conditions
Contribution to Local and Regional Sustainability & Resilience Policies and Initiatives
• such as renewable energy initiatives, climate change legislation (for example, carbon-trading economy and climate adaptation), eco-job strategies, regional land-use policies, regional and local sustainability objectives (for example, ecological restoration goals, water use), and sustainable resource consumption • site cleanup activities may trigger specific wider investments or developments in an area that were not part of the original project, and not foreseen in the original remediation investment. These may include the treatment of other contaminated land or water in the area. The attraction of new investment and new businesses to an area may be a deliberate strategy for a brownfields restoration initiative, to create new economic clusters.

5.4.4 **Documenting Hidden Benefits**

One of the most important steps in SRR is documenting the outcomes of the project and measuring progress toward goals. This includes clearly identifying desirable outcomes or benefit categories from the outset and linking them to relevant metrics or progress indicators where possible. Although some of the social and economic benefits of SRR are somewhat qualitative, or site-specific in nature, a number of metrics have been established in recent years for assessing a wide range of social, economic, and environmental benefits from land cleanup. These can be chosen to fit the context of a specific project. Reviewing and choosing metrics at the beginning of a project can also help guide identification of project goals and selection of more diverse benefit categories. Stakeholders should be consulted in the selection of metrics to build consensus and reduce the chance for controversy over SRR outcomes.

In addition to the overview of benefits presented in this document, further guidance on frameworks, performance metrics, and tools for identifying and documenting SRR benefits can be found in (among others) Section 6.1.4.2 of this SRR guidance, the SURF library, frameworks and metric toolboxes, the ASTM guidance on sustainable cleanups (ASTM 2013a, 2015, 2016), the Institute for Sustainable Infrastructure Envision Rating System, or the 2011 ITRC framework and state of the science documents on green and sustainable remediation (ITRC 2011a, b).

5.5 Integrating Sustainability and Resiliency into Brownfields Redevelopment

Whether a contaminated property is urban, suburban, or rural, it often remains abandoned until there is a social or economic reason for cleanup. Brownfields, often located in underserved and highly impacted communities, are one more challenge for achieving social and economic benefits. Brownfields are underused properties whose redevelopment or reuse may be complicated by the presence of contamination. Brownfields redevelopment supports communities by reusing contaminated properties for commercial, residential, or institutional buildings and infrastructure. They can lead to healthier environments when used for parks and open spaces. By incorporating sustainable and resiliency strategies into the cleanup, redevelopment can play an important role in strengthening a community by addressing vulnerabilities and mitigating threats from climate change.

Climate change poses potential threats to the redevelopment of brownfields site from extreme weather (hurricanes, tornadoes, and storm surges), increased precipitation and flooding, decreased precipitation and droughts, wildfires, and warmer temperatures. Incorporating resilience and sustainable practices at brownfield sites is critical for the successful development of contaminated properties and results in many environmental, social, and economic hidden benefits.

By identifying the unique challenges and solutions posed by climate change on brownfield sites, communities can support their redevelopment. The Climate Smart Brownfields Manual (USEPA 2016b) provides a comprehensive approach for communities to think about climate mitigation, adaptation, and resilience for development of brownfield sites. The manual encompasses varied topics, from the role of local communities and the public in land-use planning, zoning, and building codes to support resilient and sustainable redevelopment to the techniques, practices, and adaptive strategies for greener cleanups and resilient land use.

Section 6.2 of this guidance provides more information on site characterization.

An ASTM Phase I Environmental Site Assessment (ESA), or an equivalent investigation, is often conducted to identify the potential risk associated with contamination when a property is being sold or developed. The fundamental objective of an ASTM ESA is to identify the potential for releases of oil or hazardous materials at a property. The Phase I ESA compiles a site history for the property to identify current and historic practices. It relies on a variety of sources, including previous reports prepared for the property, municipal records, historic and geologic maps, interviews with knowledgeable persons, and a site inspection (ASTM 2013b).

Changing climate conditions and risk factors can be included in the Phase I ESA process to identify factors that may need to be incorporated into a brownfield cleanup and reuse. The Phase I ESA can be expanded to identify site vulnerabilities. Authoritative sources such as websites from the U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration’s (NOAA) National Climatic Data Center, colleges and universities, and state or local resources should be reviewed to identify observed and potential changing climate conditions. Potential risk factors should be classified, such as location (for example, proximity to waterfronts and the ocean; infrastructure vulnerabilities; property affected by a revised FEMA floodplain map; vulnerabilities related to changes in frequency and intensity of precipitation events; vulnerabilities of soil type due to moisture and hydraulic changes; vulnerabilities to wildfires; and ground- and surface drinking water vulnerabilities) (USEPA 2014). During the site visit the practitioner should observe the natural setting and how potential vulnerabilities could impact remedy selection, design, and construction.

Sustainable redevelopment of brownfield sites can start with assessment, reducing the project's environmental footprint from the start. The investigation of contaminated properties may include sampling soil, groundwater, sediment, surface water, and indoor air. Buildings scheduled for demolition may be tested for asbestos, lead paint, polychlorinated biphenyls (PCBs), and other toxic pollutants. Many BMPs can be incorporated in the investigations (ASTM 2016, USEPA 2015a, b).

Examples of sustainable investigation practices are:

- Use local staff whenever possible to minimize resource consumption.
- Use local analytical laboratories and consolidate delivery schedules.
- Use in situ data loggers and transmit with solar-powered telemetry systems.
- Quickly restore disturbed areas of vegetation serving as stormwater controls.
- Install permanent wells for maximum reuse.
- Use minimally invasive drilling techniques.
- Compress the number of days needed for a given round of sampling.

5.5.1 Sustainable and Resilient Development

According to the Resilient Design Institute (RDI), resilient design is defined as "the intentional design of buildings, landscapes, communities, and regions in response to vulnerabilities to disaster and disruption of normal life." Development on brownfield sites requires attention to this intent.

5.5.1.1 Deconstruction and Demolition

Development of a brownfield site often first entails razing existing structures. Deconstruction involves taking a building apart, piece by piece. Full deconstruction is easier to achieve when incorporated as an intentional design element in the planning phase. This can range from a soft strip, in which only the most high-value and easy-to-extract materials are removed intact, to a full deconstruction, in which the entire structure is "un-built" to maximize reuse of existing materials. Deconstruction can be a good fit for buildings with valuable salvage materials, such as rare wood species or intact bricks. For more reading on this topic check out this helpful RecyclingWorks article. The USEPA Deconstruction Rapid Assessment Tool enables organizations to triage building stock slated for demolition; it assembles data that can help prioritize structures for deconstruction and salvage.

Even if the buildings are not candidates for complete deconstruction, sustainable demolition BMPs may be employed. Predemolition surveys will identify asbestos-containing materials which must be appropriately abated before demolition. PCBs in building materials such as caulk, window glazing, paint, and mastic should be assessed and appropriately disposed. Building products found to contain ≥ 50 ppm PCBs are classified as PCB bulk product waste under federal regulations through the Toxics Substances Control Act (TSCA) found in Chapter 40 of the Code of Federal Regulations (40 CFR 761). Hazardous building materials surveys are often required for state or local government demolition permits.

Asphalt, brick, and concrete (ABC) can be crushed and reused on site to raise site grades or as subgrade materials, or it can be reused off site rather than disposed in a landfill. Reuse of ABC materials may be regulated by local and state authorities and should be done in compliance with these regulations and requirements. Specifications that address many aspects of the demolition, such as waste salvage, hazardous materials, and earthwork, instruct the contractor on specific technical requirements (USEPA 2013c).

5.5.1.2 Greener Cleanups

Green remediation strategies can increase the net benefit of a cleanup, saving project costs and expanding the universe of long-term property use or reuse options without compromising the cleanup goals. USEPA has developed five core elements of a greener cleanup: materials & waste, land & ecosystems, water, air & atmosphere, and energy. The methodology suggests how to reduce the footprint during cleanup selection, design, implementation, and operation (USEPA 2015a). USEPA resources include the Superfund Green Remediation website and CLU-In website.

ASTM has developed Standard E-2893-16 to provide a systematic protocol to identify, prioritize, select, implement, and report on the use of greener cleanup BMPs. The standard includes a wide range of BMPs addressing buildings, materials, site preparation and land restoration, managing surface- and stormwater, and power and fuel (ASTM 2016).

Use of renewable energy resources provides a significant opportunity to reduce the environmental footprint of activities conducted during investigation, remediation, and monitoring of hazardous waste sites. Substitution of energy from fossil fuel resources with energy from renewable resources is a primary approach for addressing energy as one of the five core elements of green remediation strategies. There may be significant life-cycle benefits of local/on-site generation of renewable energy, not only being more cost-efficient over the long term, but also being more resilient by eliminating fuel deliveries. Renewable sources of energy for production of electricity or direct power needed for site cleanup can include the following (USEPA 2011):

- solar resources captured by photovoltaic (PV), solar thermal, and concentrating solar power systems wind resources gathered through windmills to generate mechanical power, or turbines of various sizes to generate electricity
- geothermal resources, primarily through geoexchange systems such as geothermal heat pumps or by accessing subsurface reservoirs of hot water
- hydrokinetic and marine resources, through the hydropower of rivers and streams or the tidal and thermal influences of oceans
- biomass such as untreated woody waste, agricultural waste, animal waste, energy crops, landfill gas and wastewater methane, anaerobic digestion, and algae

The Massachusetts Department of Environmental Protection (MassDEP) issues postclosure use permits for solar and wind installations on closed and capped landfills. To date, the agency has approved more than 100 projects rated more than 220 megawatts. Most of these projects have been completed and are generating nearly 175 megawatts of renewable energy.

Site work during development often can be greener. Techniques include maximizing the reuse of contaminated soil on site, reducing reliance on off-site landfills for disposal and reducing truck trips and associated GHGs. Reuse of contaminated soils may be regulated by local and state authorities and should be done in compliance with these regulations and requirements. Gravel roads, porous pavement, and separated pervious surfaces rather than impermeable materials will maximize infiltration. Planting at the optimum time of the season (for example, late winter/early spring) will minimize irrigation requirements.

5.5.1.3 ***Resilient Development***

Many brownfield sites are along waterfronts, making them susceptible to the impacts of climate change, such as flooding, storm surges, and sea-level rise, or they may be in areas afflicted with extreme heat or wildfires. As brownfield sites are redeveloped, sustainable and resilient principles should be incorporated.

Stabilization along the waterfront, even on contaminated properties, may provide opportunities for incorporating living shorelines made of natural materials such as plants, sand, or rock rather than hard structures such as concrete seawalls or riprap. As described by NOAA, living shorelines provide wildlife habit, as well as natural resilience to communities near the waterfront.

Incorporating resilient design into the built environment, including at brownfield sites, requires rethinking traditional practices to address potential vulnerabilities. RDI has developed many practical approaches to meet the strategic goals for development, such as:

- Design and construct (or renovate) buildings to handle severe storms, flooding, wildfire, and other impacts that are expected to result from a warming climate.
- Locate critical systems to withstand flooding and extreme weather events.
- Model design solutions based on future climatic conditions as much as possible, rather than relying on past data. Create buildings that will maintain livable conditions in the event of extended loss of power or heating fuel through energy load reductions and reliance on passive heating and cooling strategies (passive survivability).
- Create durable buildings using such features as rainscreen details, windows that can withstand hurricane winds, and interior finish materials that can dry out if they get wet and not require replacement.
- Optimize the use of on-site renewable energy.
- Carry out water conservation practices and rely on annually replenished water resources, including, potentially, harvested rainwater, as the primary or backup water supply.

- Find opportunities to use gray water, which is domestic wastewater excluding sewage, for plant irrigation, gardening, laundry, and toilet flushing.
- Provide redundant water supplies or water storage for use during emergencies. For deep-well pumps, provide either stand-alone solar electricity or hand-pumping options where possible. Where there is no option for on-site water, consider water storage that can gravity-feed to building.
- Consider an option for human waste disposal in the event of nonoperating municipal wastewater systems. This could include composting toilets and waterless urinals.
- Specify products and materials that will not off-gas or leach hazardous substances in the event of flooding or fire damage.
- Provide redundant electric systems with at least minimal back-up power capacity, such as a fuel-fired electric generator (with adequate fuel storage) or a solar-electric system with islanding capability.

Soil, groundwater, and indoor air contamination may affect the implementation of some of these strategies. When buildings, parking lots, hardscapes, and landscapes are used to encapsulate contaminated soil, they must also be designed to withstand severe flooding and storms. Evaluate when stormwater or wastewaters are recharged on site so that they do not adversely impact the flow of contaminated groundwater. When developing properties contaminated with volatile organic compounds that require vapor mitigation systems, they must be compatible with passive heating and cooling systems and are provided emergency power generation, if required.

5.5.1.4 ***Green Infrastructure***

Green infrastructure is a valuable tool to address many of the impacts of climate change, such as flooding, droughts, urban heat islands, and storm impacts. Infiltration practices can manage flood waters and replenish groundwater. Urban heat islands, which increase temperatures due to dense buildings and pavement, can be mitigated with trees and other vegetation. Energy use can decrease with green infrastructure that reduces rainwater into stormwater or sewer systems, conserves water, and decreases heating and cooling requirements for buildings. More information is available on USEPA’s Green Infrastructure for Climate Resiliency website. Sustainability evaluation tools, such as USEPA’s Green Infrastructure Wizard, can be used to capture the beneficial externalities of green infrastructure.

5.6 Ecosystem Services

Human populations rely on the many benefits provided by aquatic and terrestrial ecosystems.

Supporting services are those ecosystem services not used directly by people, but which are necessary for all other ecosystem services. They include soil formation, photosynthesis, and nutrient and water cycling.

Provisioning services refer to ecosystem products that are used by or directly impact human populations, including food, fuel, and fresh water.

Regulating services relate to ecosystem process regulation and include air quality, climate, water, and pollination.

Cultural services are the human benefits obtained through ecosystem services, such as cultural diversity, recreational opportunities, or aesthetic amenities.

Figure 5-1 shows how human well-being depends ultimately on renewable and cultivated natural capital. Renewable natural capital refers to well-functioning ecosystems and their living components, that is, native biodiversity. Cultivated natural capital includes traditional crop varieties and livestock races, as well as traditional agroecological knowledge. The internal pyramid conveys the feedback through which increased human well-being has positive benefits that flow back through the system. This suggests that society must support and participate in the restoration of natural capital and thereby reap additional benefit from the full spectrum of enhanced ecosystem services, as well as the inherent value of restored ecosystems.

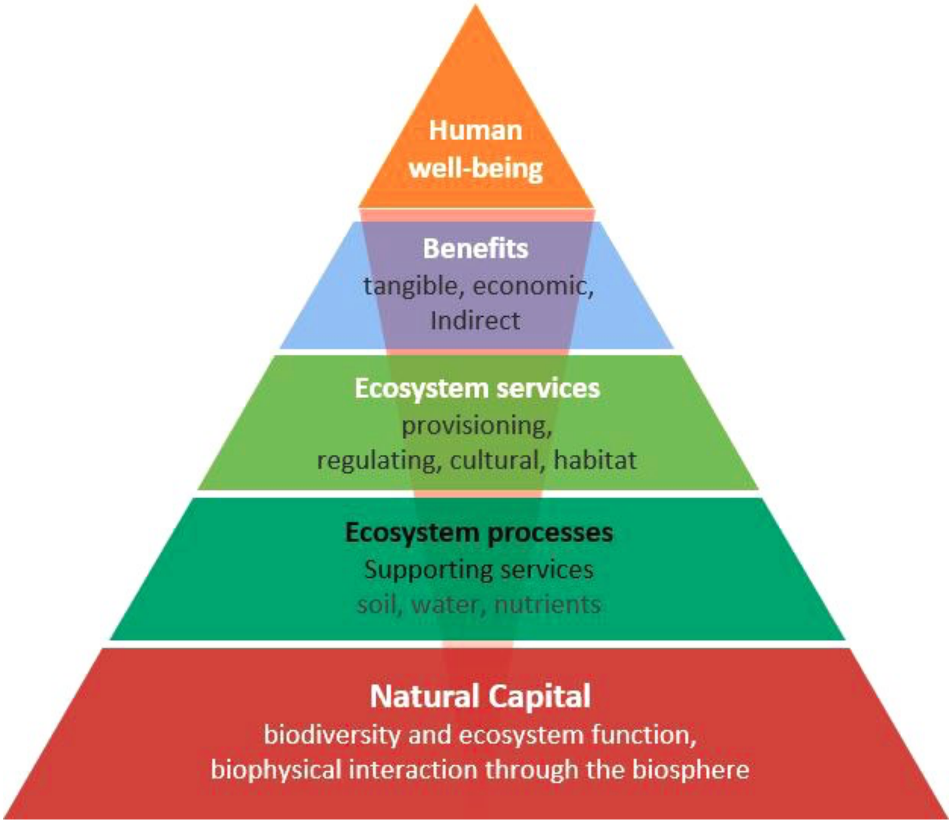


Figure 5-1. Natural capital hierarchy.

Source: Alexander et al. (2016). U

5.6.1 Value of Ecosystem Services

Ecosystem services provide many benefits that have economic value. But because ecosystem services have traditionally been treated as a public good, their actual values are seldom captured in decision-making processes. Assigning value to the range of benefits provided by ecosystems can help decision makers to ensure the values ecosystem services provide are included in site decisions. Forests play a critical role in maintaining water quality. Because healthy forests can reduce the costs of treating drinking water for local governments, it may be cheaper to invest in protection of the watershed than to expend funds in expensive water treatment systems. For example, New York City invested more than $1 billion to protect its primary water supply in the Catskills region of upstate New York and avoided $10 billion to build a water treatment facility and $100 million annually on operations and maintenance costs (Hu 2018).

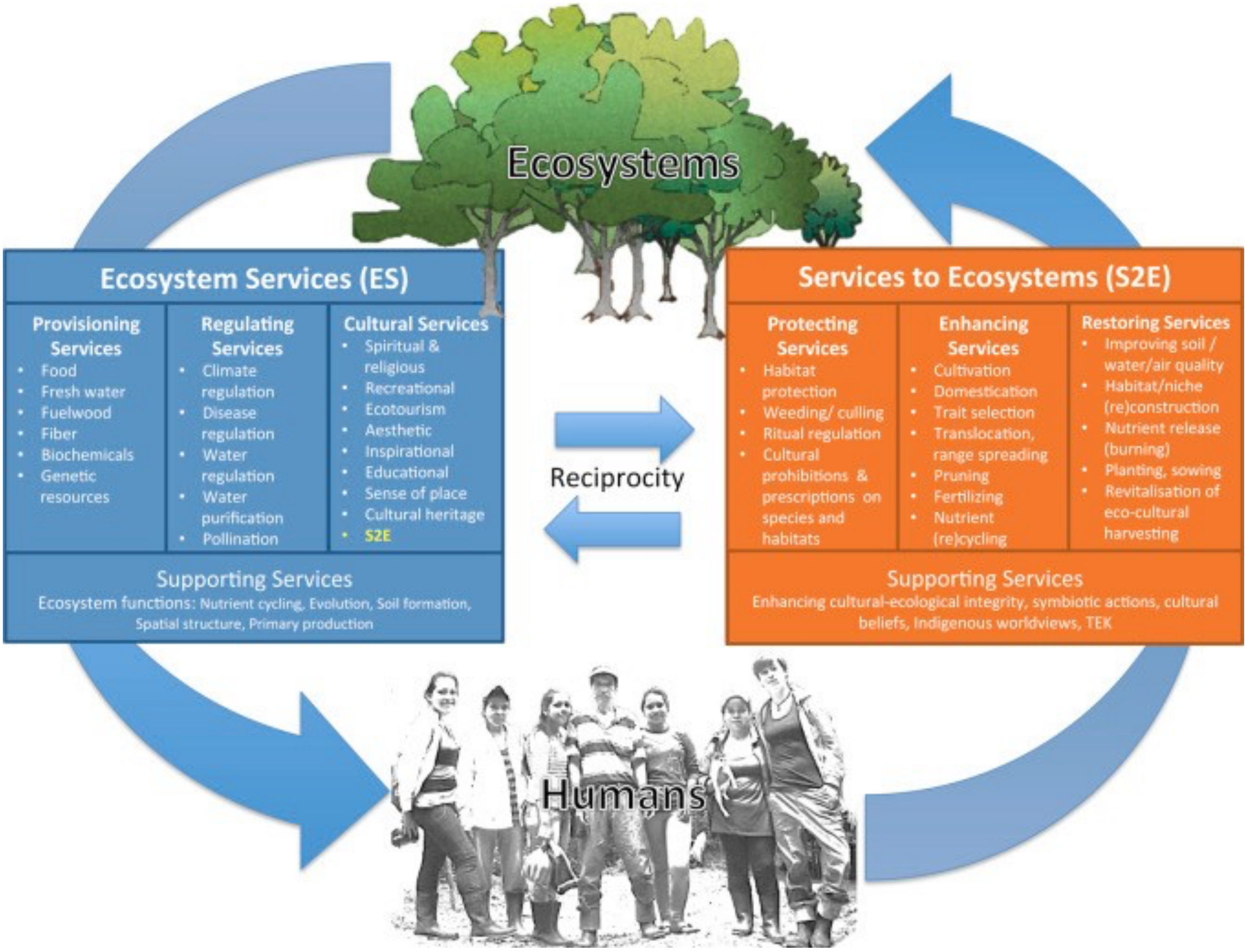


Figure 5-2. Reciprocity between humans and the environment.

Source: Comberti et al. (2015)

Ecosystem services face a range of challenges. Pollution can result in acidification of soil and water sources and can have impacts on plants and wildlife. Land-use changes and urban development can reduce and fragment open space, impacting the viability of ecosystems and their services. Meanwhile, climate changes are fundamentally altering the habitats, fauna, and flora of ecosystems and the services provided by those systems across the globe. These climate impacts will require considerable adaptation for ecosystem services to remain viable or we will suffer a concomitant change in the level of services provided. Ecosystem management and conservation activities are common methods to protect ecosystems and maintain the services they provide, avoiding the need for costly alternative providers of service.

Communities sometimes promote activities to provide the ecosystem services that are in jeopardy. A common practice is “wetlands mitigation”—in which lands are set aside for development of wetlands to compensate for wetlands where disruption or destruction was unavoidable. One concern is that the constructed wetlands may never fully achieve the services that were provided by the original wetland, so it often better and more cost-effective to avoid the damage in the first place.

Tyndall Air Force Base implemented resilience initiatives oriented toward operational recovery and response. Ecosystem services were also employed in these SRR guidance case studies in Appendix A: DeSale; Shark River; Berry Lane; Iron Mountain.

5.6.2 **Valuing Ecosystem Services**

There are many "tools" used to compare costs and benefits of ecosystem services, including land acquisition and conservation easements, as well as sustainable land management practices that protect important ecosystem services (USEPA 2017b).

There are two main ways to assign value to ecosystem services: avoided costs and replacement costs.

Avoided costs refer to costs that are not incurred because ecosystem services are protected or preserved (see Hu 2018)

Replacement costs are the costs of engineered systems to replace ecosystem services (for example, engineered stormwater systems to replace natural functions; see ITRC's Stormwater Best Management Practices Performance Evaluation guidance (ITRC 2018b).

Each remedial site should not only look to the technical aspects of cleanup, but also to the end use. Regulators are responsible for making a variety of decisions related to community growth and change, and many of these decisions directly affect ecosystem services. For example, decisions concerning the location and design of remediation—including infrastructure facilities and activities—will have significant impacts on the extent to which existing ecosystems will be able to provide services to the community. Markets have emerged to compensate landowners for the ecosystem services their land provides. Through these markets, buyers (governments, nongovernmental organizations, corporations) purchase credits from sellers (landowners), who provide ecosystem services through conservation or sustainable land management practices. Examples of successful markets include those for trading sulfur dioxide emissions and for wetlands mitigation.

New approaches to conservation are emerging that may expand the valuation of ecosystem services. Markets and payments for carbon sequestration, watershed management, ecotourism, and a host of other services may supplement traditional valuations and promote good stewardship, especially when used together with other conservation tools. The US Forest Service (USFS) has published information on valuing ecosystem services.

5.6.3 **Involve Community Stakeholders**

Community stakeholders can be engaged in the valuation process to identify the best method to use to determine the values (see Section 5.9.1.5). Stakeholders should remain involved and informed throughout the analysis to ensure that the process remains transparent. At the beginning of the process, key stakeholders should be identified for involvement. Stakeholder groups to be considered would include community members, interest groups, agencies, and elected officials. Community members should be engaged to develop a common vocabulary on ecosystem services and identify broader community goals. Discussions with stakeholders should be held in order to find out what have historically been issues in the community. They may have anecdotal information that could lead to discovering other issues. It is helpful to establish relationships and solicit inputs from interest groups that will benefit from the ecosystem services, such as agriculture, recreation, and ecotourism, to help fine-tune needs and project requirements.

Stakeholders can be enlisted to help with the inventory of ecosystem resources. Activities conducted with stakeholders should be consistent with plans that are in place. Partnering with local government officials can help to identify mechanisms in place that are impeding any natural resources functions.

Meetings with the public should be conducted to discuss outcomes and products of the ecosystem inventory and associated issues. The focus of the meeting should be on ecosystem service benefits, and costs incurred if those benefits are decreased. Open communication in these meetings is encouraged in order to allow for questions and comments and an openness to change. The goal is for stakeholders to "own" part of the process and the outcome along with the project leaders.

Stakeholder involvement in alternatives analyses is encouraged in order to identify scenarios that address the community needs or issues. Any actions taken should be consistent with existing planning and implementation mechanisms.

5.6.4 **Expert Help to Protect Ecosystem Services**

Sustainable land management practices promote ongoing sustainable management of resources for productive use. There are governmental programs and funding to protect land and their associated ecosystems. For example, the USFS Forest Stewardship program assists landowners through the state and private forestry programs to promote land stewardship and agroforestry practices that will result in long-term sustainability of forest resources and landscapes. The U.S. Department of Agriculture (USDA) can provide technical support through extension offices situated in many counties and universities throughout the nation. Also, nongovernmental agencies and conservation groups can provide technical expertise and volunteers to help transform remedial sites into areas that return ecological services to nature and the community.

5.7 Green Infrastructure and Resiliency

Green infrastructure refers to ecological systems, either natural or engineered, that use or mimic natural processes to sequester, infiltrate, evaporate, transpire, or reuse stormwater. Green infrastructure helps manage destructive precipitation and can help mitigate potential flooding in communities. These ecological systems provide a service in terms of sustainability and resiliency. Green infrastructure also has preferable attributes such as lower maintenance and cost, and improved access. Some green systems are resilient with respect to flooding, drought, wildfire, temperature extremes, and salt-water intrusion.

Green infrastructure provides many benefits by reducing capital investment in built (gray) infrastructure for stormwater control and management, thereby slowing erosion, improving aquifer recharge, and lowering energy use. When effectively managed, human health benefits are improved from reduced pollution and heat stress, as well as cultural, societal, and aesthetic benefits from access to safe, green space. Green infrastructure projects may provide refuge for threatened and endangered species, provide a safe space for pollinators, and help sequester GHGs. But green infrastructure projects may be limited by restrictive land-use regulations, by access issues, or by the available diversity of plants and/or animals. These projects may also create adverse site characteristics due to changes in climate, soils, and/or habitat, which may cause an increase in nuisance plants or animals. Adverse changes to green infrastructure can often affect the chance or intensity of wildfires and flooding.

Sociocultural changes, specifically reliance on controlled-temperature interiors, tend to limit usefulness of some green infrastructure measures. Green roofing allows buildings to naturally regulate their thermal environment by:

- Retaining heat during the cool period by insulating the building
- Deflecting heat during the warm period by reflecting solar radiation and absorbing solar radiation through photosynthesis and evapotranspiration of the vegetation.

Extreme temperatures may bring the building interior beyond comfortable levels and require the ongoing use of heating and cooling systems (for example, HVAC, furnace, air conditioners).

More and more communities are employing green infrastructure and conservation of surrounding watersheds to improve resilience to changing climates (Cassin 2019). For instance, increased development around Boston, Massachusetts, during past decades eliminated many wetlands and increased roadways, parking lots, and other impervious surfaces. A series of dams along the Charles River historically controlled flooding, but these dams had insufficient capacity for large precipitation events, which have become more common. Rather than build more dams at great environmental, social, and economic costs, the U.S. Army Corps of Engineers, the city, and surrounding communities agreed to set aside from development and protect the remaining wetlands by creating the Charles River Natural Valley Storage area. These wetlands provide critical green infrastructure and flood resilience to the city, and expand recreational amenities for the entire region.

5.7.1 **Opportunities for Green Infrastructure in Site Remediation**

During the past 25 years, the ITRC has focused on cleanup and has produced many documents related to technologies. Many of these technologies (linked below) may also have a green infrastructure and/or sustainable option that may help reduce costs, improve cleanup efficiencies, and expand community acceptance.

- In Situ Bioremediation – The In Situ Bioremediation (ISB) documents address the systematic characterization, evaluation, and appropriate design and testing of ISB for biotreatable contaminants.
- Bioremediation of Dense Non-Aqueous Phase Liquids (DNAPLs) – These documents address the selection and design of ISB systems for chlorinated ethene DNAPL source zones, as well as technical and related regulatory considerations (ITRC 2005, 2007, 2008b).
- Enhanced Attenuation: Chlorinated Organics – The Enhanced Attenuation (EA): Chlorinated Organics document provides direction to regulators and practitioners on integrating EA into remedial decision making for a smooth transition between aggressive remediation and monitored natural attenuation (ITRC 2008a).
- Enhanced In Situ Biodenitrification – This document addresses nitrate-contaminated groundwater, which is associated with environmental and health problems, and an emerging technology for remediating and protecting public and domestic supply wells (ITRC 2000).

- Natural Attenuation – The Natural Attenuation documents provide a framework for thinking about natural attenuation based on science, focusing on the basic information needed to determine and document the conditions necessary for natural processes to be an effective part of remediating contaminants in groundwater.
  Phytotechnologies – These documents provide practical information on the process and protocol for selecting and applying various plant-based technologies to remediate contaminated soil, groundwater, surface water, and sediments (ITRC 2009).
- Stormwater – This guidance is intended to provide a nationwide perspective on the challenges facing the stormwater industry in evaluating the performance of postconstruction BMPs throughout a project life cycle. The guidance describes historic, existing, and developing postconstruction BMP performance verification and certification programs and captures existing program data in a new BMP screening tool to assist practitioners during the design of projects (ITRC 2018b).

5.7.2 **Brownfield Sites**

Cities are redeveloping brownfield sites, properties where the presence (or likely presence) of contaminants could complicate redevelopment or reuse (see Section 5.5). Integrating green infrastructure into these sites can benefit the environment and the community. But implementing infiltration-based stormwater management practices must be done carefully, so contaminants in the soil are not mobilized, increasing the risk of groundwater contamination.

It is important to perform site analysis and planning during the design and planning stages of any remedial project. In 2013, the USEPA released Implementing Stormwater Infiltration Practices at Vacant Parcels and Brownfield Sites (USEPA 2013b). This document guides decision makers through a series of questions to determine whether infiltration or other stormwater management approaches are appropriate for a specific brownfield property.

The creation of public green space on a brownfield site is considered a “soft reuse,” where the soil remains unsealed, versus a “hard reuse,” where the soil is covered by “built” structures or infrastructure. It may be difficult to monetize benefits of soft reuse (sustainable) services for the restoration of brownfields. A brownfield opportunity matrix is proposed to compare soft- versus hard-reuse options through sustainability linkages (Bardos et al. 2016). The CSM can provide the linkages between the services provided by the green infrastructure (ecosystem) and the overall costs for the restoration project (Bardos et al. 2016).

Demonstrating the economic merits of green infrastructure practices is integral to acceptance, funding, and implementation. A robust comparison of sustainable alternatives will help communities decide where, when, and to what extent green infrastructure practices should become part of future planning, development, and redevelopment. A recent guide provides methodology and considerations for detailed calculations of most ecosystem services provided by green infrastructure alternatives and across regions (CNT 2011).

Incorporating green infrastructure into a site remedy can reduce overall costs and improve sustainability if the project uses renewable resources (wholly or mainly), and green infrastructure provides habitat and promotes a varied ecosystem. If businesses in the surrounding community are hired to supply materials, plants, and labor for building green infrastructure projects, then the local economy and community will also benefit from the project.

5.7.3 **Flooding Resilience for Green Infrastructure**

Resilience may be a concern for sites and facilities that rely on infrastructure and/or utilities to maintain operations. During extreme climate scenarios, even green infrastructure may not be sufficiently resilient to withstand weather extremes. While smart landscaping or other, common sense measures can slow a small or slow-moving fire, long periods of hot, dry weather combined with winds can create firestorms that can leap over these preventive measures. Most floods can be managed by floodplain or building restrictions and improved infiltration measures; however, extreme flooding can overwhelm the capacity of even large acres of floodplains and wetlands. While resilient to most weather conditions, even green infrastructure may be burned or washed away during extreme events. Selecting native plants for bioretention structures will ensure the plants can tolerate typical temperature and precipitation ranges experienced in their habitat, without relying on lawncare and climate control measures to thrive. This practice allows the designed and constructed green infrastructure to be more resilient to climatic fluctuations.

Figure 5-3. Examples of green infrastructure (left: retention basin; right: permeable pavement) that mitigates flooding and high temperatures while allowing infiltration to help replenish the local groundwater system during drought conditions.

Sources: Klausing Group. Unilock Turfstone. Used with permission.

In some instances, green infrastructure is more resilient than engineered landscapes to cope with increased risk of floods and droughts. One community (Napa, California) solved flooding problems by restoring the Napa River's natural channel and wetlands (that is, allowing floodplains and infiltration to mitigate flooding) instead of lining the river with concrete. The natural landscaping also benefits the local community by providing new parks and open space (Figure 5-4). The consequences of drought can be mitigated by installing green infrastructure; during infrequent rainfall events, rainwater has time to infiltrate where it lands instead of contributing to a flash flood. Local infiltration benefits the wider ecosystem as the rainwater replenishes groundwater stores, maintains baseflow toward local rivers and streams, and can be used during times of surface-water shortage.

Figure 5-4. Examples of green infrastructure installed to mitigate the effects of and be resilient in the face of flooding (Napa, CA). Flood terrace restoration near the confluence of Sulfur Creek (left) and regraded bank with a wider setback and gravel/cobble bar (right) in St. Helena, CA.

Source: Napa County Stream Maintenance Manual. Used with permission.

Top-down and stakeholder-supported considerations are needed to mitigate deleterious and costly effects from uncontrolled or unmanaged volume and movement of water across the landscape, and to speed recovery from damaging events. USEPA's [Community Flood Resilience checklist] provides an excellent summary of issues.

5.7.4 **Wildfire Resilience for Green Infrastructure**

Green infrastructure and the ecosystem services it provides are typically devastated by wildfires. Loss of fauna, flora, clean water, and habitat is often sudden, catastrophic, and may take many years to recover in a manner that will support a wide diversity of plants and animals (see Section 7.7).

Post-wildfire concerns include flooding and mudflows. Depending on the loss or accumulation of soils from flooding or mudflow, the vegetation will experience drastic changes. Invasive plants—often nonnatives—will grow, which will significantly change the soil structure and associated animal species (see Section 7.8).

New contaminants may be introduced into the environment, raising health and safety concerns after a wildfire, either by short-term exposure to water or inhalation or other factors such as things burned (that is, building materials, vehicles) or by dispersal of contaminated surface soils by winds or floods. Long-term, residual contamination of soils from wildfires can cause persistent exposure hazards to humans and wildlife.

Green infrastructure projects and measures can speed the recovery process by controlling erosion, protecting surface waters, restoring nutrient cycling, and rebuilding the area’s to support plants and animals, including those used for agriculture (USAID 2017).

Several tools exist to determine whether a site or community is prepared for wildfire events, such as the Fire-Adapted Network’s community assessment tool.

5.8 Selecting Sustainable and Resilient Passive or Low-Energy RemediationTechnologies

When considering a remediation technology, it is a good practice to first identify the remediation concerns for the site. This will aid in establishing the remediation goals and determining the remediation cleanup objectives. More information about identifying concerns, establishing remediation goals, and determining remediation cleanup objectives is found in ITRC's Light Non-Aqueous Phase Liquid Site Management Guidance (ITRC 2018a). In addition to meeting the cleanup objectives, technologies with sustainable practices that help the environmental, economic, and social benefits of the cleanup can be considered (Section 6.3.5.2). Sustainable resilient remediation technologies (Section 6.3) use natural resources and energy efficiently, reduce negative impacts on the environment, minimize or eliminate pollution, and reduce waste to the greatest extent possible (USEPA 2008). Sustainable and resilient cleanup technologies can be evaluated once the investigation portion of the conceptual site model (CSM) has been built. The next step is to build or update the remedy selection and remedy design portion of the CSM. Sections 6 and 7 of this guidance, along with ITRC's Green and Sustainable Remediation: A Practical Framework (ITRC 2011a) and Green and Sustainable Remediation: State of the Science and Practice (ITRC 2011b) are good resources for approaches and BMPs that should be considered when building the CSM.

5.8.1 Characterizing the Site

When determining which remediation system to select for cleanup at a site, it is important to first characterize the nature and extent of the contamination and its relation to the site setting and hydrogeology. This is a critical step for cleanup decision making. It is also critical to gather information and considerations specific to the contamination relating to the risks of the contaminant source, exposure pathways, and receptors. This information should be shared with the community and stakeholders to enlist their perspective and concerns.

For example, some of the questions to fully consider before selecting a remediation system at the site are:

- Does the contamination pose a risk to human health or the environment?
- Is the contamination migrating?
- Will the remediation technology address the regulatory requirements?
- How resilient are the technologies to future impacts due to climate change?
- What is the future use planned for the site?
- What are the concerns of the stakeholders or community?

5.8.2 Transitioning to Sustainable and Resilient Remedial Technologies

To continue to make progress in the cleanup, many sites will require adaptive strategies. Typically, this may include transitioning to different remediation technologies over time. This will be necessary to achieve the remediation cleanup goals and address the contamination concerns at the site. Over the time span of the cleanup, remediation technologies will likely need to be transitioned when the remediation technology has reached its technological endpoint or when site conditions and contamination levels change. These transitions are opportune times to look at sustainable and resilient cleanup technologies and practices. While transitioning remedies to a passive or low-energy remedial technology is also an excellent time to engage or reengage the stakeholders and community on any social and economic values (including costs).

5.8.3 Selecting Goals

Remediation technologies can be selected that can be adapted to the site conditions or adapted to the needs or reuse requirements of the site or community concerns. In addition to transitioning remediation technologies to meet cleanup and risk goals, economic and social needs for the site and surrounding community should be evaluated and achieved. Examples of characteristics for more sustainable remediation technologies include:

- remediation technologies that are adapted to the desires of stakeholders and the community where the remediation or reuse is occurring
- sustainable and resilient remedies that will be less impacted by extreme weather, flooding, wildfires, and power outages
- remediation technologies that are adapted to fit within the needs of community development and social needs
- remediation technologies that use less energy, are less noisy, and are less disruptive to the stakeholders and community
- remediation technologies that have a smaller carbon footprint and are more cost-effective and adaptive to the social and economic conditions of the site or the community where the remediation is occurring

If exposure to the contamination and risk to human health and the environment are under control, transitioning to a passive or low-energy remediation technology can be considered. Passive technologies often use less energy and can be more resilient to extreme weather. Depending on site conditions, some of these technologies can be powered by wind or solar energy. Some of the technologies require no external energy source. This would reduce the carbon footprint of the remediation technology compared to a technology that uses large amounts of energy.

5.8.4 Passive or Low-Energy Remediation Technologies

Table 5-2 lists examples of several passive or low-energy remediation technologies that can be considered for light nonaqueous phase liquid (LNAPL).

Table 5-2. Passive or low-energy remediation technologies to treat LNAPL (ITRC 2018a).

Technology	Description
Biosparging/bioventing	This process is similar to air sparging/soil vapor extraction, except air/oxygen is injected more slowly with the main goal being stimulation of aerobic biological degradation of organic contamination (such as LNAPL) in the saturated and unsaturated zones. Various configurations are possible, including inducing airflow into the unsaturated zone by extraction of soil vapors.
Enhanced anaerobic biodegradation	Enhanced anaerobic biodegradation involves supplying electron acceptors other than oxygen (e.g., nitrate and sulfate). Anaerobic biodegradation can also be achieved by increasing the subsurface temperature to increase the natural biodegradation rates.
Natural source zone depletion	LNAPL is degraded via naturally occurring processes of biodegradation, volatilization, and dissolution. The predominant process is biodegradation, including direct LNAPL-contact biodegradation. LNAPL constituents dissolve, biodegrade, volatilize, solubilize in soil moisture, and also subsequently biodegrade further in the vadose zone. Biodegradation produces gaseous products, such as methane and carbon dioxide, and ultimately completely mineralizes the LNAPL.
Phytotechnology	Phytotechnologies use plants to remediate or contain contaminants in the soil, groundwater, surface water, or sediments. Phytoremediation is generally considered a phase-change technology, enhancing subsurface biodegradation, but, to a lesser extent, can also be considered mass control technology if designed for hydraulic control.

In addition to LNAPL technologies, USEPA's green remediation primer (USEPA 2008) provides a discussion of how energy-intensive remedies can be transitioned to more natural, low-energy treatment processes such as enhanced aerobic bioremediation, permeable reactive barrier walls, engineered wetlands, and monitored natural attenuation (ITRC 2011a). For more examples of passive or low-energy remediation technologies, please refer to other ITRC documents below.

- LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies (ITRC 2018a)
- Remediation Management of Complex Sites (ITRC 2017)
- A Systematic Approach to In Situ Bioremediation in Groundwater, Including Decision Trees on In Situ Bioremediation for Nitrates, Carbon Tetrachloride, and Perchlorate (ITRC 2002)
- Remediation Process Optimization: Identifying Opportunities for Enhanced and More Efficient Site Remediation (ITRC 2004)
- Optimizing In Situ Remediation Performance and Injection Strategies (ITRC 2020a)

Other GSR and infrastructure examples can be found in Section 5.5.1.4. Information and examples using passive ecosystem services and infrastructure for remediation can be found in Section 5.6.

Transitioning to a passive remediation technology can be sustainable and resilient if it addresses the cleanup goals and site conditions, is protective of human health and the environment, meets regulatory requirements, and addresses the concerns of the community and stakeholders.

5.9 Social and Economic Impact Evaluations

This section provides an overview of the process, indicators, and tools to evaluate social and economic impacts from cleanup activities and subsequent land revitalization. The identification and selection of sustainable resilient indicators and tools to be applied should be informed by the CSM, stakeholder needs and concerns, risk management strategies, and future use scenarios. Applicable metrics and tools to evaluate project specific sustainable resilient indicators will likely evolve throughout project planning and implementation of cleanup activities. We recommend that you develop sustainable resilient objectives to guide the formulation of project specific **SMART** (that is, **s**pecific, **m**easurable, **a**ttainable, **r**elevant, and **t**imely) goals focused on SRR process implementation to help attain those objectives. Once developed, the goals and objectives must be regularly revisited and revised as needed to ensure appropriate project progress. Note that conducting a stakeholder engagement session with a community is not the same as consideration and assessment of the impacts on social, economic, and environmental factors of a project. The latter is a process to evaluate sustainability impacts, which may include stakeholder engagement activities to obtain input.

Social and economic factors can be represented as indicators of either beneficial or unintended impacts of cleanup and restoration activities. These indicators are helpful when articulating what socioeconomic impacts mean in the context of the project, and in measurable ways to define and evaluate a project's broader sustainable and resilient risk management goals. Using these indicators to communicate with stakeholders is also beneficial to support project decision-making rationale and evaluate the SRR return on investment (S-ROI). Table 5-1 provides ten main social and economic goals and broad indicators. These indicators and related impacts may be applicable in a short-term, interim, and/or long-term context.

Examples of SRR goals applicable to the remedy implementation stage are:

- consideration of site worker and community health and safety during operation under normal and severe weather event conditions
- mitigation of unintended community impacts due to cleanup activities
- stimulation of the local economy

Examples of SRR goals applicable to the land restoration/revitalization stage are:

- maximization of S-ROI of cleanup activities, such as mitigation of community displacement and other social justice concerns due to revitalization
- restoration of ecosystem services for wildlife habitat, recreational use, and/or storm-surge protection
- implementation of risk-based land management to facilitate property reuse in a timely manner

The social dimension of SRR includes consideration of stakeholder concerns and needs. In this context, multiple stakeholder values inform site-specific objectives, goals, and processes of an SRR assessment (Cundy et al. 2013). Stakeholder identification is an important part of the engagement process (Ridsdale and Noble 2016). Different stakeholder groups need different levels of engagement at different stages of the project life cycle—for example, those directly affected and those indirectly affected. Research has shown that when communities are consulted adequately, perceptions of sustainability are increased (Fidler 2010), and acceptance of project decisions and outcomes is easier (Greenberg and Lewis 2000). Alternatively, when communities are not consulted, they feel more distrust and are less agreeable to final outcomes (Letang 2017). The next section will provide an overview of stakeholder engagement methodologies. Additional resources can be found in Section 6.1.2, Stakeholder Engagement.

5.9.1 **Select Metrics, SRR Evaluation Level, and Boundaries**

ITRC has developed a three-level approach to conducting GSR evaluations as described in the GSR-2 technical and regulatory guidance document (ITRC 2011a). This approach provides different levels of detail for GSR evaluations and embraces the concept that GSR evaluations are scalable to any type of project or site. Level 1 evaluation can be achieved for all project types by implementing SBMPs to maximize relatively easy sustainability gains from site activities. Levels 2 and 3 evaluations consist of Level 1 BMPs and either a “simple” or “complex” value assessment. The results of SRR evaluations and assessments provide optimization opportunities that can benefit projects by comparing remedial solutions for their social, economic, and environmental values (benefits and costs).

The ITRC GSR three-level evaluation approach includes consideration and assessment of social, economic, and environmental indicators of SRR. Subsequent information presented herein provides a compilation of resources, methods, and tools to support an SRR evaluation in the context of social and economic indicators. This compilation is comprehensive but not necessarily all encompassing, as additional indicators, metrics, and tools may be applicable and pertinent. To learn more about how to apply the GSR three-level evaluation to project planning, see Section 6.1.5.2, Determine SRR Evaluation Level. We recommend that you engage an SRR subject matter expert to support determination of the level of evaluation that is in alignment with site-specific objectives and goals.

*5.9.1.1 **ITRC GSR Level 1 – Best Management Practices***

The objective of the ITRC GSR Level 1 approach is to adopt BMPs based on common sense to promote resource conservation and process efficiency (ITRC 2011a, b). This objective can be expanded upon to adopt BMPs to promote quality of life improvements and mitigate unintended impacts that directly affect the community and indirectly affect broader society.

Table 5-3 presents a resource summary to help practitioners identify, prioritize, track, evaluate, and report social and economic BMPs and related indicators that best represent their project. The GSR Level 1 approach is a basic desktop analysis of these resources and subsequent implementation of BMPs.

More information on the process of BMP identification, selection, implementation, and tracking can be found in ASTM E2876 – 13 Standard Guide for Integrating Sustainable Objectives into Cleanup (ASTM 2013a) and the ITRC GSR-2 Guidance (ITRC 2011a).

Table 5-3. Level 1 social and economic BMP resources.

Social and Economic BMPs Resource	Resource Summary
ASTM E2876 – 13 Standard Guide for Integrating Sustainable Objectives into Cleanup (ASTM 2013a)	Appendix X1 presents a comprehensive sustainable remediation BMPs list to serve as a starting point for practitioners. This list may be added to or modified based on additional resources and site-specific factors.
USEPA 542-R-17-004 Ecosystem Services at Contaminated Site Cleanup (USEPA 2017b)	This document provides examples of greener cleanup BMPs that address ecosystem services.
Institute for Sustainable Infrastructure Envision Pre-Assessment Checklist	This simple self-assessment preplanning checklist evaluates project sustainability by increasing awareness of issues, including quality of life, leadership, resource allocation, natural world, and climate and risk.
Section 5.4, Social and Economic Sustainability Through Constructive Change and Protective Remedies	Section 5.4 of this document discusses consideration of social and economic indicators, including ecosystem services, quality of life, and mitigation of climate change impacts.
U.S. NOAA, Fisheries Community Social Vulnerability Indicators (CSVIs)	The CSVIs data series from 2009 to 2016 consists of a suite of indicators that describes and evaluates a coastal community's ability to respond to changing social, economic, and environmental conditions.
Sustainable Remediation Forum – United Kingdom (SuRF-UK)	Supplementary Report 1 of the SuRF-UK Framework: A general approach to sustainability assessment for use in achieving sustainable remediation Supplementary Report 2 of the SuRF-UK Framework: Selection of indicators/criteria for use in sustainability assessment for achieving sustainable remediation Both available (free) from https://www.claire.co.uk/projects-and-initiatives/surf-uk

5.9.1.2 *ITRC GSR Level 2 – BMPs and a Simple Evaluation*

The ITRC GSR Level 2 evaluation approach combines the selection and implementation of BMPs with some degree of qualitative and/or approximate quantitative evaluation (ITRC 2011a, b). This level of evaluation assesses how site cleanup and restoration activities may result in beneficial or unintended social, economic, and environmental impacts. The ten main social and economic goals and broad indicators presented in Table 5-1 provide a foundation to identify and select metrics that can be evaluated qualitatively or semi-quantitatively. Identified stakeholder concerns and needs should also be considered in the assessment. Table 5-4 summarizes methods and tools to perform an approximate quantitative evaluation of social and economic impacts. Table 5-5 provides market and nonmarket inputs for an enhanced cost-benefit analysis.

Table 5-4. Level 2 social and economic impact evaluation methods.

Method	Method Summary
Rating and Scoring System (Harclerode et al. 2015)	This is a technique used to summarize and communicate information crucial to the decision-making process. This method includes a rating metric and an aggregation rule that combine individual ratings into a single overall score. Remediation decision makers are then able to draw conclusions based on the results of the scoring.
Social Sustainability Evaluation Matrix (SSEM) Tool (Reddy, Sadasivam, and Adams 2014), *a rating and scoring system*	This Excel-based tool evaluates impacts across the four key social dimensions: (1) social-individual; (2) socio-institutional; (3) socioeconomic; and (4) socio-environmental. A series of key measures (i.e., impact indicators) is listed for each dimension.
Institute for Sustainable Infrastructure EnvisionOnline Scoresheet, *a rating and scoring system*	This system provides an online scoresheet for rating achievement toward sustainability credits encompassing quality of life, leadership, resource allocation, and natural world, as well as climate and risk sustainable and resilient metrics.
Ecosystem Services at Contaminated Site Cleanup (USEPA 2017b)	Appendix A presents a compilation of evaluation tools that have been developed for different ecosystems, levels of technical expertise, management questions, and anticipated outputs. Types of tools include maps and spreadsheet kits.
Enhanced Cost-Benefit Analysis (CBA) (Favara et al.2019, Harclerode et al. 2015)	A CBA accounts for and compares all the benefits and costs of particular courses of action. Recently, the cost analysis of remedial activities has been extended to include socioeconomic factors, resulting in a CBA focused on social feasibility. This enhanced CBA evaluates whether the monetized benefits to society exceed the monetized costs to society of undertaking particular courses of action. At the Level 2 GSR evaluation, market and nonmarket inputs are assessed by a semiqualitative/semiquantitative approach using publicly available information. Integration of cost metrics can help practitioners normalize disparate sustainability metrics into one unit for ease of comparison. These market and nonmarket inputs can also serve as indicators or metrics for project decision making even if a CBA is not performed.
Social Science Methodologies to Support Qualitative Assessment (Harclerode et al. 2015, Ridsdale and Harclerode 2019)	1) *Surveys* are an inexpensive method that allows the remediation practitioner to evaluate generalizable social impact indicators, perceived local economic benefits, and community well-being. Surveys can be transparent communication tools, as there is negligible subjectivity in compiling answers, and the community can fully participate in the review of survey results, which can be used to address community concerns and identify areas where knowledge transfer to the community is needed. 2) *A design charette*is a collaborative platform during which stakeholders can sketch designs to explore and share a broad diversity of site restoration and redevelopment ideas. 3) *Social network analysis* is a complex method recently introduced in environmental management. For sustainable remediation, the method appears to be promising, as it can offer valuable insights into how stakeholders are involved in remediation processes rather than how remediation practitioners choose to involve them.
Multi-Criteria Decision Analysis (MCDA) (Favara et al.2019, Harclerode et al. 2015)	MCDA is a tool used to evaluate multiple site-specific cleanup criteria, including SRR indicators. For example, stakeholder input presents their level of preference on criteria used to select a proposed project, remediation alternative, or preferred land-use scenario.

Additional resources: (CRCCARE 2018, Harclerode et al. 2015)

Table 5-5. Enhanced cost-benefit analysis market and nonmarket inputs.

Market Inputs	Nonmarket Inputs
• Capital costs • Operation and maintenance costs • Decommissioning costs • Redevelopment costs • Property value increase (benefits) • Employment opportunities (benefits) • Local business stimulation/revenue (benefits)	• Relative societal externalities associated with emissions generation and natural resource consumption (costs) • Value of natural resources protected (benefits)/damaged (cost) • Value of ecosystem services enhanced or restored (benefits) • Improvement in quality of life from remediation/redevelopment (benefits)

5.9.1.3 ***ITRC GSR Level 3 – BMPs and Advanced Evaluation***

The ITRC GSR Level 3 evaluation approach combines the selection and implementation of BMPs with a rigorous quantitative evaluation (ITRC 2011a, b). This level of evaluation assesses how site cleanup and restoration activities may result in beneficial or unintended social, economic, and environmental impacts. The ten main social and economic goals and broad indicators listed in Table 5-1 provide a foundation to identify and select metrics that can be evaluated quantitatively. Identified stakeholder concerns and needs should also be considered in the assessment. Table 5-6 summarizes methods and tools that can supplement those presented in Table 5-4 to perform a quantitative evaluation of social and economic impacts.

Table 5-6. Level 3 social and economic impact evaluation methods.

Method	Method Summary
Institute for Sustainable Infrastructure Envision Framework	This is an in-depth guidance and rating system used to assess and improve the sustainability aspects of all types and sizes of infrastructure projects. A site can be Envision-verified by the Institute for Sustainable Infrastructure.
Ecosystem Services at Contaminated Site Cleanups (USEPA 2017b)	Appendix A provides a compilation of evaluation tools that have been developed for different ecosystems, levels of technical expertise, management questions, and anticipated outputs. Types of tools include software models.
Economic Valuation Techniques to Support Enhanced CBA (Harclerode et al. 2015, Favara et al. 2019)	Willingness to pay is the maximum amount an individual is willing to sacrifice to procure a good (such as a regional groundwater management program) or avoid something undesirable (such as contaminant mobilization due to a severe weather event). Opportunity cost is the loss of a potential benefit from other cleanup alternatives not applicable to the selected alternative. For example, the implementation cost of treated groundwater reuse for Alternatives A and C represents the opportunity cost for not implementing this sustainable practice under Alternative B.
Cost-Benefit and Sustainability Analysis (CRCCARE 2018)	Cost-benefit and sustainability analysis is an economic evaluation technique that combines elements of enhanced CBA and MCDA evaluation. Impacts that can be readily monetized are assessed as part of the enhanced CBA, while those impacts that can only be quantified are assessed as part of a standard MCDA. The results of the CBA and MCDA are then combined and assessed to maximize the sustainable and resilient outcome of cleanup and restoration activities.

*5.9.1.4 **Community Involvement and Stakeholder Engagement***

Community involvement and engagement of other stakeholders can play an essential role in identifying inadvertent or unintended impacts felt by community members. The social and economic impact evaluation methods presented in Section 5.9.1.3 can be performed with community members and other stakeholders as an engagement activity, in-person, virtually or web-based. The overall objective of community involvement in an SRR context is to gain deeper insight into community concerns and values throughout the project life cycle to inform decision makers and practitioners on cleanup activities and future use (see Section 5.9.1.5). Different levels of engagement are needed for various stakeholder groups (for example,those directly affected vs. indirectly affected), and those stakeholder groups may change during the project life cycle. Referto the Read More below for community involvement resources and tools.

Community engagement resources:

- ATSDR Principles of Community Engagement (ATSDR 2011)
- International Association of Public Participation spectrum of public involvement
  USEPA Superfund Community Involvement Handbook (USEPA 2020a)
- USEPA Risk Communication in Action: The Risk Communication Workbook (USEPA 2007)

The success of stakeholder engagement relies on identifying the appropriate stakeholders and knowing how and when to engage them most effectively. The ITRC Risk Communication Toolkit provides guidance and resources to perform stakeholder identification and assessment (ITRC 2020b). During community involvement and/or stakeholder engagement activities, the decision makers will learn who will be most affected by the site activities and their level of interest, knowledge, and concern. Don't assume that the lead organization and other decision makers understand the concerns of the people in the surrounding community. Recognize that people may be skeptical that the lead organization is telling the truth, cares about them, and is willing to work with them. Research the full range of opinions and concerns, including general attitude, knowledge, and perceptions about the cleanup activities. This can be accomplished by regularly asking community leaders and the stakeholders you are working with if there are other groups of individuals who are missing from the outreach and who should be involved. One of the best ways for regulators and responsible parties to reach stakeholders is to identify members of the stakeholder groups who are willing to act as liaisons between the community and the regulators (ITRC 2020).

Engaging the community and other stakeholders on community impacts from site activities can be controversial. This is understandable as issues of health and safety are of deep importance to communities. How a community and the stakeholders within that community view risk management efforts proposed or being performed will depend on myriad factors, including the community's and other stakeholders' trust in the agency or lead organization, the nature of the hazard itself, and a range of stakeholder characteristics, such as numeracy and scientific literacy. Therefore, early and effective stakeholder engagement is important. Community involvement and other forms of stakeholder engagement should emphasize timely access to data, transparency, and responsiveness to stakeholder questions and concerns DD(ITRC 2020b)D. Furthermore, it is beneficial to consider whether certain members of a community might bear a disproportionate burden of exposure to contaminants or unintended impacts from site activities.

USEPA's Superfund Community Involvement Toolkit is a comprehensive, complementary resource to the Community Involvement Handbook that provides detailed information and recommendations about specific aspects of the community involvement process, such as how to develop a community involvement plan, conduct community interviews, create a community profile, prepare fact sheets, and perform many other activities.

5.9.1.5 ***Conceptual Stakeholder Assessment Road Map***

Stakeholder engagement will assist practitioners in defining site-specific sustainability and resiliency objectives and goals, identifying indicators and metrics, and obtaining data to implement methods and tools to evaluate environmental, social, and economic impacts. The purpose and process of stakeholder engagement evolves throughout the project life cycle. During project planning, we recommended development of a site-specific stakeholder assessment road map to define the purpose and process of engagement, and most importantly the difference between the two. More specifically:

- Purpose: define level of stakeholder engagement versus outreach; discuss the reason(s) for engagement project
- Process: develop stakeholder engagement and outreach SMART goals; identify methods and tools to support stakeholder engagement and outreach activities in alignment with SMART goals; determine if regulatory authority risk communication and/or community involvement processes are applicable

SURF's Sustainable Remediation Framework calls for "a systematic, process-based, iterative, holistic approach beginning with the site end use in mind" (Holland et al. 2011, page 10). "This holistic approach can incorporate planning for uncertainty, reducing the rate and extent of local, regional, and global climate change impacts, and address social impacts, equity concerns, and opportunities. Setting criteria and indicators for measuring progress provide for more transparency and can gain stakeholder support" (Maco et al. 2018, page 10).

The purpose of the road map is to provide a simplified framework to assess the site-specific role of stakeholder engagement and to aid in engagement planning and execution. During project planning we recommend identifying stakeholder groups and defining their role and influence on decision-making milestones and development of SRR goals and objectives. Figure 5-5 presents a conceptual stakeholder assessment road map with the purpose of identifying and integrating stakeholder sustainability and resiliency values throughout the cleanup project life cycle (Favara et al. 2019, Ridsdale and Harclerode 2019). The process of stakeholder engagement is continuous and should be a means of partnership and information exchange. The conceptual road map shown defines four stages of stakeholder engagement summarized in Table 5-7. Ridsdale and Harclerode (2019) are currently developing the conceptual stakeholder assessment road map to facilitate SRR.

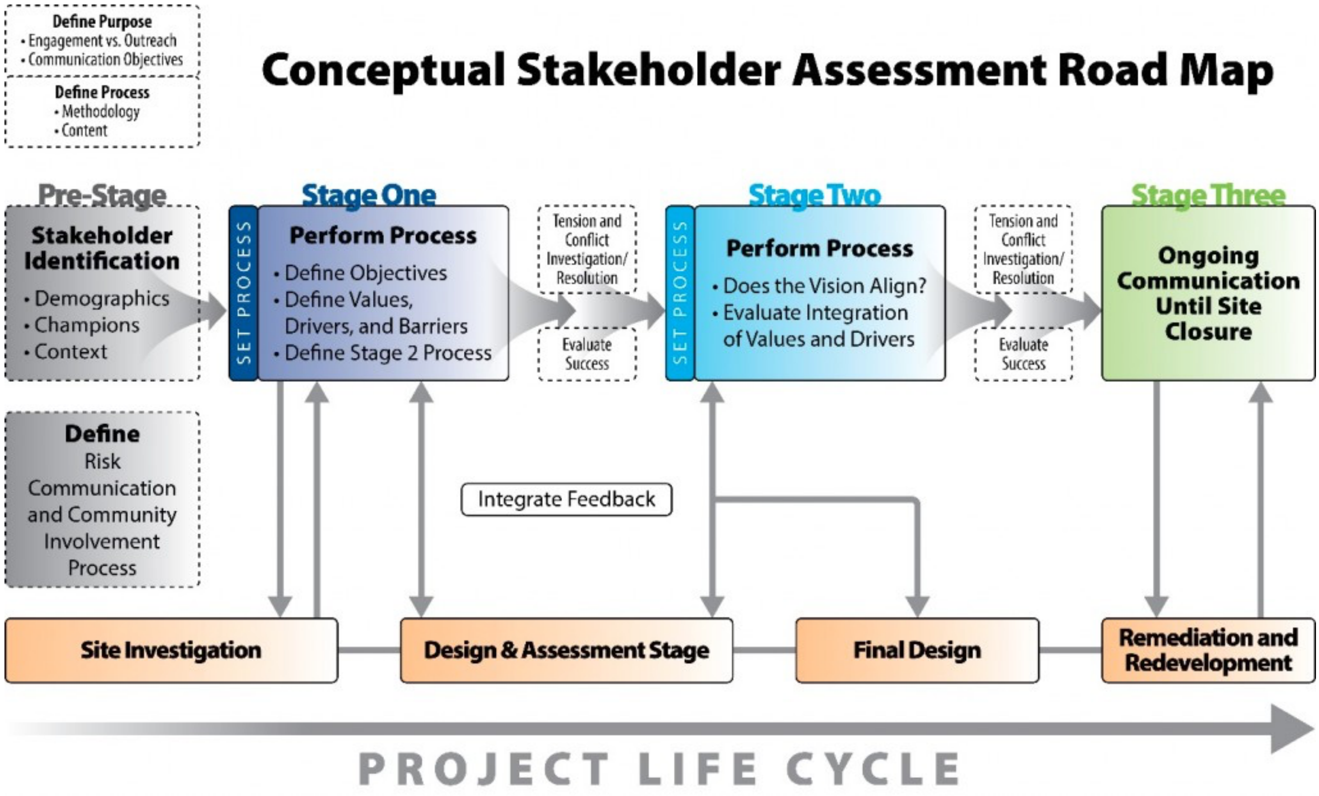


Figure 5-5. Conceptual stakeholder assessment road map.

Source: Ridsdale and Harclerode (2019). Used with permission.

Table 5-7. Conceptual stakeholder assessment road map objectives and implementation phase

Road Map Stage	Objectives	Project Life-Cycle Phase
Pre-Stage	• Define the purpose of stakeholder assessment for each site-specific project with project team • Identify stakeholders, context, and values • Define risk communication and community involvement strategies	Section 6.1, Project planning
Stage 1	• Define the purpose and level of stakeholder engagement for site-specific project with ongoing stakeholder input • Define SRR objectives • Engage stakeholders and identify values • Identify SRR drivers and barriers* • Define Stage 2 process with information gathered during engagement activities • Resolve conflict, as applicable	Section 6.2, Site characterization Section 6.3, Remedy planning
Stage 2	• Confirm SRR objectives were met or document justification for not meeting • Evaluate and debrief on integration of stakeholder values • Identify new or changed SRR objectives and stakeholder values • Resolve conflict, as applicable	Section 6.3, Remedy planning
Stage 3	• Perform ongoing communication on the status of cleanup and restoration activities • Identify and adapt to new or changed SSR objectives, stakeholder values, drivers, and barriers • Resolve conflict, as applicable	Section 6.4, Remedy execution Section 6.6, Site closeout

*see Harclerode et al. (2016)

Before undertaking any communication or planning with stakeholders, the core project team should have a discussion on what the known or anticipated SRR stakeholder values are for the project, in the context of the remediation site and the affected community. A desktop review of community demographic data and applicable news and social media can help a project team preliminarily assess stakeholder needs and concerns. This is considered "Pre-Stage" (see Table 5-7). Not all projects require the same level of engagement. Determination on the level of engagement and who should be engaged should be made during project planning and revisited as new stakeholder concerns and needs arise. Furthermore, individual stakeholders' interest in and influence on a project may change over time, prompting a revised or more comprehensive engagement strategy. Additional information on levels of engagement is provided in Section 5.9.1.4.

Stage 1 is identified as the first official stage of the engagement process and involves engaging stakeholders to define early SRR objectives and values. Stage 2 involves evaluating if remedial actions are in line with the stakeholders' needs and concerns, and if any conflicts arise, developing a plan to address them. This "conflict check in" is suggested to avoid a prolonged conflict, which may lead to project delays, uncertainties in public acceptance, or unwanted negative press. Stage 3 of the road map takes place during the remediation activities and involves continued communication with the stakeholders on progress, updates, and early identification of conflicts that may arise.

5.10 Case Studies

5.10.1 Phoenix Park, Camden, New Jersey

Phoenix Park (Figure 5-6) represents an example of how cleanup can support redevelopment, provide important local services, and build bridges with communities. Camden is an urban area in southern New Jersey that has a history of early industrial activity followed by a decline that has left the city with abandoned parcels that require cleanup. Camden County's Municipal Utility Authority (MUA), New Jersey Department of Environmental Protection (NJDEP), and the Camden Redevelopment Authority worked together with local community groups to turn a vacant riverside plot into much needed open space and stormwater management capacity that improved functioning of the city's water treatment system (Figure 5-7). Partnering with the local community and visioning uses that support environmental and social goals has turned this brownfield redevelopment into a shared resource that enjoys broad community support.

Figure 5-6. The location of Phoenix Park, in Camden, New Jersey, was an abandoned riverside industrial area that has been transformed into a walkable park that provides much needed stormwater management for this dense urban area.

Source: Photos courtesy of Camden County Municipal Utility Authority

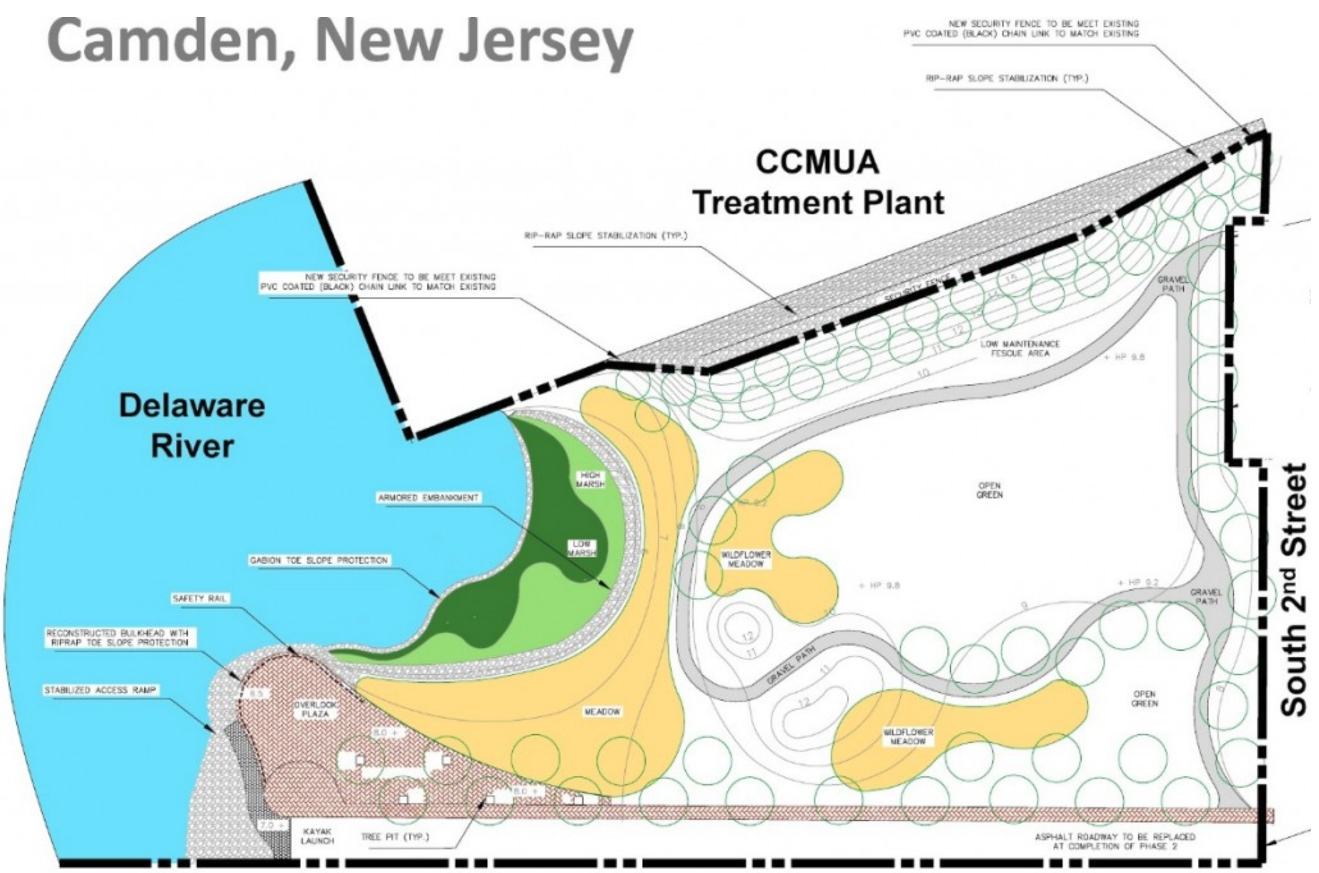


Figure 5-7. Site reuse plans show the ecosystem services and park spaces in this new open space.

Source: Photos courtesy of Camden County Municipal Utility Authority

Camden is a city in southern New Jersey, across the Delaware River from Philadelphia, with a population of almost 74,000. Historically, Camden was one of the major industrial centers of the Atlantic Coast, with a strong role in shipbuilding and metals processing. It was the home of Campbell's Soup and RCA Victor, a pioneer in phonograph production. Those industries largely abandoned Camden in the mid-20th century but left behind a legacy of environmental contamination that the city still struggles with to this day. With the flight of capital, the city has lacked the resources it needed to tackle both cleanup and infrastructure development.

The development adjacent to the Delaware River grew out of a partnership between Camden County's MUA, NJDEP, the Camden Redevelopment Authority, the City of Camden, Cooper's Ferry Partnership, Rutgers Cooperative Extension Water Resources Program, New Jersey Tree Foundation, and the Nature Conservancy. This strong partnership and a commitment to serve the needs of the communities who lived with the low-level radioactive waste contamination for decades resulted in green spaces and infrastructure.

The park occupies a 5-acre riverfront space next to Camden County's MUA wastewater treatment plant that was formerly occupied by a site known as American Minerals Industrial. Discussions with the community revealed a real need for green space in an urban environment that was mostly concrete and abandoned buildings. At the same time, the neighboring treatment plant was interested in separating the flows from a combined sewer system to focus on treating residential wastewater while diverting stormwater. To separate flows, the impervious surfaces that made up the vast majority of the site were removed. This allowed the stormwater to infiltrate into the ground surface, eliminating the need for storm sewer inlets, significantly reducing the stormwater flow into the combined sewers.

Listening to and involving local representatives throughout the process means that local communities feel connected to this park and have a sense of ownership. This collaboration helped rebuild trust between the community and government agencies, something that cannot be taken for granted when working with historically disadvantaged communities.

5.10.2 **Senator Joseph Finnegan Park at Port Norfolk, Boston, Massachusetts**

After more than 30 years, since residents first locked arms to block toxic dumping, the Shaffer Paper site in Dorchester, a neighborhood of Boston, Massachusetts, has been transformed into the Senator Joseph Finnegan Park at Port Norfolk (see Figure 5-8).

Figure 5-8. Senator Joseph Finnegan Park, an urban oasis along the Neponset River in Boston, Massachusetts.

Source: Photo by Halvorson Design. Used with permission.

This 12-acre waterfront park along the Neponset River is the last link of the 5-mile Neponset River Greenway, which provides a variety of scenery from urban wilderness through a mill village to a salt marsh at the mouth of the Neponset River. Located in Port Norfolk, a quiet, lovely historic neighborhood cut off from the rest of Dorchester by the interstate highway, the park was formerly a lumberyard, a commercial flounder fishing pier, and then an industrial area, which led to hazardous waste contamination by heavy metals and polychlorinated biphenyls (PCBs).

To ensure that site cleanup would result in a beautiful passive park for all to enjoy, while being protective of both human health and the environment, the Massachusetts Department of Conservation and Recreation engaged an integrated and collaborative team of an environmental consultant, landscape architect, and permitting specialist from the earliest planning stages through construction that executed the project within the allotted budget and time frame.

The Park was designed to sit lightly on the land and blend with the coastal environment. A site-specific risk assessment identified the areas of contaminated soils that required excavation and off-site disposal. A dilapidated sheet pile seawall was demolished and replaced with a living shoreline. Native saltmarshes were preserved and expanded, including transplanting a salt marsh which had grown on top of asphalt to a new location on a formerly rubble-strewn part of the bank. Park elements include paths, lawns, salvaged granite seat stones, and new trees and shrubs. Lawns were planted with native grass and wildflower species chosen to be wildlife-friendly, low maintenance, and drought-resistant. Structures were deliberately excluded from the park. The design incorporated greenspaces capable of absorbing floodwaters and rising water levels.

5.10.3 **Harrison Avenue Landfill/Cramer Hill Waterfront Park Project**

The Harrison Avenue Landfill is a former 86-acre municipal landfill in the Cramer Hill neighborhood of Camden, at the intersection of Harrison Avenue and East State Street, where the Cooper River flows into the Delaware River. The Harrison Avenue Landfill has been converted into a community center and public park under the cooperative work of the City of Camden, NJDEP, the Camden Redevelopment Agency, the Salvation Army, Coopers Ferry Partnership, and the residents of the Cramer Hill neighborhood.

Figure 5-9. Conceptual graphic of the waterfront park (left) and an aerial photo of the Salvation Army Ray and Joan Kroc Corps Community Center (right).

Source: www.nj.gov/dep/nrr/cramer-hill.htm

The City of Camden operated the former landfill as an unregulated municipal landfill from 1952 to 1971, but it was never capped or officially closed, which left the site subject to unauthorized dumping in subsequent years. In 2006, the Salvation Army applied monies it received from the estate of Ray and Joan Kroc to construct the Salvation Army Ray and Joan Kroc Corps Community Center on 24 acres of the landfill in partnership with the City of Camden, the Camden Redevelopment Agency, and the NJDEP. The Kroc Community Center opened in 2014 and serves over 8,000 residents of the Cramer Hill neighborhood and the surrounding communities with educational, recreational, social service, fitness, art, and worship programs and early childhood care center amenities.

The remaining 62 acres of the landfill is in the process of being redeveloped as open space, involving the restoration and creation of freshwater tidal wetlands, a living shoreline, an endangered species habitat, and a tidally fed fishing pond.

Project challenges include federal and state regulations impacting development of the waterfront, bald eagle endangered species foraging area, wetlands, cross-jurisdictional state regulatory authority regarding the closure of the unregulated landfill, and the associated environmental cleanup and redevelopment of the property.

5.10.3.1 ***Restoration Summary***

The 62-acre restoration project and creation of the Cramer Hill Waterfront Park has four main components: (1) shoreline protection; (2) landfill closure; (3) natural resource restoration; and (4) park construction.

The shoreline protection involves regrading and stabilizing over 3,000 feet of shoreline on the Delaware River where municipal solid waste and soil contamination, including pesticides and PCBs, are exposed on the surface of the unstable, steep slopes in this area of the landfill.

The landfill closure includes excavating and redistributing approximately 375,000 cubic yards of solid waste and soil onto the interior of the landfill, installing a passive gas venting system, and constructing a 0.6-m thick semipermeable cap of clean fill material and vegetation.

Natural resource restoration consists of enhancing and expanding the existing freshwater wetlands by constructing approximately 7 acres of tidal freshwater wetlands on the Cooper and Delaware Rivers, creating 450 feet of living shoreline in areas along the back channel of the Delaware River, preserving areas of existing trees as bald eagle forage habitat, replanting trees within the remainder of the bald eagle forage habitat, including an area where large specimen trees will be planted. Over 375,000 plantings are included as part of the site restoration. The tidal freshwater wetland on the Cooper River will connect to a fishing pond that will also be a prominent feature of the waterfront park.

The waterfront park will include features for use by the community, such as an amphitheater, an entry plaza, exercise stations, a fishing plaza, hiking/biking paths and trails, historic/educational signage, a kayak launch, a picnic area, a playground, a sensory garden, shoreline observation areas, and a summit vista with panoramic views of downtown Camden, the Camden Waterfront, the Delaware River, Petty Island, the Benjamin Franklin Bridge, and the City of Philadelphia.

Figure 5-10. Cramer Hill Waterfront Park ongoing development facing west (May 2020).

Source: www.nj.gov/dep/nrr/cramer-hill-gallery.htm

Figure 5-11. Cramer Hill Waterfront Park ongoing development facing east (May 2020).

Source: www.nj.gov/dep/nrr/cramer-hill-gallery.html

5.10.4 **Bellingham Waterfront, Bellingham, Washington**

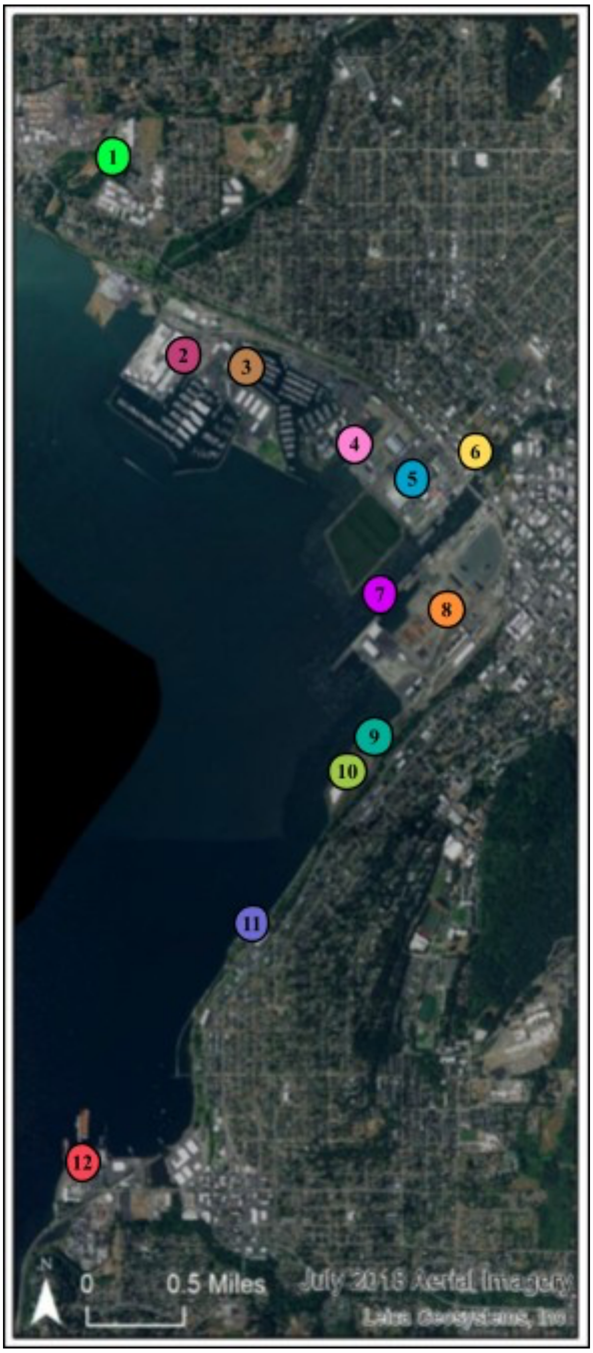
Figure 5-12. Aerial picture of Bellingham Bay.

Source: Photo courtesy of Nick Kelly / Public Domain.

Bellingham Bay's cleanup and redevelopment is a prime example of what can be accomplished when multiple agencies and organizations work together to plan cleanups that meet the needs of local communities using principles of integrated project planning and public participation in decision making. Bellingham Bay has an industrial history as a key port for lumber processing, creation of paper goods, and other maritime trades. As with many industries, advances in technology and a changing local economy have led to some of those businesses closing doors or leaving town for other locations. When businesses leave, they do not always take all their hazardous waste with them. In Bellingham, that meant waterfront lots with easy access to infrastructure were being left idle—an opportunity to get prime land at a cost even a government can afford—if they could find ways to build public support for a potentially costly cleanup.

Building public support has been a group effort. The Bellingham Bay cleanup effort began as the Bellingham Bay Demonstration Pilot Project in 1996, comanaged by Washington Department of Ecology (Ecology) and the Port of Bellingham. This baywide effort included 12 agencies from federal, tribal, state, and local governments, and the former paper mill. The goal of the project was to coordinate sediment cleanup, control pollution sources to sediment, and restore habitat, with consideration for land and water uses. In 2000, the Bellingham Bay Comprehensive Strategy was finalized and still guides current cleanup efforts. Today, this group is called the Bellingham Bay Action Team. It has a slightly different composition and is mainly led by Ecology. Local environmental protection nonprofits, like RE Sources, also join in the group efforts through their environmental education supported by one of Ecology's Public Participation Grants. Public support for outreach, visioning, and communication continues to be critical to getting a diverse group of stakeholders on the same page about a future for the bay.

Today on the Bellingham Waterfront, there are new infrastructure improvements; community amenities, including a park and kayak launch; social support, including a public meeting space and job training center; restoration of critical habitat; and places for local businesses. By taking the time to identify all these co-uses and learn what the community needed, this project has turned into a win for everyone involved. This vibrant waterfront brings people together, includes plans to provide affordable housing, provides rental income to the Port and tax income to the city, and improves the health of residents and that of the natural environment.


1
2
3
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July 2018 Aerial Imagery
Leica Geosystems, Inc

(1) Eldridge Municipal Landfill Contaminated soil due to former municipal landfilling activities.
(2) Weldcraft Steel & Marine Contaminated soil, sediment, and groundwater associated with former shipyard practices.
(3) Marine Services NW Contaminated sediment associated with past boatyard practices.
(4) I & J Waterway Contaminated sediment associated with former industrial practices.
(5) Central Waterfront Contaminated soil and groundwater associated with former municipal landfilling and industrial activities.
(6) Holly Street Landfill Contaminated soil due to former municipal landfilling activities.
(7) Whatcom Waterway Contaminated sediment associated with past pulping operations.
(8) Georgia Pacific West Contaminated soil and groundwater associated with former industrial operations.
(9) R.G. Haley Contaminated soil, groundwater, and sediment associated with former wood treatment facility.
(10) Cornwall Avenue Landfill Contaminated soil, groundwater, and sediment associated with past municipal landfilling activities.
(11) South State St. Manufactured Gas Plant Contaminated soil, groundwater, and sediment associated with a former gas manufacturing facility.
(12) Harris Avenue Shipyard Contaminated soil, groundwater, and sediment associated with former industrial activities at an active shipyard.

Figure 5-13. A map showing the cleanup sites associated with Bellingham Bay and a table describing their contaminants.

Source: Washington State Department of Ecology

For more reading on the Bellingham Bay cleanups, check out these resources:

- Washington Department of Ecology Port of Bellingham page
- Bellingham Bay Cleanup Fact Sheet
- Port of Bellingham Environmental Cleanup page

5.10 How to Identify Potential Site or Cleanup Impacts on Highly Impacted or Socioeconomically Vulnerable Communities

This section is intended to support people in scoping and identifying a project's impacts to highly impacted or otherwise vulnerable communities. Project planners can use information in this section as SBMPs to improve project outcomes. State agencies can use information in this section as SBMPs to improve project outcomes, to identify communities for communication needs, to prioritize use of limited resources where they might do the most good, and to plan initiatives or grant programs to redress negative social impacts of cleanups.

5.11.1 Background

Understanding the characteristics of people who will be affected by cleanup sites and cleanup activities is a necessary first step in planning and carrying out cleanups that avoid, mitigate, or redress disproportionate impacts to communities. While cleanups, by their nature, provide long-term environmental improvements, cleanups can directly affect communities with short-term impacts such as air pollution, traffic, noise, and accident risk, or indirectly affect communities with gentrification and displacement. Understanding the affected population can also provide project proponents with a way to identify potential recipients of project cobenefits identified in other portions of this report (for example, improved green infrastructure, Section 5.7). Planning projects that avoid impacts and provide benefits to affected communities is central to integration of economic and social considerations in the sustainability framework (Section 5.9) and can provide real benefits to project proponents (Section 5.4).

5.11.2 Key Practices

The following information is provided in steps that can help you structure your identification and consideration of highly impacted communities and potential cumulative impacts.

- **Identify.** Use publicly available map tools (for example, EJScreen from USEPA) to understand impacted communities and identify potentially highly impacted communities.

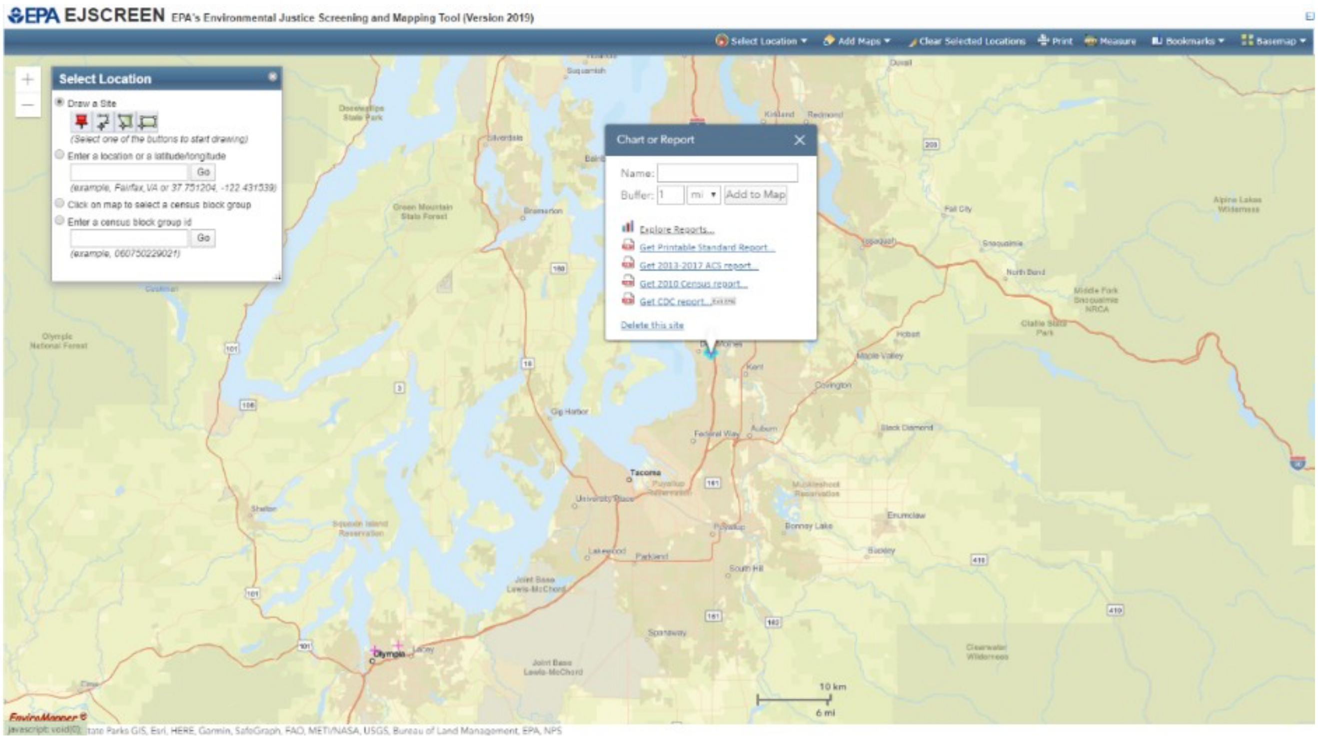


Figure 5-14. Screenshot of USEPA's EJScreen map tool.

Source: U.S. Environmental Protection Agency, EJScreen website.

- **Define.** Highly impacted communities might be defined by your local or state government but are generally understood as groups/communities that have historically faced economic or political barriers to participation in environmental decision making. For example, Executive Order 12898 (NARA 1994) originally instructed federal agencies to look at how projects impact people of color and low-income people, but has been understood by USEPA to include national origin. Look to your state's equity and environmental justice regulations and use your existing local knowledge to define who your project might highly impact.

- **Screen.** Use the data or maps to screen according to a consistent metric for potential to affect highly impacted groups. For example, many federal and state projects look for impacts to communities above the 80th percentile to understand the most highly impacted groups. If a location is above the 80th percentile for a particular environmental harm, consider how your project or project activity might contribute to impacts to the community.

Figure 5-15. Screenshots showing the types of impacts and community characteristics you could consider for this analysis.

Source: U.S. Environmental Protection Agency, EJScreen website.

- **Avoid.** Consider ways to avoid the particular impact, or, if it cannot be avoided without compromising the project, consider ways to offset or mitigate the impact. Examples of changes to a project include:
  - changing the timeline to allow seasonal use of important cultural or recreational resources choosing on-site power generation that avoids diesel emissions in areas that are already heavily impacted by particulate matter or have a large number of children
  - planning more robust site management and emergency planning options in densely populated areas with vulnerable communities.

- **Mitigate.** Offsets and mitigation steps can be tailored to the impacted group through consultation with elected officials and community groups or that meets needs identified in public planning or community visioning documents/meetings.

- **Communicate.** Make the results of your analysis part of your existing communication plans and include in reporting on corporate social responsibility or equity and inclusion targets.

5.11.3 **Additional Resources**

*5.11.3.1 **State Resources***

Some states have their own map tools available to assist with identification of highly impacted or vulnerable communities and to assess cumulative environmental risks. For more resources, please see:

- California – CalEnviroScreen 3.0, California Office of Environmental Health Hazard Assessment
- Maryland – MD EJScreen, Community Engagement, Environmental Justice, & Health
- Washington – Washington Tracking Network, Washington State Department of Health

*5.11.3.2 **Federal Resources***

If your state does not have its own resources available, you can find data using the following federal resources:

- EJScreen, USEPA
- American Community Survey, Census Bureau

*5.11.3.3 **Nonprofit Resources***

You can also find related information on this topic through nonprofit organizations that provide guidance or scoring metrics for the reporting of social responsibility. Some examples include:

- ISO 26000, Social Responsibility, International Standards Organization (ISO) (2010)— ISO publishes internationally recognized standards that facilitate cross-border recognition for following recommended practices or using standardized scoring metrics. ISO 26000 supports Social Responsibility reporting and contains information that will allow you to measure and report consideration of social and economic factors at the organizational level.
- Envision Certification, Institute for Sustainable Infrastructure—This is an accreditation nonprofit that has developed and administers Envision, which is a tool for planning, executing, and documenting sustainable infrastructure development. Envision provides tools for practitioners to follow its guidelines and has options for third-party verification and awards for levels of project accomplishment. Envision includes social and economic considerations in its framework and in many cases its highest levels of achievement require local cobenefits.
- FAC Self-Assessment Tool, Fire Adapted Communities Learning Network—This tool is provided to allow communities at risk from wildfire and other sources of fire to conduct a self-assessment. The tool provides steps for identifying who in the community is at most risk and what valuable community resources could be impacted. It also provides advice on planning and organizing responses around fire risks.

Many organizations centered on specific impacts (for example, wildfire, coastal flooding, earthquake, etc.) provide tools for assessing risk to communities. If you know your site is in an area prone to one of these risks, these toolkits (while not designed around remediation) can provide frameworks that benefit your project and impacted communities.

6. Integrating Resilience and Sustainability into the Remedial Project Life Cycle

This section provides an interactive view of the remediation project life cycle, the various components integral for successful completion, and recommendations on how SRR can be implemented in specific project life-cycle phases, starting with project planning and moving through site characterization, remedy planning, implementation, operations, maintenance and monitoring (OM&M), and site closeout (Figure 6-1). The expansion and evolution of the CSM, as well as stakeholder engagement and their importance in a successful remediation program, are highlighted.

This guidance is an update to ITRC's 2011 Green and Sustainable Remediation (GSR) framework in that it incorporates resilience into the remediation project life cycle. Figure 6-1 provides a snapshot of the interactive remediation project life-cycle tool developed by the ITRC SRR Team. **Users are encouraged to click through the various stages of remediation projects and learn where and how to integrate SRR into their project on our online document .** As a project progresses through the various phases of the project life cycle, the components below them are considered and integrated.

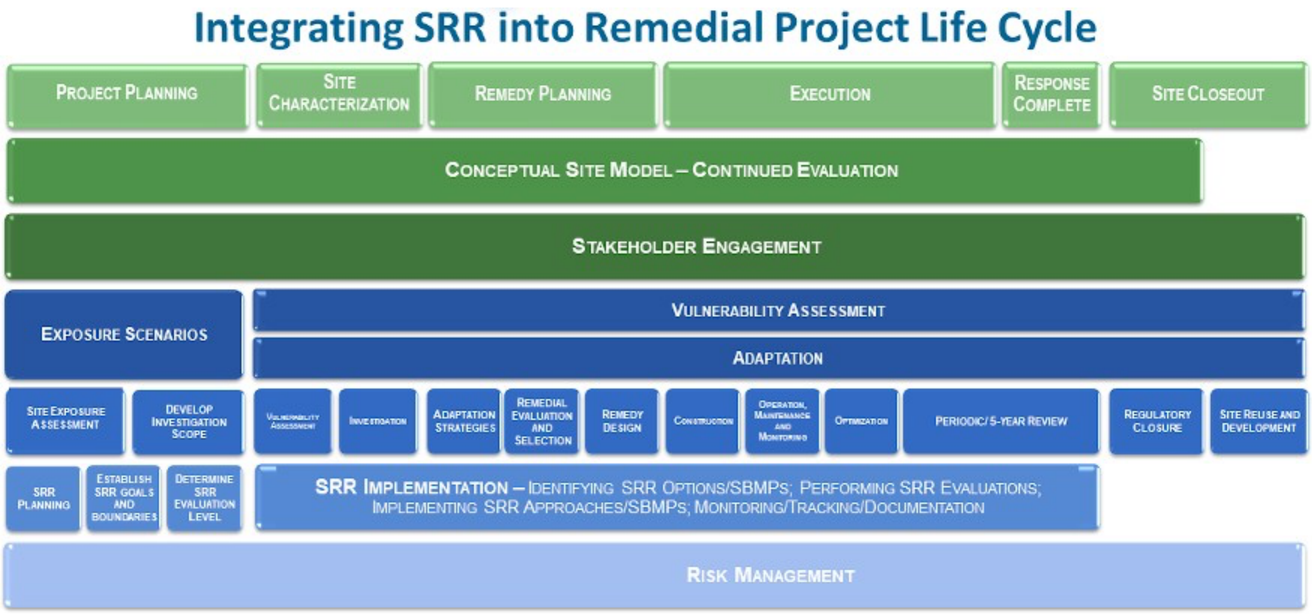


Figure 6-1. SRR framework.

Source: ITRC SRR Team

6.1 Project Planning

Project planning is considered the starting point for integrating SRR principles and practices into a remediation project (Figure 6-2). The SRR planning process can be used to prepare proposals, contracts, and scopes of work, as well as to evaluate and optimize ongoing or completed projects. In this stage of the project while developing the SRR CSM and engaging with stakeholders, the SRR objectives and boundaries are developed and the SRR evaluation level is selected. During project planning, we recommend that you develop sustainable resilient objectives to guide formulation of project-specific SMART (that is, **s**pecific, **m**easurable, **a**ttainable, **r**elevant, and **t**imely) goals focused on SRR process implementation to help attain those objectives.

Understanding the end use of the site or remediation area at the outset is important to define the SRR boundaries as well as overall SRR objectives.

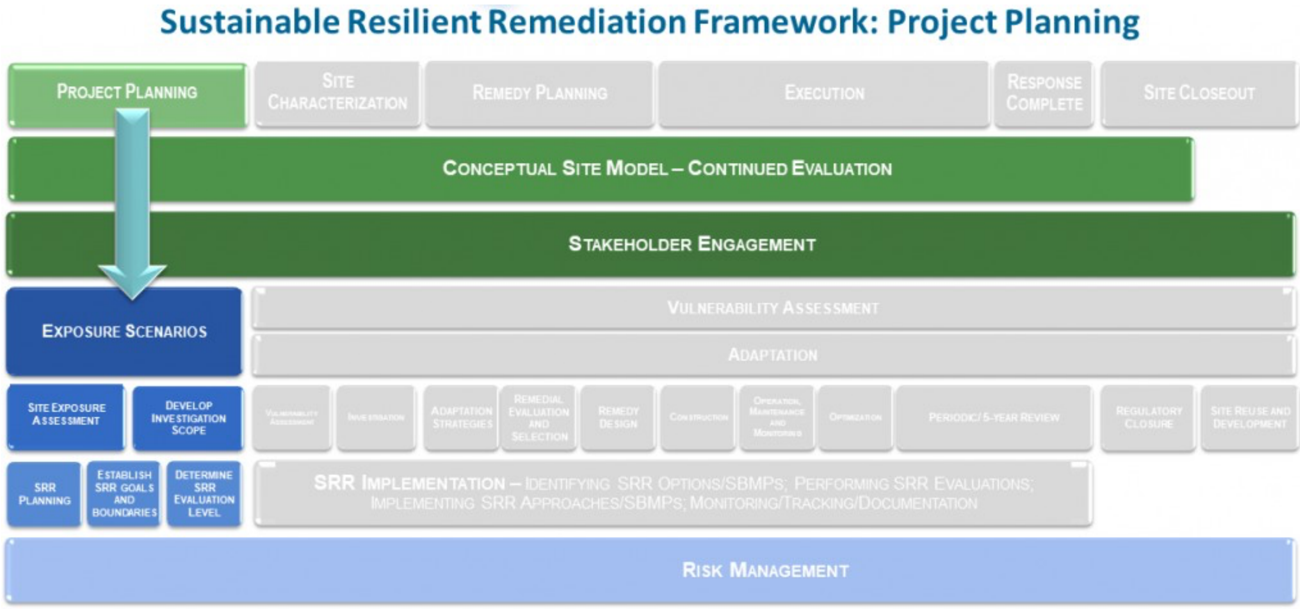


Figure 6-2. SRR framework: Project planning.

Source: ITRC SRR Team

6.1.1 SRR CSMs

CSMs are critical to the development and implementation of remedial approaches. Traditionally a CSM is a written or illustrative representation of the site conditions and the physical, chemical, and biological processes that control the transport, migration, and potential impacts of contamination to human or ecological receptors (NJDEP 2019). Traditional CSMs typically do not incorporate sustainability considerations or resilience to local climate change impacts. The lack of sustainability considerations can result in a remedy that creates an unnecessary depletion of natural resources and unanticipated increases in GHG emissions. In the absence of local climate change data in the CSM, remedial designs often incorporate default or regional climate information. This remedial design approach may not necessarily generate the appropriate level of engineered resilience for the anticipated life of the remedy (Thun 2019). Emerging CSM frameworks have begun to recognize inadequacies in the traditional CSM approach (Kumar and Reddy 2020). USEPA (2011) recommends an iterative approach to the CSM that accounts for stakeholder considerations and new site information as the project progresses (Figure 6-3). An expanded CSM that anticipates SRR and stakeholder expectations is now essential.

General Environmental Cleanup Steps	CSM Life Cycle	
Site Assessment	Preliminary CSM Baseline CSM	Conceptual
Site Investigation and Alternatives Evaluation	Characterization CSM Stage	
Remedy Selection	Design CSM Stage	
Remedy Implementation	Remediation / Mitigation CSM Stage	Quantitative
Post-Construction Activities	Post-Remedy CSM Stage	
Site Completion		

Figure 6-3. Environmental cleanup best practices: Effective use of the project life cycle CSM.

Source: USEPA (2011).

ITRC extended the USEPA's CSM framework further to account for site challenges that are both technical and nontechnical, such as changes in future site use, ownership, and funding (ITRC 2017). This framework has been updated to recognize and incorporate sustainability and remedy resilience as specific site challenges to be considered as part of the CSM development and refinement (Figure 6-4), as well as throughout each of the various components of the overall project. Ultimately this SRR CSM is meant to provide the information necessary to consider remedies that are protective to human health and the environment—both in anticipation of more frequent and severe weather events and wildfires and other climate change–linked impacts and in consideration of important social and economic influences to the site and community. The CSM and its continual update are the cores of the overall remediation process (Figure 6-5) and provide for remedy influences beyond chemical hazards and physical environment conditions.

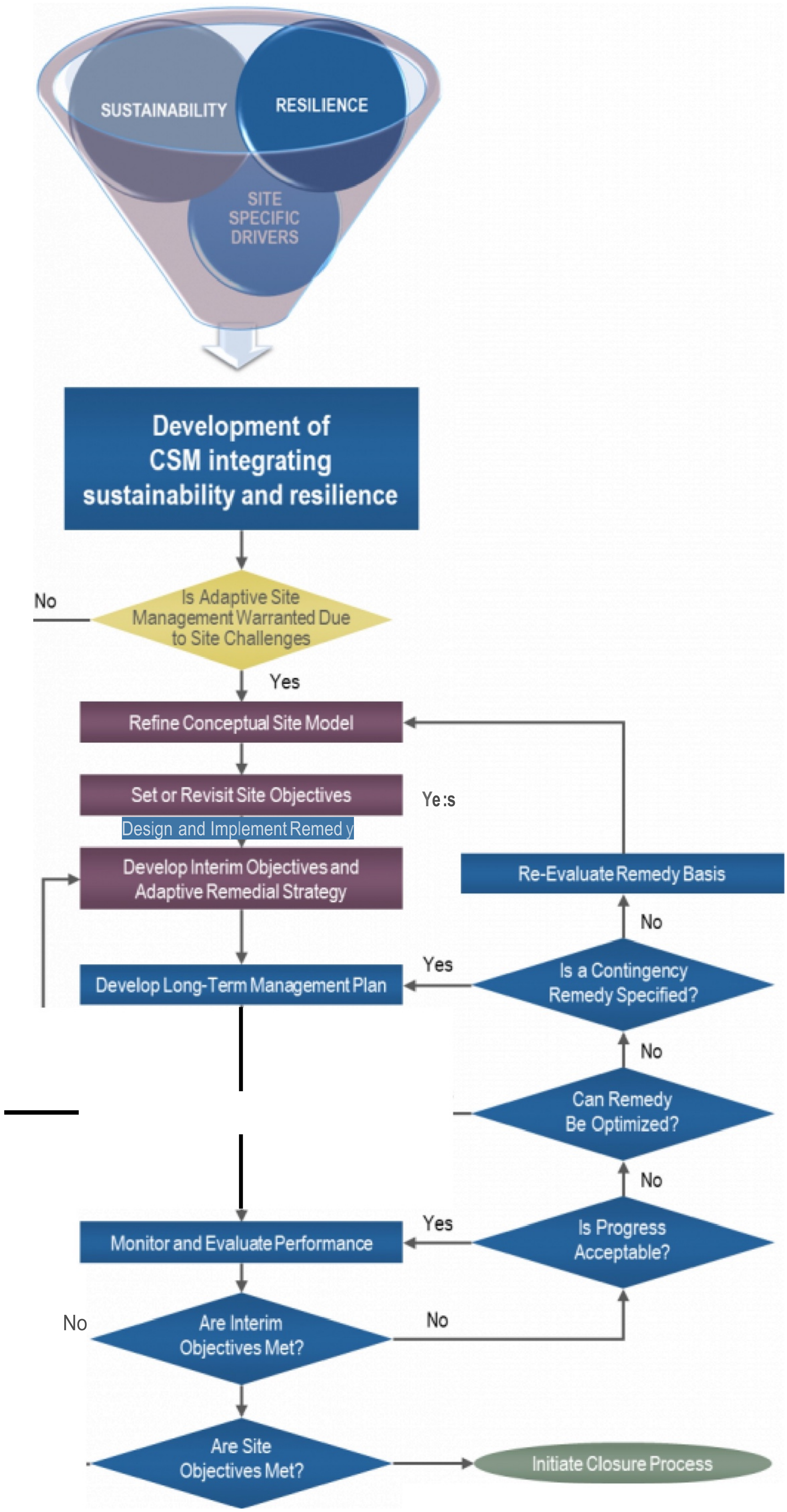

SUSTAINABILITY
RESILIENCE
SITE SPECIFIC DRIVERS
Development of CSM integrating sustainability and resilience
Is Adaptive Site Management Warranted Due to Site Challenges
No
Yes
Refine Conceptual Site Model
Set or Revisit Site Objectives
Design and Implement Remed y
Develop Interim Objectives and Adaptive Remedial Strategy
Ye:s
Re-Evaluate Remedy Basis
No
Develop Long-Term Management Plan
Yes
Is a Contingency Remedy Specified?
No
Can Remedy Be Optimized?
No
Monitor and Evaluate Performance
Yes
Is Progress Acceptable?
No
Are Interim Objectives Met?
No
Are Site Objectives Met?
Initiate Closure Process

Figure 6-4. SRR CSM.

Source: Adapted from ITRC (2017).

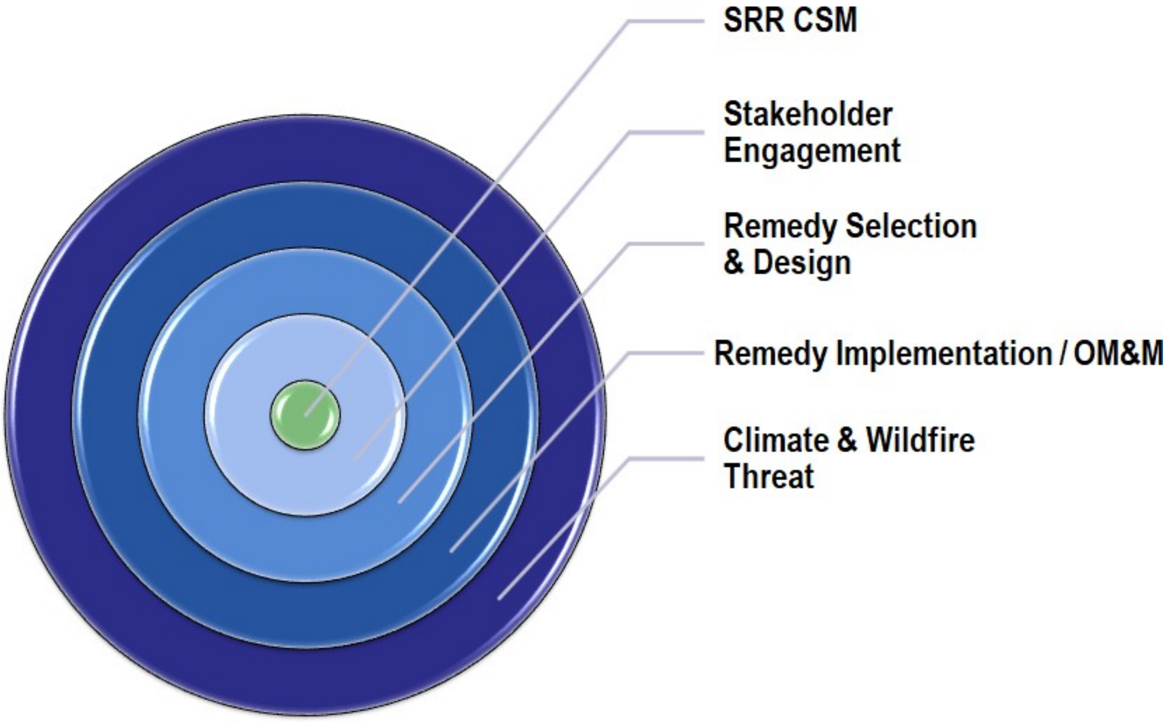


Figure 6-5. Expansion of CSM influences.

Source: Roy Thun. Used with Permission.

The SRR CSM uses forecasted changes in the frequency and severity of extreme weather events and wildfires and longer term changes (such as sea-level rise, temperature, and precipitation trends) at the site level as a means to consider future direct and indirect impacts to the remedy. These impacts might include remedy effectiveness, decline in natural resources, acceleration of geomorphic processes, and prolonged environmental stressors such as sea-level rise and drought. An SRR CSM also incorporates frequent updating to take advantage of new climate change information and forecasting.

One source for U.S. national and regional climate information is the Global Change Research Program's U.S. Climate Resilience Toolkit. This resource provides a variety of modeling tools that can be used to forecast major climatic events. The website is managed by NOAA's Climate Program Office and is hosted by NOAA's National Centers for Environmental Information. These tools are also organized by extreme event in Section 7, as well as by state in the State Resource Map.

The SRR CSM also incorporates environmental, social, and economic sustainability through consideration of carbon footprint and other environmental assessments, natural resources use assessments, and stakeholder engagement about social and economic areas of concern. While not required, the adaptive nature of the SRR CSM could be enhanced through additional tools such as the USEPA's Spreadsheets for Environmental Footprint Analysis (SEFA) and Battelle's SiteWise to estimate GHGs, air pollutants, and energy use, among others. Some sustainability tools to address economic and social metrics are discussed in Section 5.9. Others may become more readily available and appropriate (ITRC 2011c, Reddy and Adams 2015).

A key factor in evaluating the long-term effectiveness and permanence of the remedy is to consider the increased frequency and severity of extreme weather events and other forecasted climate change–linked impacts at a local level. Agencies are incorporating anticipated climate change impacts into their definitions of a permanent solution (MassDEP 2020). See additional information on state-specific EOs (Section 3.1.2.3) and voluntary guidance or policy (Section 3.1.2.4).

6.1.2 **Stakeholder Engagement**

The social dimension of SRR includes consideration of critical stakeholder needs and concerns (often called stakeholder values). In this context, site-specific objectives, goals, and processes for an SRR assessment are informed by multiple stakeholder values (Cundy et al. 2013). Project stakeholders can include emergency personnel, utility providers, and hazardous waste management specialists (Kumar and Reddy 2020). Transforming sustainable, resilient benefits and mitigating unintended impacts to environmental justice (Section 5.2) and other underserved communities are core components of SRR risk management (Section 6.1.6).

Stakeholder engagement supports comprehensive assessments by allowing practitioners to recommend site-specific sustainability and resilience objectives and goals and identify indicators and metrics that are representative of stakeholder values. These assessments can then be used to inform methods and tools to evaluate environmental, social, and economic sustainability metrics, as well as climate change–related impacts.

The purpose and process of stakeholder engagement evolves throughout the project life cycle, demonstrating the importance of developing and implementing a continuous, phased engagement process. Detailed guidance on involving stakeholders and the social dimension of SRR are discussed in Sections 5.9.1.4 and 5.9; highlights are below.

During project planning, a site-specific stakeholder assessment road map is developed to define the purpose and process of engagement (Ridsdale and Harclerode 2019). We recommend developing SRR objectives and SMART goals for a site in alignment with stakeholder values. Stakeholders' understanding of site complexities can benefit from the use of the SMART approach to developing site objectives. SMART goals help a project team determine and communicate how integration of sustainable and resilience practices and decisions will be measured and achieved during project implementation. Subsequently, these SMART goals inform SBMPs, indicators and metrics, and methods and tools to be implemented for an SRR evaluation (ITRC 2011b). As part of SRR, practitioners perform an assessment of how the remedy will impact social and economic factors (Section 5.4), including the impact on these factors should the remedy not perform as intended because of extreme weather events or wildfires.

Example 1

- SRR SMART goal: Integrate adaptation measures in sediment cap design to maintain remedy integrity to higher frequency and severity storm events via hydrodynamic modeling during 30% design stage.
- Stakeholder engagement
    - Purpose: Identify assumptions, challenges, and values, and build data sets to support analysis of storm events with higher frequencies and severities. For example, local and regional resilience planning may require consideration of specific estimates of sea-level rise (for example, 5 feet based on NOAA), emission scenarios (for example, Intergovernmental Panel on Climate Change Representative Concentration Pathway 2.5 scenario), and design life horizon (for example, year 2100). Stakeholder engagement will be performed to select the SRR evaluation level and determine data set needs, the availability of tools, and financial feasibility.
    - Process: Hold a remedial design workshop with or send a survey to stakeholders to identify both remedial design factors that integrate their values (that is, optimally integrate resilience factors thatare most important to them) and considerations that may have been overlooked in initial design planning. Then incorporate stakeholder input in remedial design documentation, including rationale for input that was not incorporated.

Example 2

- SRR SMART goal: Consider applicable metrics and tools during the alternative analysis stage and select a remedy that has the greatest enhancement of future recreational use and wetland restoration.
- Stakeholder engagement
    - Purpose: Identify indicators and metrics for stakeholders' values in terms of successful enhancement of recreational use and wetland restoration (for example, creating pedestrian walking access, and habitat for sensitive and threatened ecological species). Determine data set needs, the availability oftools, and financial feasibility to select the SRR evaluation level.
    - Process: Use the Social Sustainability Evaluation Matrix (SSEM) tool or a sustainability rating/scoring tool, such as Institute for Sustainable Infrastructure's Envision online scoresheet, so stakeholders can identify and rate the applicability of site-specific future recreational use and wetland restoration indicators and metrics per proposed alternative. Follow up with stakeholders via a virtual meeting to communicate the findings and obtain stakeholder input on proposed metrics and tools to be applied (for example, Ecosystem Services at Contaminated Site Cleanups (USEPA 2017b) to evaluate enhancement of future recreational use and wetland restoration as part of the alternative analysis stage).

6.1.2.1 ***Resources***

The ITRC Risk Communication Toolkit provides guidance and resources to perform stakeholder identification and assessment, including identifying communities and constraints, performing stakeholder and community assessments, interacting with communities, and using tools (ITRC 2020b). Additional resources on community engagement include the Agency for Toxic Substances and Disease Registry's (ATSDR's) Principles of Community Engagement (ATSDR 2011) and theInternational Association for Public Participation's Public Participation Spectrum

6.1.3 **Resilience: Exposure Scenarios**

The first step in addressing resilience in the remedial project life cycle is to identify extreme climate impacts exposure scenarios. Identifying exposure scenarios is a process of determining the system's exposure to climate or weather hazards. This is an important process not to be overlooked that entails identifying specific or multiple hazards of concern considering various climate and extreme weather scenarios (for example, extreme precipitation events).

The Fourth National Climate Assessment provides a comprehensive assessment of the science of climate change, historical changes, and projections for the United States by region (USGCRP 2017). Additionally, other organizations such as the USEPA, NOAA, and U.S. Geological Survey maintain regional resources and downscaling tools that are useful in bringing regional climate data to the site scale.

After identifying the site-specific climate impacts that a site may be exposed to, it is critical to assess the site's vulnerability to each potential exposure—that is, how the potential or proposed remedial actions will be impacted by the exposure under short-term (for example, during the site investigations and remedial design and implementation) and long-term conditions (many years of required operations and monitoring). All remediation project life-cycle stages are considered in this evaluation and potential changes in site conditions (for example, hydrogeology, fate and transport of contaminants, efficacy of remediation system, and risk management) are assessed. Many of these aspects should be addressed throughout CSM evaluations (see Section 6.1.1). For more information about conducting a vulnerability assessment, see Section 6.2.3. Section 7 provides many tools to build or adapt a remediation site with resilient measures.

In addition to addressing resilience of the overall remediation approach, assessment of the proposed adaptation measures to the project sustainability goals (environmental, economic, and social) should occur concurrently. An interactive, adaptive approach may be needed to optimize both resilience and sustainability in any SRR project.

Additional detail on assessing site exposure is provided in Section 6.1.4.1, Site Exposure Assessment.

6.1.4 **Detailed Project Life Cycle**

*6.1.4.1 **Site Exposure Assessment***

A site exposure assessment is performed to understand site history, location, and contaminant impacts and identify the specific site's potential exposure to extreme weather events or wildfires. From this information, identify if a particular exposure scenario should be evaluated further in the vulnerability assessment (Section 6.2.3). It is critical to identify potential technical, broader environmental, economic, and social impacts associated with the site at the outset of the remediation project. In terms of remediation resilience, the USEPA offers several climate resilience resources at Climate Change Adaptation Resource Center (ARC-X), as well as the Superfund Climate Resilience pages, which can be used to assess site exposure. Site-specific economic and social impacts are also identified at this stage. Other state and federal resources, or tools specific to assessing vulnerability to a specific extreme event, are also available in Section 7.1.

Sites should be assessed for exposure to climate change and extreme weather event related impacts, at a minimum, for the following (depending on location):

- changing precipitation patterns
- changing extremes and severe weather (i.e., hurricanes, tornadoes, hot and cold temperatures)
- evapotranspiration and droughts
- rising sea levels and salt-water intrusion
- changes in air temperature
- ocean temperature and acidification
- atmospheric water vapor content
- changing snow cover and decreasing glaciers
- permanent and temporal changes in the groundwater table elevation
- changing wildfire patterns and intensity
- landslides
- permafrost stability
- wind

Based on this site exposure assessment, a site specific vulnerability assessment may be needed. Additional discussion on conducting a vulnerability assessment is provided in Section 6.2.5.1. The climate metrics causing extreme events are monitored, and the data are readily available at the state and federal and state levels and are parsed in Section 7 as they relate to specific extreme events.

6.1.4.2 *Develop Investigation Scope*

The investigation phase of a project is used to determine the nature and extent of impacted media. Considering sustainability and resilience as part of a project investigation process provides the greatest benefit (that is, reduces overall project costs and maintains project schedule) when employed early in the review process.

Considering resilience as an aspect of the project investigation helps provide a sustainable project when viewing the entire lifetime of a project. There are different ways in which resilience can be considered in the investigation process:

- *Resilience to changing climate* – How will climate change impact the investigation process? Will the investigated data still be relevant by the time remediation begins (for example, will the site suffer from a drought or drop groundwater prior to remediation, new sediment may make old data obsolete)?
- *Resilience to climate hazard* – How will climate hazards impact the investigation process? Will the investigation itself be compromised (that is, more extreme conditions increasing risks during field events)?

Users identify the indicators and metrics they want to use to evaluate the sustainability and resilience associated with the investigation process. Table 5-1 provides social and economic goals and broad indicators, and Section 7 provides information associated with vulnerability risks. Possible resilience indicators and metrics include:

- expected change in site conditions prior to project implementation that would require additional investigation
- risk that extreme weather events or wildfires would interfere with the investigation

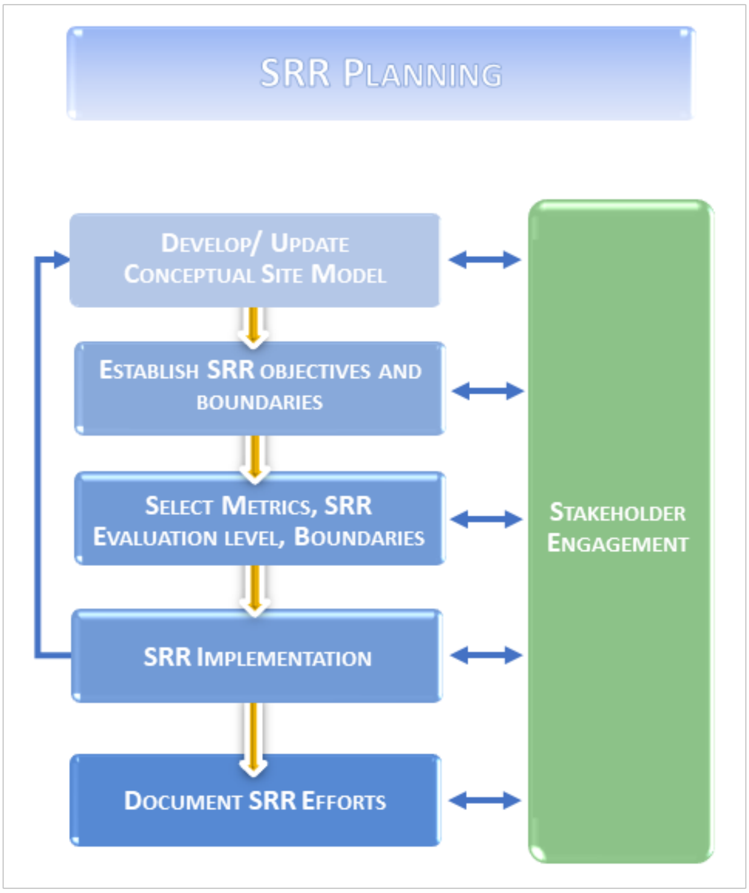
These resilient focused SBMPs are shown at the bottom of Table 6-1.

Table 6-1. Examples of sustainable best management practices (SBMPs) to be considered during site investigation (modified from ITRC 2011a).

SRR Consideration	SBMP
Environmental	Collect data to evaluate off-site, on-site, and in situ treatment and management options.
	Collect data to understand the risks associated with treating and containing contaminated media on site.
	Identify methods to minimize generation of investigation-derived waste.
	Quickly restore disturbed areas of vegetation serving as stormwater controls.
	Use portable field analysis approaches and technologies to complete site characterization without multiple mobilizations (for example, use in situ data loggers and transmit information with solar-powered telemetry systems).
	Identify recycling options for materials generated during site investigation.
	Identify methods that minimize impacts to the ecosystem (Section 5.6).
	Develop and refine CSM to identify all exposure pathways.
	Design field studies to minimize travel or number of trips to site.

Social	Conduct community outreach on investigation schedule and activities.
	Update key contacts list to facilitate communications.
	Minimize contamination risks on site for workers performing investigation.
	Alleviate undesirable community impacts, such as noise, traffic, odor, business disruptions, and compromises in local heritage, and address cultural concerns.
Economic	Use field-screening technologies to reduce mobilization and off-site sample shipping.
	Use local contractors and staff to minimize travel.
	Use locally produced products.
	Use local analytical laboratories and consolidate delivery schedules.
Resilience	Identify the potential climate hazards associated with the site.
	Predict the financial risks associated with climate hazards at the site.
	Develop resilient measures to combat potential climate-based hazards.
	Gain input from stakeholders on perceived climate risks and communicate how risks will be evaluated during the site investigation.

6.1.5 SRR Planning



The SRR planning process consists of five general steps that are meant to provide a conceptual structure for guiding the integration of SRR into each phase of the cleanup project (Figure 6-6). After completing the applicable steps, an SRR evaluation may be performed and SRR activities implemented.

Figure 6-6 SRR planning.

Source: ITRC SRR Team.

- *Develop and update conceptual site model* (Section 6.1.1) – The CSM synthesizes and summarizes what is already known about a site that is pertinent to decision-making requirements. It is a depiction and narrative of how the contaminants released at a site interact with the environment and potential human and ecological receptors. It is built on all currently available information about site conditions that could influence future remedy selection, design, or performance. Because the CSM forms the basis for defining and implementing an effective overall strategy for the site, it evolves throughout the life cycle of the cleanup project. When new information and valid data become available, the CSM is evaluated and updated accordingly. Evaluating and updating the CSM also offers the opportunity to incorporate consideration of potential climate and other extreme event impacts, environmental, economic, and social considerations and potential SRR opportunities. The tiered level approach (Section 5.9.1) can be used as a means to inform the CSM.
- *Establish SRR objectives and boundaries* (Section 6.1.5.1) – Establishing objectives and corresponding SMART goals is a key element of SRR planning. SRR objectives can be influenced by a number of factors, including the need to meet resilience to climate and other extreme event impacts, sustainability objectives, stakeholder requirements, response to a regulatory policy, or response to a desire to lower the potential impacts from a project and make it more resilient and sustainable.
- *Involve stakeholders* (Section 6.1.2) – Stakeholders should understand that SRR considers resilience to climate impacts and reduces negative environmental, economic, and social impacts. Once identified, those values can be reflected in the development of the overall project approach. Stakeholder engagement can help confirm or revise the SRR goals.
- *Select metrics, SRR evaluation level, and boundaries* (Section 6.1.5.2) – For each of the SRR objectives identified appropriate metrics must be selected to assess, track, or evaluate those goals. Further, the boundaries to be applied to an SRR evaluation must also be considered. The SRR evaluation may help identify data gaps and may require revising the CSM. See Section 5 for considerations on social and economic goals and indicators. For environmental indicators consider the following:
    - **Energy consumption**
    - **Air**
        - Minimize air pollutants and GHG emissions
        - Minimize generation and transport of airborne contaminants and dust
        - Use heavy equipment efficiently (for example, diesel emission reduction plan)
        - Maximize use of machinery equipped with advanced emission controls
        - Use cleaner fuels to power machinery and auxiliary equipment
        - Sequester carbon on site (for example, soil amendments, revegetation)
    - **Groundwater and surface water**
        - Minimize water use and impacts to water resources
        - Minimize depletion of natural water resources
        - Capture, reclaim, and store water for reuse (for example, recharge aquifer, drinking water irrigation)
        - Minimize water demand for revegetation (for example, use native species)
        - Employ BMPs for stormwater management
        - Soil and ground conditions
    - **Ecology and natural resources**
        - Protect land and ecosystems
        - Minimize areas requiring activity or use limitations (for example, destroy or remove contaminant sources)
        - Minimize unnecessary soil and habitat disturbance or destruction
        - Minimize noise and lighting disturbance
        - Waste Generation

- *Document SRR efforts* – Documenting SRR efforts is an important part of determining whether SRR objectives and SMART goals are being achieved at a site and communicating ongoing benefits/accomplishments to stakeholders. If SRR objectives and SMART goals are not being achieved, stakeholders may want to consider repeating the SRR evaluation, reconsidering other action items, and/or revising the CSM and/or goals.

6.1.5.1 ***Establish SRR Goals and Boundaries***

The objectives of SRR are established at the outset of the project, integrating stakeholders and identifying site-specific drivers. Climate science is evolving, and global climate model predictions are improving. Moreover, the uncertainties of downscaling modeled forecasts need to be considered. In light of these challenges, performing a deterministic analysis for resilience provides multiple perspectives and a clear understanding of uncertainty. Overly conservative assumptions of impacts may cause undue financial burden. Hence, climate impacts and associated risks are properly weighed and incorporated into design for climate resilience that meets environmental and societal expectations. SRR goals will depend on project-specific considerations, regulatory guidance/policy drivers, and stakeholder input.

SRR boundaries are identified for each SRR evaluation. The SRR boundaries can be defined as the degree to which the SRR evaluation is conducted. A variety of factors influence the boundaries of an SRR evaluation, such as the overall approach to the evaluation and whether life-cycle considerations are to be addressed, as well as the phase of the project, data availability, stakeholder considerations, timing, and budget. Boundaries for the resilience assessment ought to extend beyond project features within the project location and include nearby human community and environmental receptors (that is, downstream or downgradient) and the general location of the site (that is, storm surge, flooding, landslide, and wildfire potential). Sustainability boundaries can vary significantly from considering full cradle-to-grave analysis for energy and materials used from the mining of raw materials to the ultimate disposal or reuse of residuals to a less rigorous approach considering only the impacts that occur on the site.

6.1.5.2 ***Determine SRR Evaluation Level***

Once SRR boundaries are defined, the level of SRR evaluation can be determined. The SRR evaluation level builds off the GSR three-tiered approach. This approach has been updated to incorporate resilient remediation.

Resilience management during the initial and ongoing planning efforts entails understanding what extreme weather, wildfire, and other climate-linked events could potentially impact the site and how often. It means understanding that site conditions and weather conditions can change.

Knowing the possible climate impacts may help identify stakeholders that might not otherwise be considered, such as the public health department or the local emergency response agency. If an investigation and/or remedy is vulnerable to an impact, knowing whether the investigation program and/or remedy will be able to adapt to or recover from a weather disruption may guide the remedy selection.

The resilience of the investigation and remedy are considered in the initial planning, periodically evaluated, and reevaluated as new information is learned about the site and about extreme weather impacts.

We recommend a tiered approach consisting of three levels of detail in conducting SRR evaluations (Figure 6-7). These levels allow incorporation of resilience and sustainability to the extent possible and scalable to any type and size of project. The goal is to achieve both resilience and sustainability simultaneously. First and foremost, the goal is for the remediation to be climate-resilient, so options for achieving this are identified first. Once the feasible resilient options are identified, they can be subjected to sustainability (environmental, economic, and social impacts) assessment. These tasks may require an iterative approach until the project SRR goals are achieved.

Selection of the site-specific SRR evaluation should be guided by stakeholder considerations and availability of data. Consideration of stakeholder values can help a practitioner determine the applicable SRR evaluation at a specific project life-cycle stage. Understanding stakeholder needs and concerns in the context of SRR evaluation (Section 5.9.1.4) can inform on identification and selection of site-specific SRR metrics, data sources, and assessment tools (Section 5.9.1.5). Furthermore, consideration of stakeholder demographics (Section 5.11) can help identify and screen potentially highly impacted communities from both site remediation activities and site-related climate (severe weather) event vulnerabilities. To learn more about how to select site-specific SRR evaluation level, metrics, and tools, refer to Section 5.9.1.

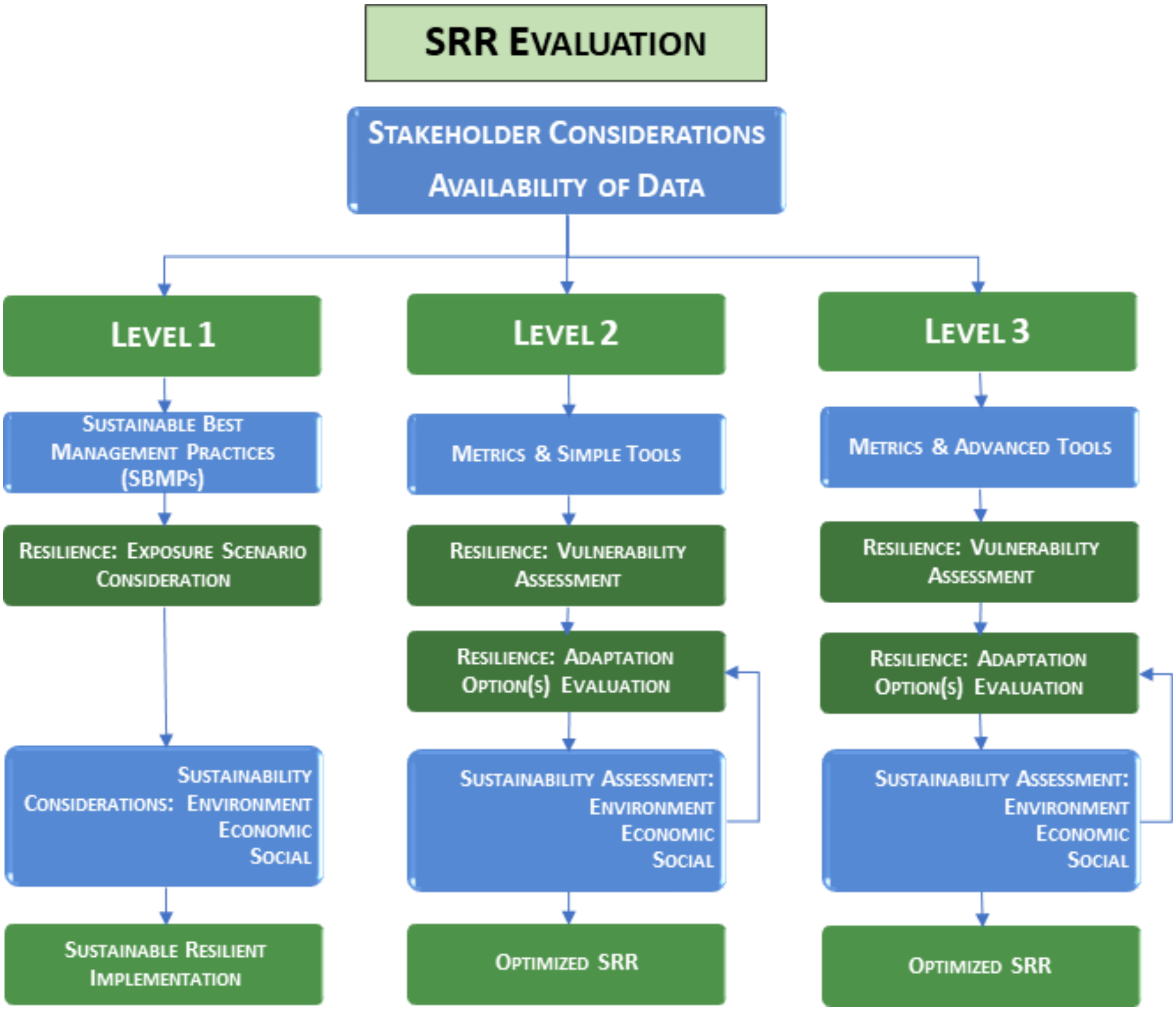


Figure 6-7. SRR evaluations.

Source: ITRC SRR Team.

SRR Level 1 Evaluation: SBMPs – The objective of a Level 1 approach is to evaluate the exposure scenario, determining which climate and/or extreme weather events and wildfire scenarios may be possible at the site (ITRC 2011a). Then adopt SBMPs based on common sense to promote resilience and sustainability with the goal of uncompromised performance of remedial actions while reducing any negative impacts on the environment, community, or economics. SBMPs do not attempt to compare or quantify SRR metrics, but they could be compared to one another so that the ones yielding obvious benefits, including cost savings, are selected. SBMPs are essentially approaches or practices that, when implemented, improve the resilience and sustainability aspects of a remedial project, during any phase from site investigation through project closeout. See Table 6-1 for examples of SBMPs during the site investigation phase of a remediation project.

SRR Level 2 Evaluation: SBMPs + Simple Tools – A Level 2 evaluation combines a vulnerability assessment with the selection and implementation of SBMPs that have some degree of qualitative or semiquantitative evaluation (ITRC 2011a). Qualitative evaluations may reflect tradeoffs associated with different remedial strategies or use value judgments for different SRR goals to determine the best way to proceed. Semiquantitative evaluations are those that can be completed using simple mathematical calculations or intuitive tools. An initial effort is done to weight and rank each approach, which may be revised based on stakeholder input. Examples of simple tools are Spreadsheets for Environmental Footprint Analysis (SEFA) and SiteWise for environmental sustainability, social cost of carbon for externality cost, and Social Sustainability Evaluation Matrix (SSEM) for social impacts (Reddy and Adams 2015, ITRC 2011a). Examples of simple tools for assessing resilience are provided on the U.S. Climate Resilience Toolkit website.

SRR Level 3 Evaluation: SBMPs + Advanced Tools – A Level 3 evaluation combines a vulnerability assessment with the selection and implementation of SBMPs with a rigorous quantitative evaluation (ITRC 2011a). The evaluation often relies on advanced climate models downscaled to site location for resilience assessment, often combined with life-cycle assessment (LCA) for environmental sustainability or life-cycle sustainability (LCS) assessment (considering triple bottom line) approaches (Reddy, Cameselle, and Adams 2019, Reddy, Kumar, and Du 2019, ITRC 2011a). Accordingly, Level 3 evaluations require more time and expense to complete than Level 2 evaluations. In addition, moderate to significant learning curves are expected for practitioners who do not have experience in performing LCA- or LCS-type evaluations. As with Level 2 analyses, if weighting is used, we recommend that appropriate weights be developed prior to performing the evaluation. Generally, resilience to climate impacts must be ensured, while environmental, economic, and social aspects could be weighed differently depending on the project-specific conditions and stakeholders' preference. The distinction between Level 2 and Level 3 evaluation may not always be clear and requires professional judgment for identification.

6.1.6 **SRR Risk Management**

Multiple types of risks need to be managed in SRR, including the risk associated with climate and severe weather event impacts (addressed by resilient risk management); risk associated with adversely affecting environmental, social, and economic impacts (addressed by sustainable risk management); and risks associated with other unintended adverse impacts from cleanup activities (addressed by remediation risk management (RRM)) (Figure 6-8). Each of these is discussed further below. Because these components of SRR risk management are interrelated, there may be some overlap of risks considered among the three risk management approaches (ITRC 2017).

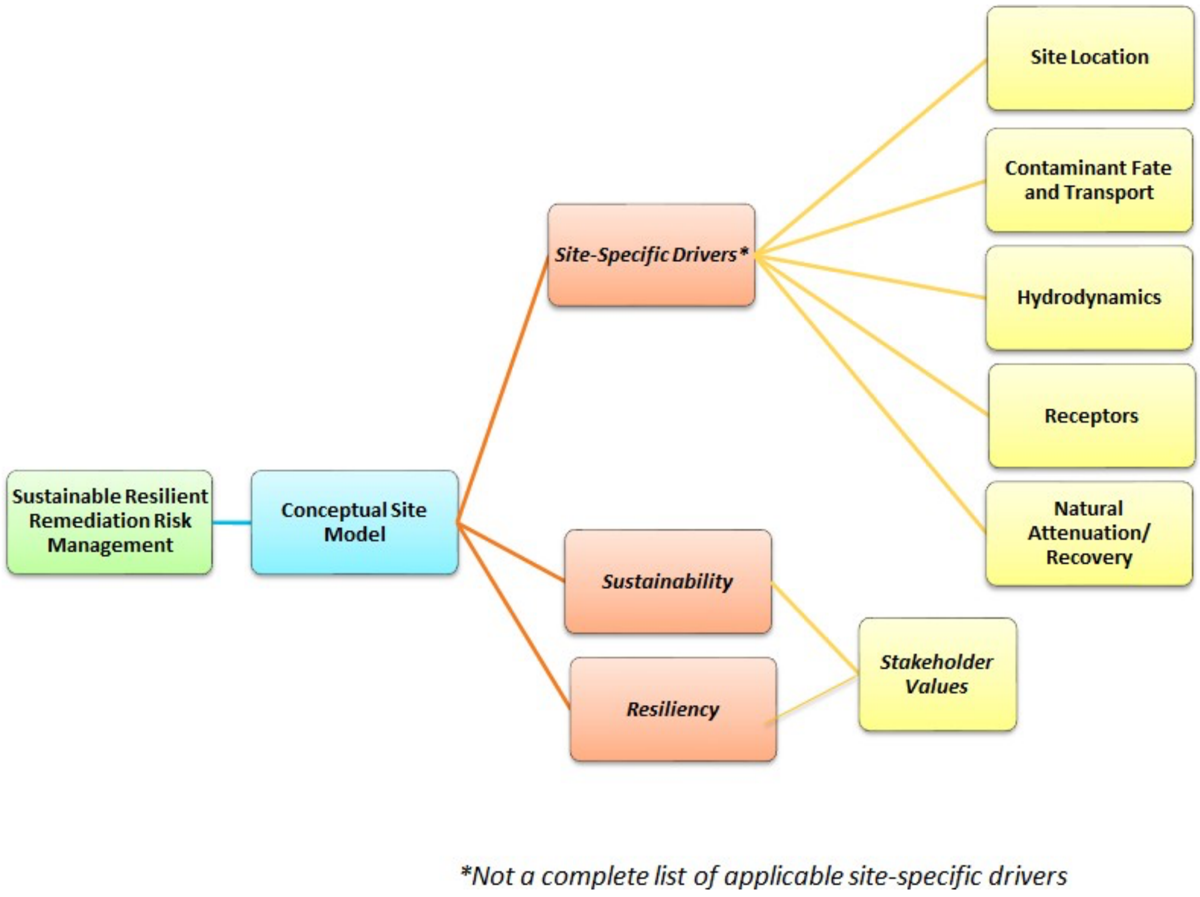


Figure 6-8. Example of SRR risk management approach.

Source: ITRC SRR Team.

6.1.6.1 ***Remediation Risk Management***

The RRM approach identifies and assesses site investigation and remediation activity risks apart from the risks associated with chemical contamination. Examples include inadequate remedy performance, risks to ecological habitats resulting from remediation activities, health and safety concerns, GHG emissions caused by remediation, consumption of energy and other resources needed to perform remediation, the risks of traffic accidents, and other unintended adverse impacts. The purpose of RRM is to significantly improve the quality of remedial decision making throughout a project life cycle regardless of the site size and complexity, type of cleanup program, or stage in the cleanup process (ITRC 2011c).

The remedial time frame where contaminant sources need to be managed is a primary factor in RRM. A key consideration in SRR is that the probability of an event occurring increases substantially over time due to climate change impacts (Section 6.3.5.3). A USGS study determined climate change has and will continue to alter the means and extremes of precipitation and other natural events, and recommends not relying on a single episodic event, such as the 1% annual chance storm event (Milly et al. 2008). Managing the uncertainties associated with climatic impacts and the site's adaptive capacity (that is, resilience) in responding to these impacts is not included in traditional uncertainty quantifications. Evidence supported logic methodology is one approach used in such formalized decision-making settings to help identify those uncertainties that have the greatest impact on overall confidence in meeting SRR objectives (Kumar and Reddy 2020).

6.1.6.2 ***Resilient Risk Management***

Resilient risk management is the process of identifying, evaluating, selecting, and implementing actions that are adaptive to climate change–related impacts and extreme weather events. The risk is defined by the vulnerability, sensitivity, and adaptive capacity of remedial strategy components to these potential impacts. Due to dynamic site conditions and realized effects of climate change impacts on cleanup sites, resilient risk management extends to identifying and assessing CSM (Section 6.1.1) characteristics in terms of contaminant mobilization and exposure to receptors during an extreme weather or wildfire event. When warranted, resilient adaptation measures are implemented to eliminate or minimize the impact of climate change–related hazards affecting remedial strategy effectiveness (USEPA 2014). Along with the recommendations in this section, the USEPA's climate resilience technical fact sheets provide a summary of cleanup site vulnerabilities and adaptation measures for three high-priority remediation systems.

Ecosystems and communities that are affected by cleanup and restoration activities also need to be considered in resilient risk management. Identifying and assessing site-specific climate change and extreme weather event–related vulnerabilities aids practitioners in selecting and designing a remedial strategy that maintains protectiveness if such an event occurs. In addition, rising sea levels, declining snowpack, long-term stress on water availability, dynamic groundwater levels, acidification, and rising temperatures represent further threats to ecosystems and communities (Maco et al. 2018). It is essential that the integrity and protectiveness of the remedial action is resilient to potential climate change impacts to lessen nonsite-related climate change risks to local ecosystems and surrounding communities (Section 5).

6.1.6.3 ***Sustainable Risk Management***

Cleanup sites are often complex in nature due to underlying technical and nontechnical challenges that make it difficult to fully remediate environmental contamination and meet multiple stakeholder needs within a reasonable time frame and in a resource-effective manner (Hadley et al. 2014, Harclerode et al. 2016, ITRC 2017). Due to these underlying technical challenges, cleanup activities can be costly and resource intensive. They can go through several remediation attempts made or continue to be implemented for an extended time period (Vogel 2015, USEPA 2004, NRC 2013). Furthermore, cleanup properties may enter a “no-man’s land,” becoming either underused or a low valued asset in which the environmental, economic, and social costs of the remediation appear disproportionately large compared to measurable benefits (that is, risk reduction) to human health and the environment (ESTCP 2011, Farkas and Frangione 2010, NRC 2013, SURF 2009, NRC 2005). Integrating sustainable remediation practices and risk-based cleanup approaches, such as alternative endpoints and adaptive management strategies, is a proactive approach to sustainable risk management, while continuing to protect human health and the environment.

Sustainable risk management is the process of identifying, evaluating, selecting, and implementing actions that mitigate unintended environmental, social, and economic impacts from cleanup and restoration activities. The severity of risk or unintended impact is defined by stakeholder concerns and values that align with the triple bottom line of sustainable remediation practices. These concerns and values encompass a wide range of physical or environmental, socioeconomic, and risk management drivers and barriers to implementation of sustainable remediation practices and risk-based cleanup approaches (Hadley et al. 2014, Harclerode et al. 2016). Identifying and assessing these drivers and barriers can inform the development of SMART goals and performance metrics (Section 6.1). A multitude of site management practices and tools has been developed to minimize unintended environmental, social, and economic impacts from site activities (ITRC 2011c).

Public stakeholder involvement in the decision-making process and participation of affected communities in risk mitigation activities are also essential components of sustainable risk management (Section 6). SRR promotes including multiple stakeholder values and affected community needs early in project planning to maximize benefits to the local community and society at large (Section 5). Early stakeholder engagement (Section 6.1.2) and risk communication practices (Section 5.9.1.4 and 6.1.6) provide a platform to assess and engage interested stakeholders and affected communities throughout the project life cycle.

6.2 Site Characterization

The site characterization component of the remediation project life cycle incorporates site investigation efforts and vulnerability and risk assessments (Figure 6-9). This step is conducted to (1) define the nature and extent of impacts to soil, groundwater, sediment, soil vapor, and other impacted media; (2) identify potential receptors; and (3) evaluate potential site vulnerability to climate change and wildfires that may impact future work. Systematic planning to establish clear objectives is necessary to prepare for the investigation. SRR approaches may provide the greatest benefit when employed early in the process. Therefore, investigation preparations include SRR approaches to the degree possible to optimize the results.

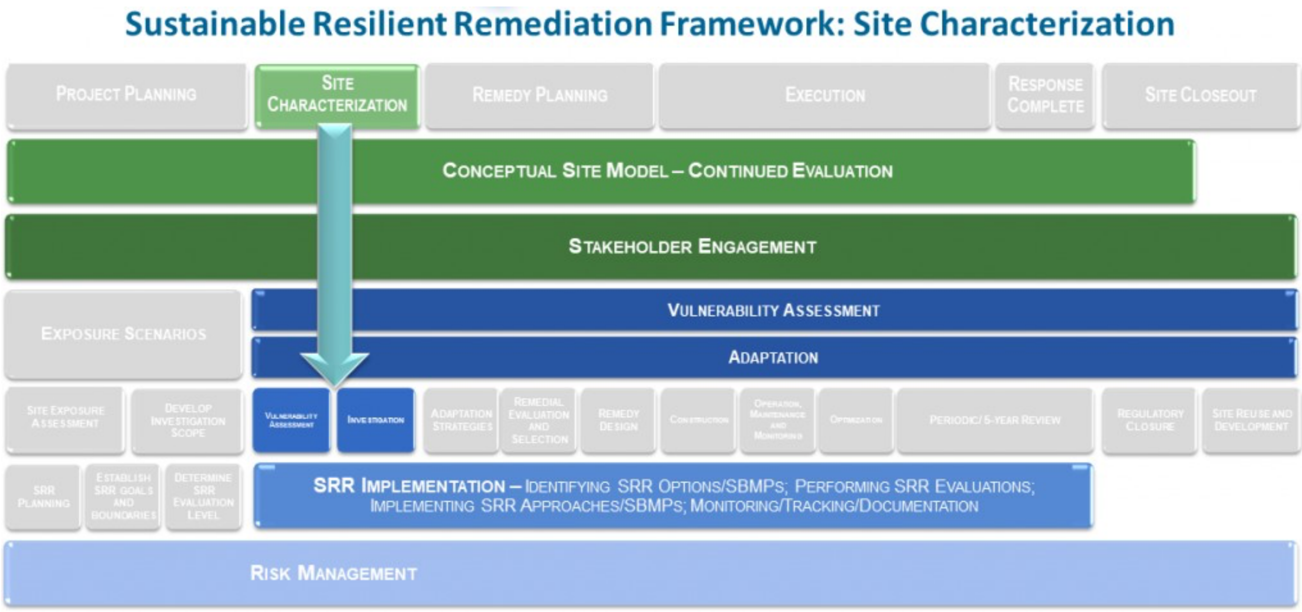


Figure 6-9. SRR framework: Site characterization.

Source: ITRC 2020.

6.2.1 **CSMs**

See Section 6.1.1.

6.2.2 **Stakeholder Engagement**

See Section 6.1.2.

6.2.3 **Resilience: Vulnerability Assessment**

Vulnerability assessments identify hazards of concern considering various climate and extreme weather scenarios (for example, extreme precipitation events). The goals and scope of vulnerability assessment are site-specific and are defined with input from the SRR CSM (Section 6.1.1). The boundaries of the assessment are also important to define and may depend on the type of project and the hazard being addressed. Several tools are available to determine regional weather and climate data (Section 6.1.4.1), and these data are used to assess the specific local impacts. The sensitivity of the existing or proposed remedial action to the potential hazards is assessed and can be expanded to include how sustainability considerations are affected. Stakeholder input is vital to inform risk acceptance. For more detailed information about vulnerability assessments, see Section 6.2.5.1.

6.2.4 **Resilience: Adaptation**

The vulnerability assessment results are used to identify and prioritize potential options to increase the site's resilience to identified potential climate and extreme weather event impacts. These adaptation options are prioritized based on effectiveness and longevity as well as sustainability considerations. The resilience associated with OM&M practices and how these practices may change over time is also addressed (for example, salt-water intrusion or hydraulic changes with sea-level rise). Multiple other factors are considered and can include stakeholder values, the size of the project, the complexity of remediation, infrastructure needs, the site end use, the site access, capital cost, and OM&M costs.

To allow sites and remedies to adapt to future conditions where weather events may be more extreme and the remedy more sensitive, it may be necessary to build additional features or more robust elements than traditionally required. Alternatively, a remedy may be designed to allow for future modifications (for example, an elevated sea wall) if needed to adapt to changing conditions. Explaining why a project is being performed the way it is (that is, to allow for potential adaptation) may be necessary for contractors and staffing personnel.

Accurate and detailed tracking and documentation associated with the SRR evaluation metrics are a key activity.

6.2.5 **Detailed Project Life Cycle**

6.2.5.1 ***Vulnerability Assessment***

Methods for systematically assessing vulnerability and developing informed adaptation actions are well established, and key resources and tools exist at the state and federal level (USEPA Superfund Climate Resilience web-based resources, U.S. Climate Resilience Toolkit and Section 7). Generally, understanding vulnerability and how systems may respond to impacts depends on evaluating the following components:

- probability and magnitude of exposure to extreme weather, wildfire, and other climate-linked events that the site location may endure
- sensitivity of the site and in-place or planned remedies to that exposure
- inherent adaptive capacity of remedial systems and their ability to respond to extreme events

In addition to the remedy resilience, aspects such as nearby community resilience could also be addressed:

- sensitivity of nearby communities to extreme weather or wildfire
- sensitivity of nearby communities to the possible failure of remedial systems or uncontrolled release of contaminant
- adaptive capacity of nearby communities and their ability to respond to both extreme events and possible contaminant releases

Hence, vulnerability can be identified in different ways. For example, site vulnerability or social vulnerability can be modeled in the following semiquantitative ways:

- Site Vulnerability = Extreme Weather & Wildfire Exposure + Site Sensitivities – Remedial System Adaptive Capacity
- Social Vulnerability = Extreme Weather & Wildfire Exposure + Community Sensitivities – Community Adaptive Capacity

6.2.5.2 ***Investigation***

The investigation phase is conducted to define the nature and extent of impacts to soil, groundwater, sediment, soil vapor, and other impacted media and to identify potential receptors. Systematic planning to establish clear investigation objectives is necessary, and SRR approaches provide the greatest benefit when employed early in the process. Therefore, investigation preparations include SRR approaches to the degree possible to optimize results. Table 6-1 lists examples of overall approaches and SBMPs to apply SRR during an investigation. These approaches are organized to identify those that apply to the environmental, social, economic, and resilience aspects of site investigation.

One goal of an investigation is to collect data to help evaluate a site's vulnerability to climate change and extreme weather events during the remedial action and long-term management of the remedy. While regional data for weather patterns may be available, detailed site-specific data may be needed to better understand the vulnerability of a site to extreme events. Prior to collecting site-specific data, available regional and local data are collected and built into the CSM. The updated CSM can be used both to perform an initial evaluation of the vulnerability of the site and potential remedies to climate change impacts and to identify data gaps that need to be filled to achieve a robust vulnerability assessment.

The type of site-specific data needed depends on the location and type of site. For a site where there are concerns about contaminants in sediments, data needed may include wind and wave action, drainage patterns of runoff into surface water, interactions at the groundwater to surface-water interface, historical rates of erosion and sediment deposition, and sediment properties that may affect sediment and contaminant transport (for example, sediment grain size and compaction). For upland sites, data needed may include historical records of storm events and drainage patterns, site flooding or standing water, and occurrence of erosion and landslides that occurred due to storm events. Additional information regarding data needs for various site types is provided by the Washington State Department of Ecology (2017).

Adaptive management strategies are used to address future remedy resilience during investigation activities. Although initial investigation activities generally focus on determining the nature and extent of contamination and performing a baseline risk assessment, initial data on the exposure to extreme weather or wildfire events can also be collected. If remedial activities are needed, subsequent investigation activities focus on reevaluating vulnerability data and identifying data gaps. If additional data are needed, data are collected to optimize the design so that the remedy is more sustainable and resilient.

Adaptive site management has been defined as an approach to resource management in which policies are implemented with the express recognition that the response of the system is uncertain, but with the intent that this response will be monitored, interpreted, and used to adjust programs in an iterative manner, leading to ongoing improvements in knowledgeand performance (NRC 2003). Through the life cycle of characterizing a site and evaluating remedial alternatives, the data needs will often evolve and thus the investigation program must adapt in an iterative manner. For example, as information for a site is obtained and evaluated, a conclusion may be reached that a long-term remedy will be required, and that additional data are needed to evaluate long-term resilience.

If extreme weather events or wildfires occur during the investigation phase, the site is surveyed immediately after the event when it is safe to do so. The vulnerable areas are mapped with respect to existing contamination and survey data are incorporated into the CSM. If a site is vulnerable to inundation, additional data may need to be collected to develop detailed surface contour maps for predicting inundation patterns and identifying vulnerable areas. If the site is near the shoreline, site-specific data (for example, currents, wind, and wave action) may be needed to further evaluate the potential for inundation. If salt-water intrusion is a potential impact to the remedy, it may be necessary to collect and evaluate water quality data (such as pH and conductivity).

6.2.6 **SRR Implementation**

The generalized SRR implementation methodology on how to identify, evaluate, select, implement, and track and document SRR practices in each phase of site remediation is shown in Figure 6-10 below. During each of the remediation project phases, SRR is incorporated by identifying SRR options, evaluating SRR options, selecting and implementing the optimal SRR option(s), and finally tracking and documenting SRR processes and SBMPs. It should be noted that SRR can be incorporated at any phase or the entire life cycle of remediation projects. To maximize sustainable and resilient outcomes of remediation activities, SRR is considered at each phase of project planning and scoping and must be in alignment with stakeholder values (Section 6.1.2).

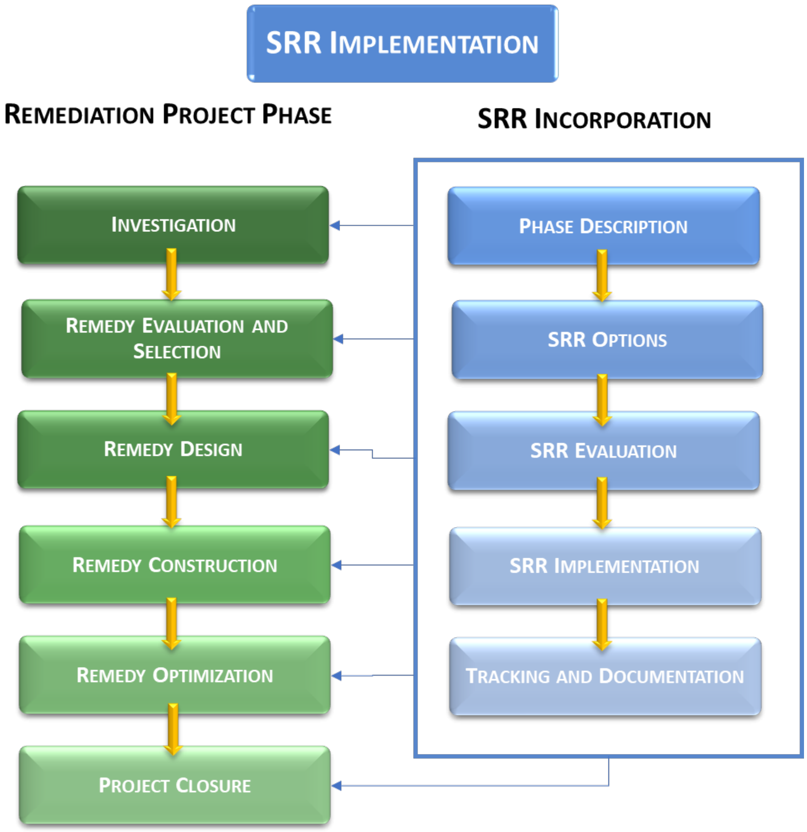


Figure 6-10. SRR implementation.

Source: ITRC SRR Team.

SRR options accomplish targeted SMART resilience and sustainability goals (Section 6.1). A practical approach may include evaluating resilient options first and then subjecting them to sustainability evaluations. The goal is to select the optimal option that achieves both resilience and sustainability. SRR evaluations can be performed at three levels, depending on CSM factors (Section 6.1.1), data availability, and budget constraints. Not all SRR metrics may be quantifiable, so some engineering and SRR subject matter expert judgment may be needed when selecting the SRR option for implementation. To communicate benefits and ROI, SRR implementation activities are documented and compared against evaluation results. Reasons for differences in estimated benefits or SBMP implementability are explained and the continuation of or modification to the implementation strategy is determined.

6.2.7 **SRR Risk Management**

See Section 6.1.6.

6.3 Remedy Planning

The remedy planning phase of remediation is conducted to identify, screen, select, and design the most appropriate remedy to meet the site-specific remedial action objectives (Figure 6-11). From an SRR perspective, the remedy evaluation and selection phase is an ideal point during the site remediation process to identify site remediation approaches and technologies with incrementally lower environmental impacts that attain the remedial action objectives and are aligned with community/stakeholder and economic development concerns and needs (that is, values). Most state and federal cleanup programs include remedy evaluation criteria well suited to include SRR considerations, such as short- and long-term effectiveness and permanence criteria. Further, the remedy selection process should incorporate adaptation strategies to understand potential impacts to the remedy design. This phase typically offers the greatest opportunity to capture the benefits associated with SRR approaches and influence the scope of the remedy design and remedy construction phases.

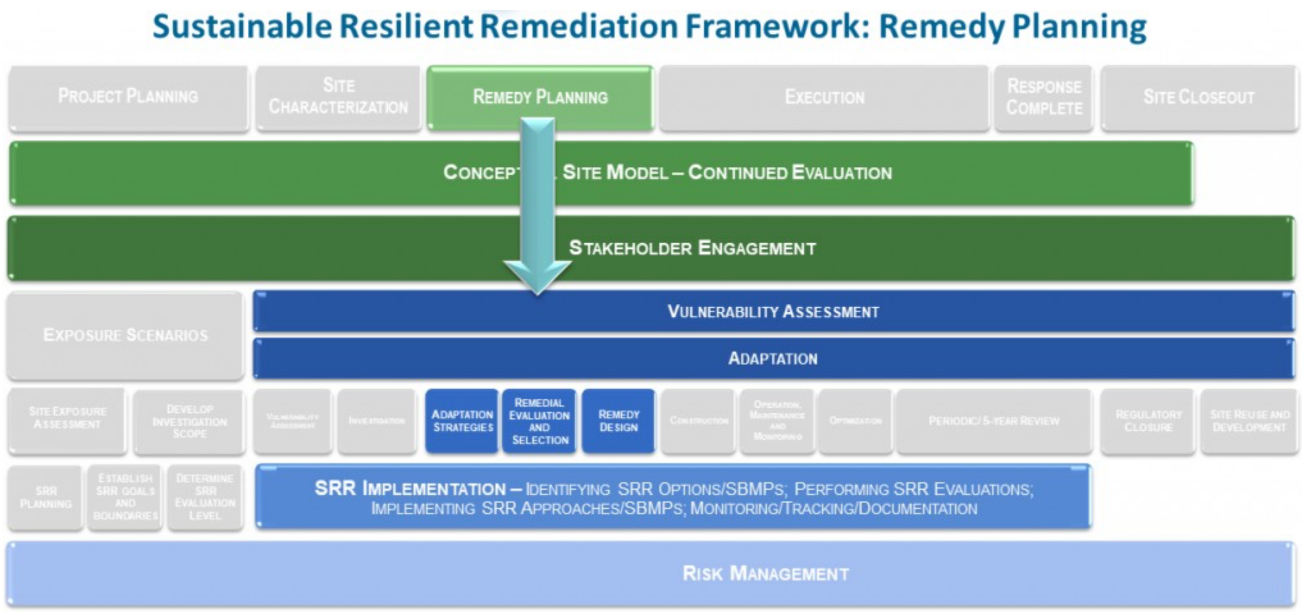


Figure 6-11. SRR framework: Remedy planning.

Source: ITRC SRR Team.

6.3.1 **CSMs**

See Section 6.1.1.

6.3.2 **Stakeholder Engagement**

See Section 6.1.2.

6.3.3 **Resilience: Vulnerability Assessment**

See Section 6.2.3.

6.3.4 **Resilience: Adaptation**

See Section 6.2.4.

6.3.5 **Detailed Project Life Cycle**

6.3.5.1 ***Adaptation Strategies***

Once vulnerabilities have been identified, the next step is to identify adaptation strategies or actions that address high-priority vulnerabilities and choose which to implement and when. Adaptation strategies that address site vulnerabilities together with social and economic vulnerabilities are most likely to be supported, to succeed, and to necessitate stakeholder involvement from the beginning. Stakeholder input is essential for understanding a community's sensitivities to extreme weather, sea-level rise, wildfires, and possible contaminant release and its adaptive capacity to respond.

The USEPA suggests resilience measures across four categories, including physically securing remediation systems, providing additional barriers to protect systems, safeguarding access to the site and systems, and alerting project personnel of system compromises when they occur. A comprehensive list of engineered solutions commonly used in climate resilience measures is also discussed in the Superfund Climate Resilience: Resilience Measures website.

The USEPA has also published climate resilience technical fact sheets where specific adaptation strategies (that is, resilience measures) are suggested in response to a subset of climate change effects. At the state level, the Washington State Department of Ecology (2017) developed guidance for cleanup project managers that includes specific options for increasing the resilience of remedial actions at soil and groundwater cleanup sites, landfills, mining cleanup sites, and sediment cleanup sites.

6.3.5.2 ***Remedial Evaluation and Selection***

Considering resilience and sustainability during the remedy evaluation phase is a component of assessing short-term effectiveness and long-term permanence of an alternative in the context of dynamic, future site conditions. An adaptive remedial strategy is developed to achieve short- and long-term, site-specific risk management objectives. The remedy evaluation and selection phase is the ideal point during the cleanup process to identify remediation approaches and technologies that have a smaller environmental footprint while focused on attainment of remedial action objectives in consideration with stakeholder values (ITRC 2011a). Likewise, managing resilience includes integrating the following site condition considerations during remedy evaluation:

- *Hydrodynamic conditions* – Coastal and riverine hydrodynamic conditions (for example, sea-level rise and wave action) are changing over time, which impacts tidal influence, erosional and depositional forces, storm surge, and mass flux and mass discharge.
- *Hydrological conditions* – Precipitation patterns are changing over time, exacerbating drought, wildfires, storm surge, and nuisance flooding, and also impacting mass flux, mass discharge, and microbial or natural contaminant attenuation.

Considering site vulnerabilities and dynamic future conditions helps practitioners select a remedial strategy that maintains protectiveness. Resilience (with a focus on the proposed selected remedy) is becoming a more frequent topic during meetings between decision makers and responsible parties and in public comments. Early consideration of resilience management while focused on attainment of remedial action objectives (in consideration with stakeholder values) should be considered and integrated in the overall site risk management strategy.

A sustainability and resilience evaluation for a remedial alternative includes the following:

- Define site boundary, including remedial action objectives, footprint of active and passive treatment, footprint of cleanup activities, and boundary of site conditions/resilience metrics (for example, hydrodynamic modeling or wildfires may need to consider a larger geographic area of influence rather than just the site boundaries).
- Perform a vulnerability assessment of different technologies to determine potential impacts to long- and short-term effectiveness using the resilience considerations and metrics identified during project planning and the site investigation.
- Reference the SRR guidance, the USEPA's climate change adaptation fact sheets, and vulnerability assessment process and provide examples.
- Determine if vulnerabilities identified for proposed technologies or risk management strategies can be mitigated through adaptation measures or SBMPs. If so, the remedial alternatives can move forward for consideration. If not, the remedial alternative is not preferred.
- For each proposed remedial alternative, identify the adaptation strategy, SBMPs (see Table 6-2 for examples of SBMPs), and other tools (such as hydrodynamic modeling) to estimate the level of effort and associated costs. At a minimum, these efforts are documented for the selected remedial alternative. The documentation may be included in the remedy evaluation document (for example, feasibility study) and in some cases in the remedial design report.

Table 6-2. Examples of SBMPs to be considered during remedy evaluation and selection (modified from ITRC 2011a).

SRR Consideration	SBMP
	Evaluate on-site and in situ treatment and containment technologies to determine whether they provide lower impacts.
	Conduct energy use and GHG and air pollutant emissions calculations to compare performance of technologies.
	Identify opportunities to create habitat.
Social	Communicate site remediation options and risk reduction achieved to stakeholders and the community.
	Obtain input on site remediation alternatives and stakeholder/community concerns/needs.
Economic	Determine short-term and long-term cost of site remediation alternatives contrasting with environmental and community benefits.
	Evaluate options to provide green space and/or restore properties for reuse.
	Create community assets (e.g., parks, open space, habitat) and/or link to community economic development plans.
	Design remedy to adapt to future site use plan.
Resilience	Evaluate vulnerability to climate-based hazards for each remedial alternative.
	Identify data gaps applicable to remedial alternatives being evaluated to be used for conducting supplemental site investigation.
	Identify mitigation measures that will need to be included in the design for each remedial alternative.
	Characterize long-term residual risk of protectiveness loss for each remedial alternative due toclimate-based hazards.
	Predict the long-term financial risk for each remedial alternative due to climate-based hazards.
	Gain input from stakeholders on climate-based risks and communicate how risks have been included in the remedy evaluation and selection process.

6.3.5.3 ***Remedy Design***

Once the remedy has been selected, the system design focuses on two objectives: preventing unacceptable risk that remedy failure results in loss of human health or environmental protection due to extreme weather events, sea-level rise, or wildfires; and (2) optimizing sustainability (with a new emphasis on social and economic dimensions – see Section 5). With respect to resilience to extreme events, the designer may need to evaluate the tradeoff between designing a more robust infrastructure to be resilient to potential future events or planning for the potential of implementing repairs should those events occur.

Integrating resilience during the design phase is of greatest importance for remedies that are expected to have a long-term operation or management phase, such as sites where contamination source areas remain for a period of time and are managed or contained as part of the remedy. Resilience is important for these sites because the long-term nature of the remedy increases the probability that extreme weather events will occur (Figure 6-12), and the protectiveness is reliant on the system not failing. Responding to failed or damaged systems can result in a loss of protectiveness, increase in pollutant emissions, higher costs, and community impacts. When the remedial time frame is established during the design phase with the proper level of resilience, the overall sustainability and long-term protectiveness of the design is enhanced.

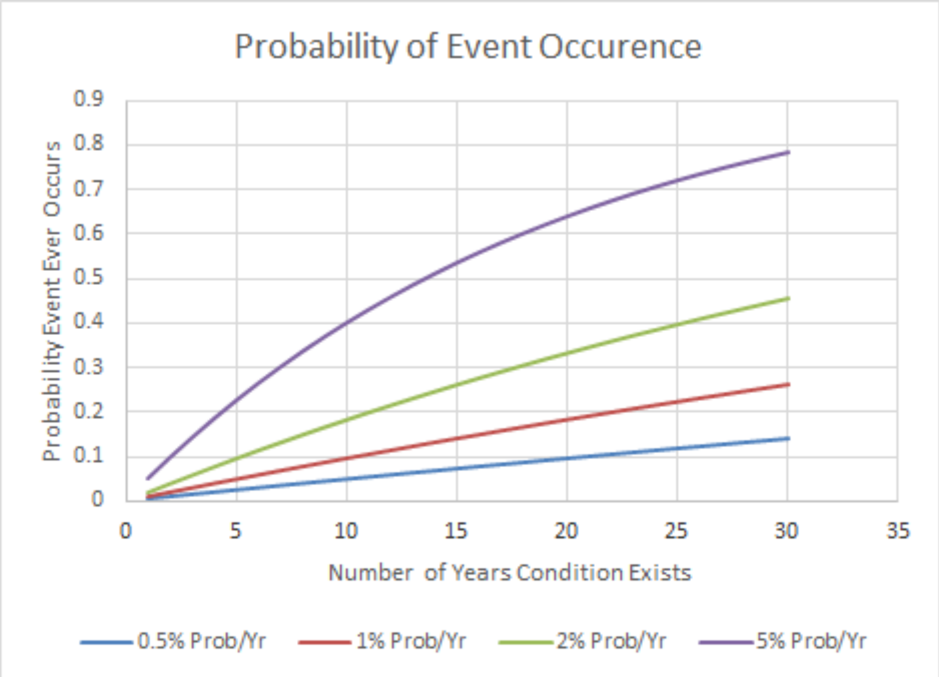


Figure 6-12. Probability of extreme weather event or wildfire occurring vs. length of time.

Source: ITRC SRR team

The following steps can be implemented during the remedial design phase:

1. Update the vulnerability assessment performed during remedy evaluation and selection to estimate the baseline probability of extreme weather events or wildfires occurring and the severity of the impacts on the remedy should they occur. This evaluation is either a qualitative characterization or a quantitative assessment of probability and detailed analysis of impacts depending on the size and complexity of the project. The evaluation of risk or vulnerability can be a risk matrix where the probability of an event occurrence and the severity of the occurrence are both considered. Additional information about risk management can be found in Project Risk Management for Site Remediation (ITRC 2011c).
2. If not performed prior to the design phase, determine if the risk of protectiveness loss is unacceptable (which may require stakeholder engagement—Section 6.1.2) and, if so, identify the applicable SBMPs (see Table 6-3 and Section 7 for examples of SBMPs) to reduce risk (for example, sea walls, backup power supplies, enhanced stormwater and erosion controls) to acceptable levels.
3. Evaluate SBMPs to determine the most sustainable and resilient approach to reducing risk to acceptable levels (Section 7). This evaluation can take the form of a cost-benefit analysis. Information on conducting a cost-benefit analysis is provided in the Guideline on Performing Cost-Benefit and Sustainability Analysis of Remediation Options (CRCCARE 2018).
4. Identify the optimum set of SBMPs and incorporate into the design to reduce the risk of remedy failure.
5. With SBMPs incorporated into design, revisit the vulnerability assessment and document the remaining risk that was accepted.

Table 6-3. Examples of SBMPs to be considered during remedy design (modified from ITRC 2011a).

SRR Consideration	SBMP
Environmental	Identify low-energy, low-emission, and low-water-intensive technologies and equipment.
	Minimize impacts to local natural resources and habitats.
	Maximize use of renewable energy and fuels.
	Minimize off-site transport of contaminated materials.
	Identify recycling options for materials generated during site remediation.

Social	Engage community leaders in design meetings to obtain input on configurations and timing of site work.
	Communicate with or notify stakeholders of site remediation plan, including short-term community impacts and long-term risk reduction.
	Obtain input on community concerns/needs.
Economic	Use on-site approaches to management of contamination to reduce costs of site remediation and potential long-term liabilities associated with off-site disposal.
	Conduct treatability/pilot studies to prove technologies before full-scale design.
	Use adaptive site-reuse approaches incorporating existing buildings into site-reuse options.
	Maximize beneficial reuse of the site.
	Design OM&M systems to minimize life-cycle costs.
Resilience	Specify vegetated components of remedies (e.g., vegetative caps and embankments) with drought-resistant grasses, shrubs, trees, and other deep-rooted plants that are wind-resistant and flood-resistant to stabilize the site and protect them from erosion, storm surges, and tidal influence.
	Design structures to be wind-resistant, withstand snow loads, and withstand rapidly moving, floating debris (for example, trees, appliances, cars).
	Design slopes with sufficient fortification to withstand wind erosion.
	Elevate mechanical and electrical systems to protect against flooding.
	Specify backup power for freeze-protection systems (for example, heat trace and heaters) and other critical systems and include temperature monitoring telemetry.
	Specify telemetry for mechanical systems to allow remote operation and monitoring.
	Design monitoring and treatment systems considering potential changes in groundwater flow, including direction, depth, volume, and rate.
	Design subgrade structures to remain out of contact with increased water table level.
	Consider the effects of increased pumping on nearby groundwater supply wells.
	Use 100-year floodplain with an additional safety factor for design (e.g., 3 feet) or perform an engineering analysis to determine the 500-year floodplain.

6.3.6 **SRR Implementation**

See Section 6.2.6

6.3.7 **SRR Risk Management**

See Section 6.2.7

6.4 Execution

The execution phase consists of implementing the selected remedy as outlined in the design documents, including constructing, operating, maintaining, monitoring, and optimizing the remedy (Figure 6-13). Depending on the remedy, unintended environmental impacts can occur during the construction phase. As recommended by this guidance, continual update of the CSM provides for resilience measures (such as preparing contingency plans for extreme weather events) that can help minimize potential negative impacts, particularly for long-term remedies. Preparing for climate change impacts in the short and long term is integral to minimizing risk.

In cases where SRR has been an integral part of the remedy design, the application of SRR elements is integrated into construction and OM&M contracts. In other cases where SRR is being considered for the first time in the remedy construction phase, SBMPs and operating practices are identified to minimize the impacts associated with the selected remedy to the local community and environment.

Additional discussions for integrating resilience and sustainability in the execution of the remedy are provided for each of the execution phases, including construction (Section 6.4.5.1), OM&M (Section 6.4.5.2), optimization (Section 6.4.5.3), and periodic and 5-year reviews (Section 6.4.5.4).

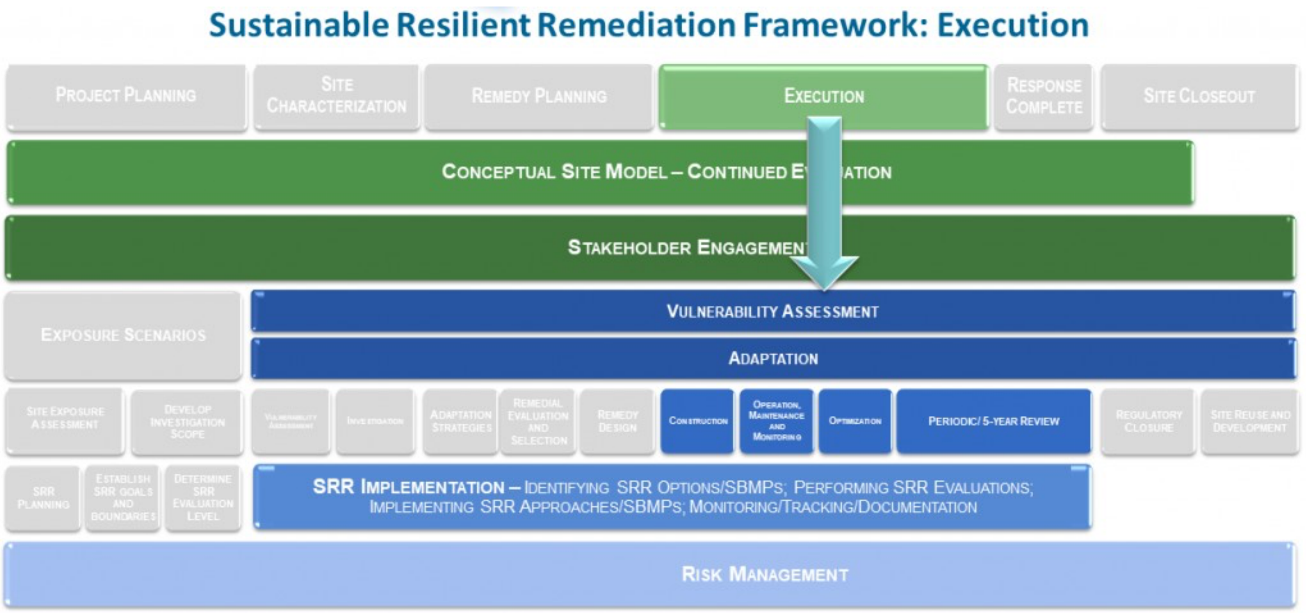


Figure 6-13. SRR framework: Execution.

Source: ITRC SRR Team.

6.4.1 **CSMs**

See Section 6.1.1.

6.4.2 **Stakeholder Engagement**

See Section 6.1.2.

6.4.3 **Resilience: Vulnerability Assessment**

See Section 6.2.3.

6.4.4 **Resilience: Adaptation**

See Section 6.2.4.

6.4.5 **Detailed Project Life Cycle**

6.4.5.1 Construction

The remedy construction phase consists of implementing the selected remedy as laid out in the remedial design documents. Depending on the remedy and the time frame to meet remedial action objectives, unintended environmental impacts can occur during construction. Considering short- and long-term climate change impacts and extreme weather events is vital to preventing unnecessary risks and associated costs. Construction can involve mobilizing large, energy-intensive equipment to a site. Fuel consumption and air emissions, along with noise and dust impacts, may result. With the movement of equipment and moving parts, site workers are also at risk for injury and must be vigilant about safe work practices. During this phase of the remedial project life cycle, many materials are brought to the site; materials remaining after construction are reused or recycled. Thoughtful planning from both a sustainability standpoint and a climate resilience perspective (such as preparing contingency plans for extreme weather events) can help minimize negative impacts (Section 6.1.3). Preparing for climate change impacts in the short and long term is integral to minimizing risk and potential issues down the road.

In cases where sustainability and resilience have been integrated into the remedy design, they can also be included in construction and OM&M contracts. In other cases, where SRR is first being considered at the remedy construction phase, SBMPs and operating practices are identified to minimize impacts to the local community and environment. Table 6-4 provides some considerations for SRR implementation during the construction phase.

Table 6-4. Examples of SBMPs to be considered during construction (modified from ITRC 2011a).

SRR Consideration	SBMP
Environmental	Minimize equipment engine idling.
	Use fuel-efficient vehicles.
	Use low horsepower equipment to complete tasks.
	Control and mitigate dust, odors, noise, and light impacts.
	Conduct monitoring of air and, if needed, odors, noise, and light.
	Set up comprehensive on-site recycling program for all wastes and residuals.
	Select construction equipment and energy sources to minimize fuel and energy use and emissions.
Social	Conduct community meetings to inform stakeholders of project progress.
	Post information on monitoring programs and project progress and plans.
	Maximize the use of local businesses for goods and services.
	Minimize contamination risks on site for workers performing construction.
	Sequence construction activities to minimize noise and traffic impacts to the local community.
Economic	Alleviate undesirable community impacts, such as noise, traffic, odor, business disruptions, and compromises in local heritage, and address cultural concerns.
	Use local contractors and staff to minimize travel.

Resilience	Integrate SBMPs and plans to address extreme weather events, sea-level rise, and wildfires into the site contingency plan.
	Ensure that key personnel (that is, construction manager, project manager, and all subcontractors) understand the site's vulnerabilities and site contingency plan.
	Implement and document SBMPs identified during design.
	Be adaptable should the contingency plan be insufficient.
	Integrate the requirements of SBMPs in contracting (for example, a clause for adaptability and contractor understanding of how to implement contingency plan).
	Document resilience actions taken in completion reports.

*6.4.5.2 **Operation, Maintenance, and Monitoring (OM&M)***

The OM&M phase includes the actions required to maintain treatment systems and monitor the performance of these systems. Remedial operations and long-term monitoring have sustainability impacts and are susceptible to climate change and extreme weather impacts. Because remedial systems may operate over long periods of time, the potential for climate change impacts and extreme weather events are evaluated along with their overall impact to reduce their environmental footprint.

Large, energy-intensive systems such as pump and treat, multiphase extraction, and other in situ treatment systems can operate for years, accounting for a high percentage of the system's overall life-cycle footprint. Over time, as diminishing returns are observed, alternatives that are greener and more energy-efficient are considered. SRR during OM&M may include using SBMPs and replacing or optimizing existing systems to identify approaches that reduce energy use, material use, or waste generation, as well as address other issues or impacts (for example, noise).

Table 6-5 shows examples of SRR approaches for OM&M. The implementation of SRR during the OM&M phase can also be conducted as part of the remedy optimization phase.

Table 6-5. Examples of SBMPs to be considered during OM&M (modified from (ITRC 2011a).

SRR Consideration	SBMP
Environmental	Use telemetry to remotely collect operational data and reduce field mobilizations.
	Recycle sample residuals.
	Identify waste minimization measures.
	Use the USEPA's five core elements associated with a cleanup project's environmental footprint.
	Minimize or eliminate idling.
	Use fuel-efficient vehicles.
	Use low horsepower equipment to complete tasks.
	Use the local or closest disposal facility.
Social	Conduct stakeholder engagement via a website and other public communication approaches.
	Maximize the use of local businesses for goods and services.
	Evaluate stakeholder acceptance and community satisfaction with the remedy.
Economic	Use low-energy, intensive approaches.
	Use local contractors and staff to minimize travel.
	Alleviate undesirable community impacts, such as noise, traffic, odor, business disruptions, and compromises in local heritage, and address cultural concerns.
	Use on-site sample testing or screening approaches.
	File electronic reports versus paper.
Resilience	Include changes caused by extreme weather events when evaluating conditions that are changing over time.
	Recognize when a condition change has the potential to impact the effectiveness of the remedy and triggers the evaluation, implementation, and documentation of SBMPs.
	Evaluate a remedy's resilience and changes in site conditions on a regular, predetermined basis.
	Regularly update the contingency plan, including SBMPs and plans to address extreme weather events, sea-level rise, and wildfires.

6.4.5.3 ***Optimization***

Remedy optimization involves evaluating existing remediation systems to improve performance and efficiency, and reduce the annual operating cost or environmental footprint while ensuring protectiveness. Considering resilience in this phase is a component of comprehensively evaluating the short-term effectiveness and long-term permanence of a risk management strategy. An SRR evaluation at this point in the remedy can be used to optimize existing remedial strategy and identify opportunities to create more sustainable and resilient remedies.

Remedy optimization may be conducted periodically (that is, annually, biennially, or as part of a 5-year review) or on an as-needed basis to ensure that the remedy is performing as expected and continuing to meet remedial action goals. During detailed remedy optimizations, nearly every aspect or component of the remedy—equipment, personnel, energy, resources, monitoring, sampling, and data analysis—is reviewed to ensure optimal and appropriate use for current site conditions (ITRC 2011c). Table 6-6 provides examples of SRR approaches and SBMPs that can be incorporated into remedy optimization.

Table 6-6. Examples of SBMPs to be considered during remedy optimization (modified from ITRC 2011a).

SRR Consideration	SBMP
Environmental	Maximize efficiency and optimize existing remedies to reduce carbon footprint, energy, and overall environmental impact of resource consumption.
	Use the USEPA's five core elements associated with a cleanup project's environmental footprint.
	Identify alternative methods or technologies that are equally protective but use less energy and resources.
	Identify waste minimization measures.
Social	Communicate with stakeholders about the efficiency of the remedial program in measurable terms (that is, contaminant mass removed per dollar).
	Communicate with stakeholders about optimizing remedies and reducing impacts on energy use and GHG production to achieve a net positive environmental impact.
Economic	Maximize the remedy efficiency to reduce energy and maintenance costs and costs associated with overall operations.
	Reallocate money saved through optimization efforts to promote sustainable and resilient solutions.
	Use low-energy, intensive approaches.
	Use local contractors and staff to minimize travel.
Resilience	Evaluate the vulnerability monitoring performed during the OM&M stage. For example, have the assumptions about sea-level rise and wave action used to design the backfill or armor size changed over time? Has the frequency or footprint of a flood or wildfire changed and now poses a greater risk? Have the plume containment strategies been impacted by climatic events?
	Revise the vulnerability assessment of the current remedy to determine potential impacts to long- and short-term effectiveness due to resilience factors or metrics.
	Rerun the contaminant fate and transport or hydraulic models used to design and construct the remedy with updated existing and future conditions (for example, precipitation, sea-level rise risk, wildfire projections).
	Regularly update the contingency plan, including SBMPs and plans to address extreme weather events, sea-level rise, and wildfires.

Like a remedy evaluation, remedy optimization assesses the vulnerability of the site and selected remedy to extreme weather events, sea-level rise, wildfires, and changing site conditions. Considering resilience in this way allows practitioners to optimize both the technology and strategy of a selected remedy or just the strategy. In the latter context, monitoring vulnerability during the OM&M stage or performing a vulnerability assessment can provide insight on how site conditions may have changed over time. The remedy optimization evaluation revisits remedy design assumptions to determine if the risk management strategy is resilient to the most current and forecasted site conditions.

If the vulnerability of the existing remedy can be mitigated with an adaptation strategy or SBMPs, remedial alternatives can be retained and optimized. If not, it may be necessary to transition to remedial alternatives or additional treatment components as part of the optimization process. Many sites require adaptive strategies for cleanup that include transitioning to different remediation technologies over time to continue to achieve remediation goals and address contamination at the site. This is an opportune time to consider passive technologies, which often use less energy. Depending on site conditions, some passive technologies can be powered by wind or solar energy. Some of the technologies require no electricity. ITRC (2018a) listed examples of several passive or low-energy remediation technologies that can be considered for light nonaqueous phase liquid (LNAPL). In addition to LNAPL technologies, the USEPA's green remediation primer (USEPA 2008) provides a discussion of how energy-intensive remedies can be transitioned to more natural, low-energy treatment processes such as enhanced aerobic bioremediation, permeable reactive barrier walls, engineered wetlands, and monitored natural attenuation. For more examples of passive or low-energy remediation technologies, please refer to other ITRC documents below.

- LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies (ITRC 2018a)
- Remediation Management of Complex Sites (ITRC 2017)
- A Systematic Approach to In Situ Bioremediation in Groundwater, Including Decision Trees on In Situ
- Bioremediation for Nitrates, Carbon Tetrachloride, and Perchlorate (ITRC 2002)
- Remediation Process Optimization: Identifying Opportunities for Enhanced and More Efficient Site Remediation (ITRC 2004)
- Optimizing In Situ Remediation Performance and Injection Strategies (ITRC 2020a)

Section 5 provides information and examples using passive ecosystem services and infrastructure for remediation.

6.4.5.4 ***Periodic and 5-Year Reviews***

Like the remedy optimization phase, periodic (or 5-year) reviews revisit remedy design assumptions to determine if remedial action objectives are attainable and the risk management strategy is resilient to the most current and forecasted site conditions. The time frame for routine or periodic reviews varies depending on the regulatory framework. In this section, a 5-year review is used for the purposes of illustration only. Vulnerability monitoring data from OM&M or performing a vulnerability assessment can provide insight on how dynamic site conditions may have changed over time. If current and forecasted conditions are not within the design assumption boundaries, optimizing the existing remedy or transitioning to a more resilient remedy may be warranted.

Periodic reviews can be strengthened by adding a review of CSM assumptions and engineering design criteria based on recognized changes in the severity and frequency of extreme weather events and wildfires. Considering resilience during the periodic review allows stakeholder values that directly influence whether site risk management approaches are acceptable to be integrated.

While some remediation projects have a built-in review process, such as the 5-year review for CERCLA sites, many do not. Where institutional or engineering controls are used as part of the remedial approach, periodic review of remedy resilience and protectiveness should be built into the inspection and maintenance process.

Return to Framework

6.4.6 **SRR Implementation**

See Section 6.2.6.

6.4.7 **SRR Risk Management**

See Section 6.1.6.

6.5 Response Complete

The response complete phase involves demonstrating that the remedy is complete and has met the remedial action objectives outlined in the remedy design. The response complete phase is the transition from remedial operations and optimization to site closeout (Section 6.6). Final SRR actions can be implemented to prepare for site closure and redevelopment (if applicable) and complete SRR tracking and documentation (Figure 6-14). Additional discussion is provided in Section 6.2.6, SRR implementation.

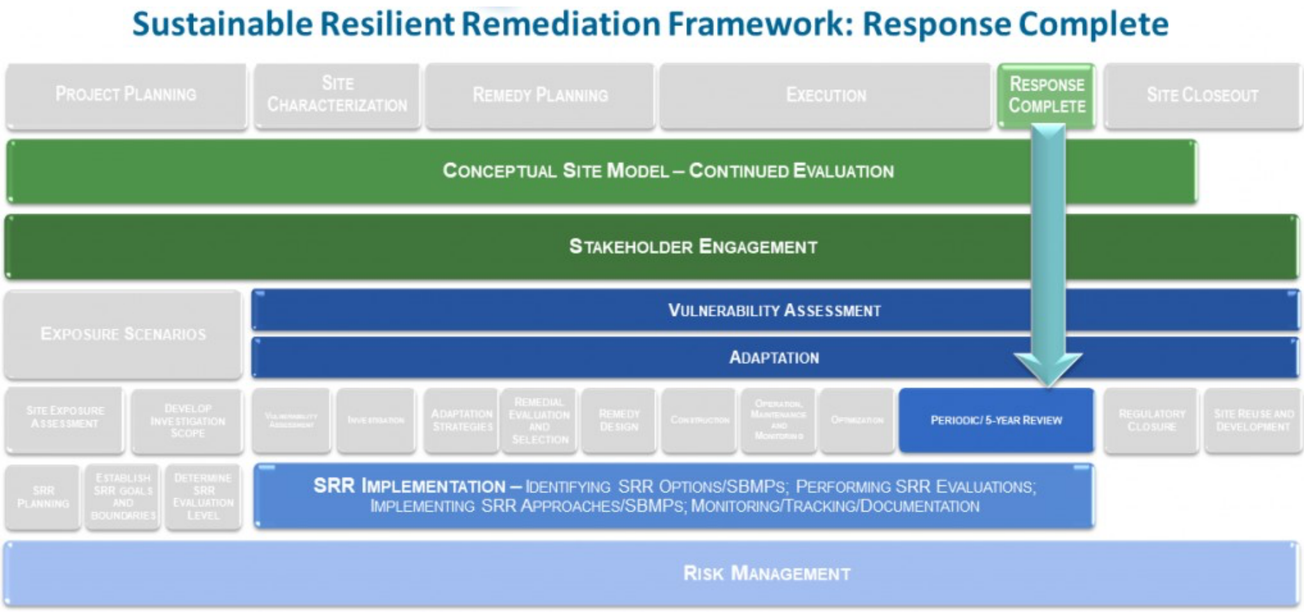


Figure 6-14. SRR framework: Response complete.

Source: ITRC SRR Team.

6.5.1 **CSMs**

See Section 6.1.1.

6.5.2 **Stakeholder Engagement**

See Section 6.1.2.

6.5.3 **Detailed Project Life Cycle: Periodic and 5-Year Reviews**

See Section 6.4.5.4.

6.5.4 **SRR Implementation**

See Section 6.2.6.

6.5.5 **SRR Risk Management**

See Section 6.1.6.

6.6 Site Closeout

The site closeout phase (Figure 6-15) involves regulatory closure (Section 6.6.3.1) and site reuse and redevelopment (Section 6.6.3.2), if applicable. Site closeout can lead to the beneficial reuse of a site if redevelopment or reuse activities have not previously been implemented. Site closeout requires the following: (1) site conditions are accurately and comprehensively documented and properly recorded; (2) institutional controls are in place and clearly defined; and (3) stakeholder inputs are reconciled. At the time of project closeout, engineering or institutional controls that are part of the site remedy are in place. While the regulatory closure process varies based on the site and geographic location (for example, federal- or state-led), SRR considerations continue if unlimited and unrestricted site use are not attained and institutional or engineering controls are required and have been implemented.

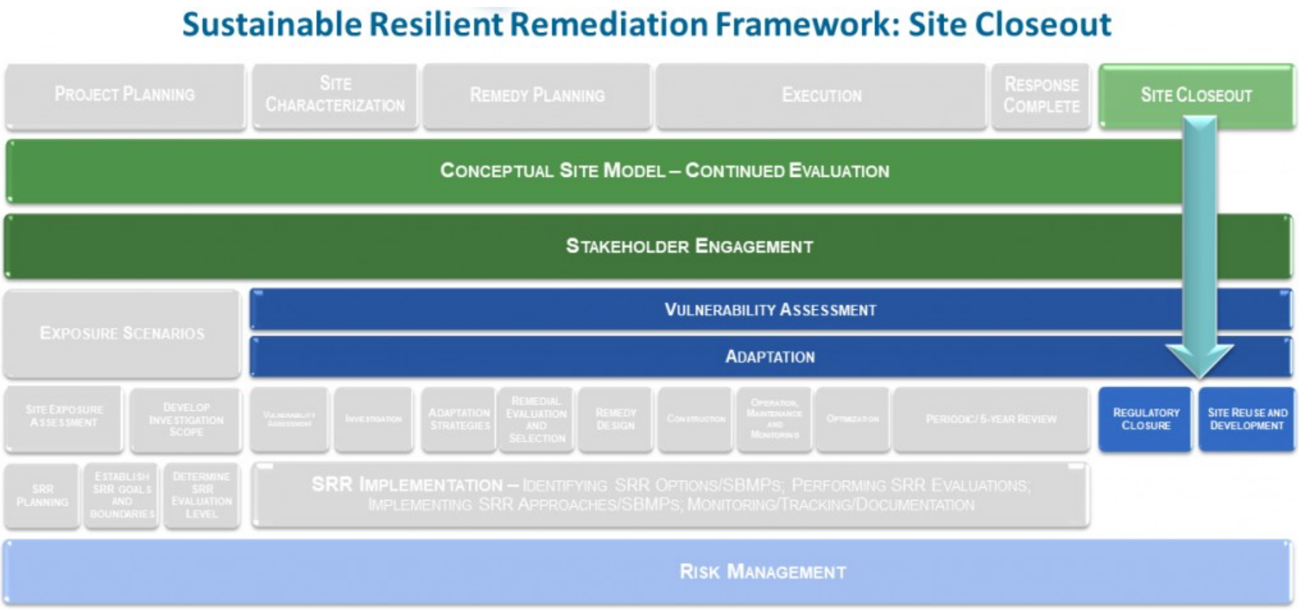


Figure 6-15. SRR framework: Site closeout.

Source: ITRC SRR Team.

6.6.1 **CSMs**

See Section 6.1.1.

6.6.2 **Stakeholder Engagement**

See Section 6.1.2.

6.6.3 **Detailed Project Life Cycle**

6.6.3.1 ***Regulatory Closure***

Resilience management in response complete (Section 6.5) or site closeout (Section 6.6) is informed by the results of existing vulnerability assessments (Section 6.2.3). The maintenance of institutional or engineering controls is planned relative to their vulnerability to extreme weather events, sea-level rise, or wildfires and other relevant site conditions. If unlimited use unrestricted exposure (UUUE) is not achieved and vulnerabilities are identified as significant, a resilience contingency plan may be needed.

Planning for extreme weather events, wildfires, and other climate-linked events is of greatest importance for sites that have not achieved UUUE at regulatory closure, and where engineering or institutional controls will be required. These sites will be managed over many years, increasing the probability that climate change impacts or severe weather events may occur and personnel or site ownership will change. Proper resilience planning and documentation are crucial in these cases. Planning may include reviewing vulnerability assessments already performed, conducting an updated (or new) vulnerability assessment, and evaluating whether identified vulnerabilities remain applicable after the project is closed out. This review considers changes made to the site as part of remedy closure or reuse and redevelopment that would impact resilience of the site (Section 6.2.3). For sites with significant vulnerability, considering in-place institutional or engineering controls after regulatory closure as part of a resilience contingency plan is crucial. Details include pre-event preparations, actions to take during an event, and actions to take after an event (Liserio 2019).

6.6.3.2 ***Site Reuse and Development***

The redevelopment of a site offers an opportunity to positively impact the community. There are also risks associated with future climate change impacts that need to be addressed during redevelopment to ensure the long-term protectiveness of public health and the environment.

The sustainability of redeveloped sites is discussed in detail in USEPA's Climate Smart Brownfields Manual (USEPA 2016b). In addition to providing numerous resources pertaining to sustainability, this document provides guidance on best practices for climate change mitigation, adaptation, and resilience at all stages of brownfields work—from planning to redevelopment. Other information related to land revitalization and green development is provided on the USEPA's Land Revitalization website.

To evaluate risk associated with extreme events for a developed site, performing a vulnerability assessment is critical to evaluate how well the remedy can accommodate the identified climate change risk factors considering long-term reuse of the site (Section 6.2.3). When the consequences involve performing future repairs, the cost of potential future repairs (along with the likelihood) is compared to the upfront cost of designing and constructing the infrastructure to prevent damage from occurring. A more robust evaluation is performed if UUUE is not achieved and extreme events could cause a loss of protectiveness with the existing engineering or institutional controls. In this case, there are several options to consider, including the following three:

1. greater restrictions on land use (for example, parklands allowed but not residential buildings)
2. more robust infrastructure for engineering controls (that is, adaptation—see Section 6.2.4)
3. more stringent remedial action objectives

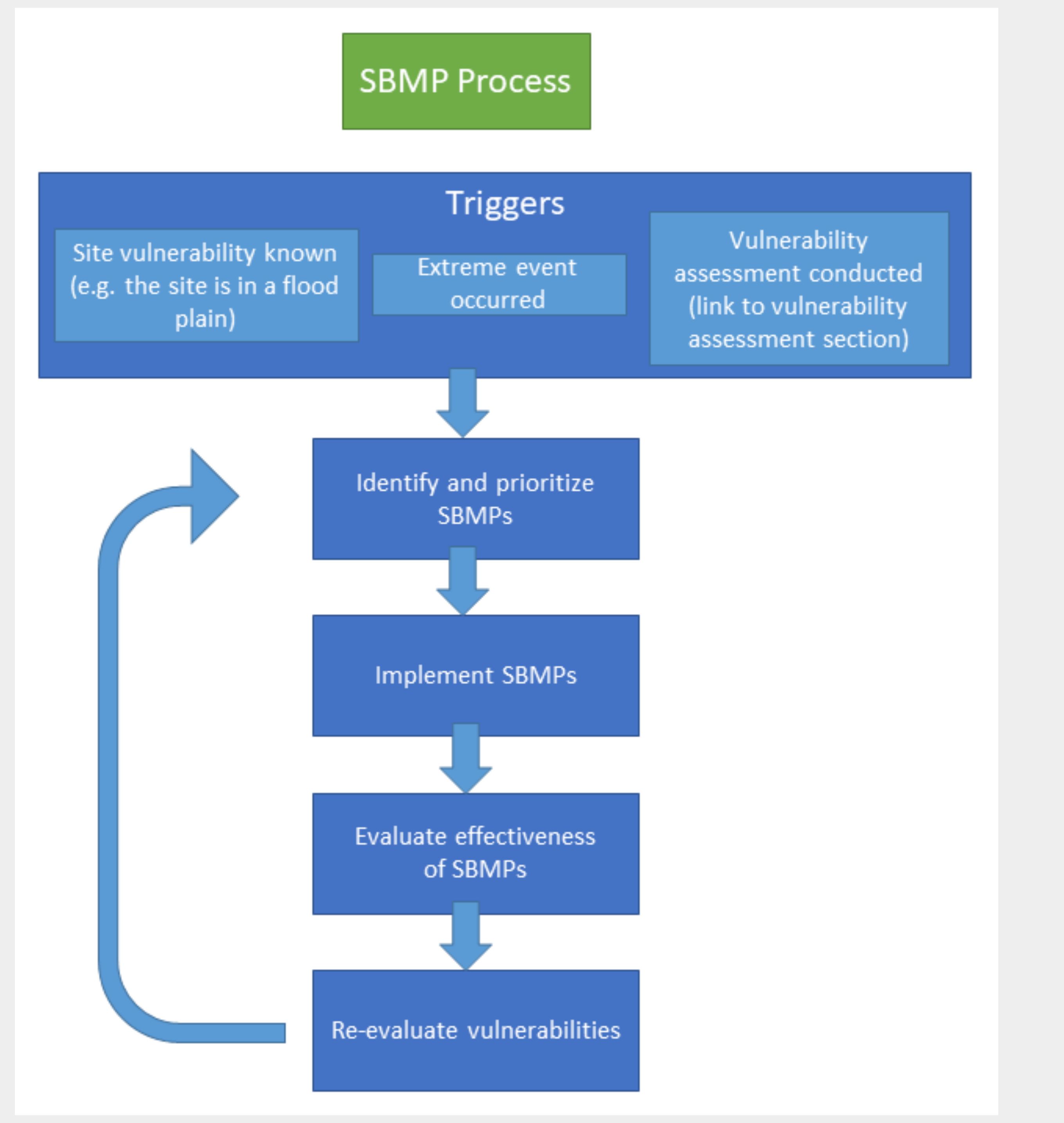
Choosing between Options 2 and 3 tends to be a more straightforward decision when the team can compare implementability and the cost or sustainability of infrastructure enhancement versus additional contaminant treatment or removal. But comparing either of those options to Option 1 requires a complex analysis and must consider all elements of sustainability, including environmental, economic, and social impacts, with an emphasis on the social element. The social element is especially important when evaluating Option 1 as the restrictions on future land use may have significant long-term impacts on the community. This evaluation requires stakeholder engagement early on to evaluate the benefits of site reuse to the community and the impact on the community should more land-use restrictions be imposed (Section 6.1.2).

7. Key Sustainable Best Management Practices for Sustainable Resilience to Extreme Weather Events and Wildfires

SBMPs are effective and practical methods or techniques to build or adapt a sustainable and climate impact–resilient environmental remediation site. SBMPs are an integral part of SRR. In other guidance, when sustainability and resilience are addressed, they may be referred to as simply BMPs.

SBMPs for resilience to extreme weather events and wildfires are often different from SBMPs for implementing a green cleanup. Green cleanups consider all environmental effects and attempt to minimize the environmental footprint of a cleanup, often with the goal of reducing further contribution toward climate change. This approach is important, and SBMPs for greener cleanups are provided by ITRC (2011a), ASTM (2016), and various federal (for example, the USEPA's Greener Cleanups website), state (for example, Ecology 2017), and other greener cleanup guidance.

This section identifies important SBMPs, key resources, and additional considerations for evaluating, implementing, and maintaining resilience to extreme weather and wildfire events at a remediation site. Response considerations and actions are also included. SBMPs are organized by type of extreme event, but some SBMPs may be applicable to more than one extreme event. Cited references provide the resources available to investigate SBMPs based on the type of remedy. Figure 7-1 describes the cyclical process to implement SBMPs. Section 6.2.3 has detailed vulnerability assessment information and additional resources. Once the different vulnerabilities of the site are identified, Table 7-1 can be used to identify the relevant SBMPs based on the factors likely to occur or already occurring at the site. Detailed lists of SBMPs are included in the discussion of the extreme event.


SBMP Process
Triggers
Site vulnerability known (e.g. the site is in a flood plain)
Extreme event occurred
Vulnerability assessment conducted (link to vulnerability assessment section)
Identify and prioritize SBMPs
Implement SBMPs
Evaluate effectiveness of SBMPs
Re-evaluate vulnerabilities

Primary vulnerabilities may cause secondary or cascading vulnerabilities. SBMPs for all associated vulnerabilities should be reviewed at this stage.

If SBMP requires maintenance, make sure it is included in OM&M plan.

Did SBMP address vulnerability as expected?

IF no,

Is SBMP maintenance being conducted?

Does SBMP need optimization?

Is a different solution needed?

If yes,

Consider optimization opportunities

Re-evaluation of vulnerabilities should include more than a re-evaluation of the original trigger-identified vulnerability. This re-evaluation should include a holistic vulnerability assessment (link to vulnerability assessment section) and a review of the prioritization of previously identified vulnerabilities.

The re-evaluation may identify new vulnerabilities due to changing site conditions, project stage, occurrence of an extreme weather event or wildfire, or other additional information.

Figure 7-1. SBMP process.

The SBMP Identification and Prioritization Tool (SBMP Tool) can be used to create a site-specific summary of SBMPs and document if specific SBMPs are applicable, prioritize SBMPs, and track implementation.

This section does not replace policy or regulatory standards, provide detailed design criteria for individual site-specific use, or verify or certify SBMPs.

Table 7-1. Relevant SBMPs based on climate change factors

	Universal	Wind	Snow and Hail	Fluctuating Groundwater Elevation Levels	Flooding	Bank and Shoreline Erosion	Pre-Wildfire	Post-Wildfire	Sea-Level Rise	Evapotranspiration	Storm Surge	Permafrost Thaw
Changes in Precipitation												
Increase	x		x	x	x	x			x		x	
Decrease	x			x			x	x		x		x
Changes in Temperature												
Increase	x					x	x	x	x			x
Decrease	x		x									
Changes in Water Level												
Increase	x			x	x	x			x		x	x
Decrease	x			x		x	x	x		x		
Other												
Increased storm frequency or intensity	x	x	x		x	x	x	x			x	

SBMPs can be used at any stage of a remediation project, from vulnerability assessment and site investigation to the 30th year of OM&M of a remedy. For example, SBMPs can help identify changes that need to be made to ensure the resilience of existing infrastructure and the remedial design.

If possible, SBMPs are considered at the earliest stages of project development (Section 6.1), such as during preplanning activities, Phase 1 environmental site assessments, and the initial investigation. Incorporating SBMPs at the earliest stages of the Remedial project life cycle provides the greatest opportunity to reduce potential impacts from extreme weather events and wildfires.

7.1 SBMPs Universally Relevant to Extreme Weather Events and Wildfires

SBMPs are aligned with SRR. The following SBMPs are generally applicable to any extreme weather event or wildfire. Event-specific SBMPs can be located under the applicable effects:

Wind	Fluctuating Groundwater Elevation Levels	Pre-Wildfire	Storm Surge
Snow and Hail	Bank and Shoreline Erosion	Post-Wildfire	Sea-Level Rise
Flooding	Evapotranspiration	Permafrost Thaw	

7.1.1 Assessing Vulnerability

Assessing whether the site is exposed to extreme weather events or wildfires, and then how vulnerable the site is to those events, is key to building resiliency. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment.

- If an extreme event has already occurred at the site, assume the site is vulnerable to that extreme event.
    - Also assume the site is vulnerable to associated secondary or cascading events (for example, an event that may occur as a result of the first event, such as flash flooding after a wildfire) identified within the SBMPs.
    - Review the relevant SBMPs and implement as applicable.
    - Conduct a vulnerability assessment to identify any other extreme events the site may be vulnerableto. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment. Review state and federal resources to identify local vulnerabilities. Review the relevant SBMPs and implement as applicable.
- If known vulnerabilities exist at the site (for example, it is in a floodplain or has permafrost), assume the site isvulnerable to those extreme events.
    - Also assume the site is vulnerable to associated secondary or cascading events (for example, an event that may occur as a result of the first event, such as flash flooding after a wildfire) identified within the SBMPs.
    - Review the relevant SBMP checklists and implement as applicable.
    - Conduct a vulnerability assessment to identify any other extreme events the site may be vulnerable to experiencing. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment. Review state and federal resources to identify local vulnerabilities. Review the relevant SBMPs and implement as applicable.
- Perform a vulnerability assessment. This can be done at any stage of the project, but earlier is better. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment. Review state and federalresources to identify local vulnerabilities.
    - Include periodic review and reassessment of the site vulnerabilities.
    - Adapt SBMPs to match any changing site conditions.

- Use publicly available tools in the vulnerability assessment. Many state and federal resources can be found in the resources map. Others are included in the SBMP sections based on extreme event. Some vulnerability assessment tools that can be used for multiple extreme events, on a national or local scale, include:
    - The U.S. Climate Resilience Toolkit
    - ARC-X from USEPA's Climate Change Adaptation Resource Center
    - The Climate Explorer from the National Environmental Modeling and Analysis Center NOAA's Climate Prediction Center
    - USEPA's Underground Storage Tank Finder web map application

7.1.2 Planning and Prioritizing Resilience and Sustainability

- At any stage of the project, seek out and review the traditional ecological knowledge (TEK) relevant to the site. USEPA through policy and memorandum (USEPA 2017c) encourages the integration of TEK into the decision-making process, including as it relates to site cleanup activities.

Traditional ecological knowledge (TEK) is defined by the U.S. Fish and Wildlife Service as "the evolving knowledge acquired by indigenous and local peoples over hundreds or thousands of years through direct contact with the environment. This knowledge is specific to a location and includes the relationships between plants, animals, natural phenomena, landscapes and timing of events that are used for lifeways, including but not limited to hunting, fishing, trapping, agriculture, and forestry." (USFWS 2011, page 1).

TEK is not a static understanding of how the environment was; it continues to evolve and identify changes in the environment. TEK is an important part of the tribal consultation process and decision making and is used by federal agencies such as USFWS and USEPA. TEK from the Yukon River subsistence users in Alaska has identified a suite of environmental changes attributed to climate change. When reviewing and evaluating SBMPs, TEK should be sought and integrated as much as practicable. Further information about TEK and a personal perspective on the subject can be found in the July 1, 2014, EPA Blog.

- At any stage of the project, prioritize green infrastructure.

Green infrastructure is a valuable tool to address many climate change impacts, and sustainability evaluation tools can be used to capture its benefits (CNT 2011). Section 5.7 has more information on green infrastructure. Green infrastructure in the form of infiltration practices can manage floodwater and replenish groundwater. Urban heat islands, which increase temperatures due to dense buildings and pavement, can be mitigated with trees and other vegetation. Energy use can decrease by using green infrastructure that reduces rainwater flowing into stormwater or sewer systems, conserves water, or decreases heating and cooling requirements for buildings. Additional benefits are provided on the USEPA's Green Infrastructure for Climate Resiliency website.

- Gain input from stakeholders on perceived climate risks and communicate how risks will be evaluated during thesite investigation.
- Incorporate extreme weather or wildfire impacts at the earliest project phase possible; at a minimum, update theCSM (Section 6.1.1) to include potential impacts. CSM updates can be made throughout the remediation project life cycle.
- Integrate consideration of extreme events in contracting and include incorporating SBMPs into the scope of work.
- Include discussions of extreme weather or wildfire risks and effects in public outreach, notification, and publiccomment and materials.
- Consider conducting a demographic analysis (Section 5.11) to identify and screen potentially highly impacted communities.
- Extend the time horizon when assessing the life of infrastructure and remedies (USEPA 2009).
- For remedies anticipated to operate for 30 years or longer, adaptation to extreme weather events and

wildfiresis particularly important over time. The USEPA's Superfund Climate Resilience: Adaptive Capacity website contains resources to maintain or build adaptive capacity.

- Use drones or closed-circuit video for broad or inaccessible areas and continuous monitoring when practical.
- Prepare a crisis management plan for the extreme weather event or wildfire. It should include:
    - an emergency operation center if evacuation is necessary
    - an area to house essential staff, supplies, and equipment near the facility to limit exposure to the event
    - a "plan B"
- Ensure that key personnel (that is, construction manager, project manager, and all subcontractors) understand the site's vulnerabilities and site crisis management plan through training and periodic review of the plan.
- Provide extreme weather event or wildfire management and response plans for the site to the impacted community.
- Predict the financial risks associated with climate hazards at the site. Case studies may provide insight on predicting financial risks (Appendix A).
- Evaluate vulnerability to climate-based hazards and potential mitigation measures for each remedial alternative.

7.1.3 Remedy Design and Implementation

- Whenever possible use green infrastructure and natural solutions such as native plantings over impervious, manmade solutions. Green infrastructure and natural solutions are typically more resilient. Native plantings should be native to the existing climate with tolerances for the types of climate events the site is likely to experience in the near future.
- Generate primary or secondary power from on-site renewable resources independent of the utility grid. It is important to note that during extreme climate scenarios, even green infrastructure may not be sufficiently resilient to withstand weather extremes.
- Integrate electronic devices for remote control of equipment during extreme weather or wildfires.
- Integrate sensors linked to electronic control devices to either trigger shutdown of equipment or an alarm toalert workers to shut down equipment.
- Move or locate remedy components away from potential danger zones (USEPA 2013a)□.
- Stormproof infrastructure by repairing, retrofitting, or relocating facilities and equipment to prevent damage anddisruptions during extreme weather or wildfire events. The USEPA's Climate Change Adaptation Resource Center website contains resources and information pertaining to climate impacts on infrastructure.
- Document SBMPs implemented in completion reports.

7.1.4 Operation, Maintenance, and Monitoring (OM&M)

- Evaluate the performance of the SBMPs in place following an extreme event.
- Include maintenance of the SBMPs in the site OM&M plan and evaluate that the SBMPs are properly maintained. Regularly update the vulnerability assessment and adapt SBMP implementation to match any changing site conditions.
- Review the CSM on a defined and regular basis to determine if adaptations to remedy design and construction need to be made.
- Inspect the alarm systems regularly.
- Regularly update the crisis management plan and OM&M plan.

7.1.5 General BMPs

- Locate equipment where accessibility is guaranteed if maintenance is regularly needed or build redundant systems.
- Maintain accurate as-built drawings so lost, damaged, or inaccessible equipment can be located and identified.
- Evaluate the impact of the extreme event or wildfire on site access, drinking water, septic system, and wastewater infrastructure at and around the site.

7.1.6 Crisis Management

- Perform an integrity inspection of infrastructure, keeping in mind that anything on the ground surface that penetrates the subsurface is a potential conduit of subsurface and groundwater contamination.
  - surface—above-grade equipment, aboveground storage tanks, and electrical equipment (for example, electrical panels, transformers, bushings)
  - subsurface—wells, subgrade piping and electrical conduit, and underground storage tanks
- Reevaluate site boundaries and potential pathways for contaminant migration. Sites that have achieved remedycompletion may need to be reevaluated if extreme events or wildfires have changed the underlying risk assessment.
- Reassess current monitoring and sampling protocols to ensure continued effectiveness.
- Revise safety procedures as necessary to reflect the likelihood or intensity of surrounding conditions.
- Assess alternative utility and transportation options in case default options are not available.

7.2 Wind

SBMPs for high winds include those universally relevant to extreme weather events and wildfires in Section 7.1. The SBMP Tool can be used to create a site-specific summary of SBMPs and document if specific SBMPs are applicable, prioritize SBMPs, and track implementation.

7.2.1 Introduction/Applicability

Areas prone to drought, hurricanes, tornadoes, and other extreme weather events risk damage due to high winds. This section addresses increased wind hazards (either straight-line or cyclonic) associated with the destruction of remediation site buildings and infrastructure and with the potential erosion of land in and around the remediation area.

Potential direct impacts include power interruption, physical damage, and reduced accessibility. Potential indirect impacts may include unintentional release of contaminants on the remediation site or to neighboring sites, accidental fire, explosions, and ecosystem damage. Overall system failures might result in insufficient treatment of contamination due to treatment system compromises or loss, operational downtime, and unexpected and additional project costs for repairing or replacing the remediation system and/or site infrastructure components (USEPA 2013a).

7.2.2 Assessing Vulnerability

The vulnerability of remediation sites to increased wind should be assessed. In addition to reviewing weather records and forecasts, trends can also be evaluated. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment.

Consult federal, state, or local sources to determine qualitative or quantitative likelihood of wind impacts in a specific area. These are some relevant resources:

- USEPA's Underground Storage Tank Finder web map application includes functionality to add ArcGIS layers of wind data viewable at the national and local levels.
- The North Carolina Climate Risk Assessment and Resilience Plan identified likely increase of hurricane intensity in the state (NCDEQ 2020).
- The state of Alaska has developed wind predictive models.
- The Minnesota State Hazard plan identified wind storms, tornadoes, and winter storms as high probability hazards (MDPS 2019).
- Severe winter storms and nor'easters are currently the most frequently occurring natural hazards in Massachusetts. The Massachusetts State Hazard Mitigation and Climate Adaptation Plan predicts a likely increased intensity of storms, with all locations vulnerable, particularly coastal areas (high-wind events, nor'easters, and hurricanes) and central counties (tornadoes).
- The New Jersey Scientific Report on Climate Change states that tropical storms in the state have the potential to increase in intensity (NJDEP 2020).

7.2.3 Planning and Prioritizing Resilience and Sustainability

- Consult local authorities and utilities to identify existing adaptation strategies.
    - The New Hampshire Department of Environmental Services Drinking Water & Groundwater Bureau has developed a Climate Change Resilience Plan to adapt to climate change, with specific recommendations for resilience of drinking water systems to severe wind storms (McCarthy 2014).

See Section 7.1.1 for an overview of vulnerability assessment.

Sites vulnerable to high winds may also be vulnerable to wildfire (Sections 7.7 and 7.8), storm surge (Section 7.11), bank and shoreline erosion (Section 7.6), or changes in evapotranspiration (Section 7.10). Review of SBMPs for those events is encouraged.

7.2.4 Remedy Design and Implementation

- Install drought-resistant grasses, shrubs, trees, and other deep-rooted plants to provide shading and wind breaks, prevent erosion, and reduce fire risk (USEPA 2013a).
- Maintain wind-resistant and regularly pruned trees on site. Trees that are diseased, weak-wooded, or have poorly formed branching structure could fall during high winds. Studies show that regularly pruned trees survived Gulf Coast hurricanes at a rate of 73% compared to 46% of unpruned trees (Urban Green 2013). Stabilize trees using tie-downs to prevent toppling.
- Plant flood-resistant trees to help ensure that the effects of soil saturation or root rot do not increase the occurrence of trees overturning during high winds following a flood event (Urban Green 2013).
- Build soft caps and armor (through techniques such as replenishing sand or vegetation or installing synthetic fabrics) to stabilize and shield surfaces from erosion, storm surges, and tidal influence (USEPA 2013a). These green infrastructure projects reduce capital investment in built infrastructure for stormwater control and
- management, slowing erosion, improving aquifer recharge, and lowering energy use.
- Install hard caps (such as those made of reinforced concrete or asphalt) to shield surfaces from extreme erosion, storm surges, and tidal influence, and prevent chronic and acute exposures to contaminants (USEPA 2013a).
- Install wind-resistant windows and doors to prevent pressure-related failures that could lead to other types of damage, such as from water (Urban Green 2013).
- Do not use pea gravel or stone as ballast to secure roofing material or temporary membranes on waste piles. These small ballasts may be lifted by high winds and become dangerous projectiles (Urban Green 2013).
- Construct structural reinforcement to protect or anchor permanent and temporary buildings and equipment from high winds. Reinforcement could include hurricane straps to strengthen the physical connection between the roof and walls of a building, shed, or housing unit (Urban Green 2013).
- Install insulated cover systems made of high-density polyethylene (HDPE) or concrete to protect monitoring equipment, control devices, and well heads from high winds and airborne debris (USEPA 2013a).
- Fortify exposed slopes subject to wind erosion by installing anchors and cables to rock or concrete elements placed against the slope. Alternatively, contain a slope by placing netting to hold back rock and debris (USEPA 2013a).
- Install permanent mounts to allow rapid deployment of a cable tie-down system during extreme wind events (USEPA 2013a).

7.2.5 OM&M

- Maintain wind- and flood-resistant trees on site. Ensure that trees are regularly pruned trees. Trees that are diseased, weak-wooded, or have poorly formed branching structure could fall during high winds.
- Maintain soft caps, armor, and hard caps to stabilize and shield surfaces from erosion, storm surges, and tidal influence (USEPA 2013a)□.
- Do not use pea gravel or stone as ballasts to secure temporary membranes on waste piles.
- Regularly review wind and storm predictions for the site and adapt SBMP implementation to match any changing site conditions.

7.2.6 General BMPs

- Perform regular vegetation maintenance.
- Perform regular site trash and debris removal.

7.2.7 Crisis Management

- Secure rapid deployment cable tie-down systems to permanent mounts when high winds are predicted.
- Inspect cover systems, tie-downs, and other fortifications when high winds are predicted.

7.3 Snow and Hail

SBMPs for increased snow and hail include those universally relevant to extreme weather events and wildfires. The SBMP Tool can be used to create a site-specific summary of SBMPs and document if specific SBMPs are applicable, prioritize SBMPs, and track implementation.

7.3.1 Introduction/Applicability

Increased snow and hail and severe winter storms can impact remediation sites. Potential direct impacts from snow and hail include power interruption, physical damage, water damage, and reduced accessibility. Potential indirect impacts may include overall system failures affecting the treatment system, possibly resulting in insufficient contaminant treatment, operational downtime, and unexpected and additional project costs for repairs (USEPA 2013a).

Ice and snow tend to accumulate on low-slope and flat roofs more readily. Melting snow tends to run more quickly off roofs with slopes greater than 3 inches of slope in 12 inches of horizontal distance (Figure 7-2).

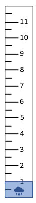
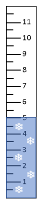
						
5 pounds per square foot	**=**	**1 inch of water or ice**	=	**3 to 5 inches of packed snow**	=	**10 to 12 inches of fresh snow**

Figure 7-2. Approximate weights of ice and snow.

Source: ITRC SRR Team

7.3.2 Assessing Vulnerability

The vulnerability of remediation sites to snow and hail should be assessed. In addition to reviewing weather records and forecasts, trends can also be evaluated. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment.

- Consult federal, state or local sources to determine qualitative or quantitative likelihood of snow and hail impacts in a specific area. Some relevant resources include:
  - USEPA has tracked change in snowfall in the contiguous 48 states from 1930 to 2007, revealing which areas have seen increased versus decreased frozen precipitation (USEPA 2016a).
  - USEPA's Underground Storage Tank Finder web map application includes functionality to add ArcGIS layers of snow and hail data viewable at the national and local levels.
  - The Minnesota State Hazard plan identified hail and winter storms as high probability hazards (MDPS 2019).
  - The Alaska Center for Climate Assessment and Policy maintains several GIS resources for predicting temperature and precipitation.
  - Severe winter storms and nor'easters are currently the most frequently occurring natural hazard in Massachusetts. The Massachusetts State Hazard Mitigation and Climate Adaptation Plan predicts higher precipitation amounts during winter storms. Heavy snowfall and ice storms are a greater vulnerability in high elevations of western and central MA.

Sites vulnerable to increased snow and hail may also be vulnerable to floods (Section 7.5), fluctuating groundwater levels (Section 7.4), or wind (Section 7.2). Review of SBMPs for those events is encouraged.

7.3.3 Planning and Prioritizing Resilience and Sustainability

- Prepare a snow-event response and removal plan based upon the Federal Emergency Management Agency (FEMA) Snow Load Safety Guide (FEMA 2013).
- Plan contingencies because during a severe winter storm, key functional equipment for maintaining remedial performance (even if protected from snow and hail) may be inaccessible for maintenance or upkeep.
- Evaluate the use of backup power for freeze-protection systems (for example, heat trace and heaters) and temperature monitoring telemetry.
- Plan for secondary impacts: rain-on-snow events create faster snow or ice melt and result in increased water discharge (Section 7.5).
- Consult local authorities and utilities to identify existing adaptation strategies.

7.3.4 Remedy Design and Implementation

- Avoid designing low-grade components if possible. If not, mark or flag key components that could be covered by ice or snow.
- Consider potential additional snow load from an extreme snow or hail event as part of roof design to prevent roof collapse. See the American Society of Civil Engineers (ASCE) Minimum Design Loads and Associated Criteria for Buildings and Other Structures Standard 7 (ASCE 2016) or the locally adopted ground snow loads □□(U.S. Green Building Council 2018)□.
- Protect against ice dam formation on low-sloped roofs. The Insurance Institute for Business & Home Safety website and the U.S. Green Building Council (2018) provide useful information on this topic.
- Protect from hail all key functional equipment for maintaining remedial performance. Select equipment that is hail impact–resistant or install hail guards or shields designed to resist uplift pressures, as recommended by the Insurance Institute for Business & Home Safety website or as defined by ASCE standard (ASCE 2016).
- Install rain-resistant louvers to prevent wind-driven snow and hail from entering building louvers, ductwork, or mechanical spaces and leading to dampness, mold, or microbial growth (USEPA 2013a).

7.3.5 OM&M

- Inspect low-grade component marking or flags to ensure they remain visible during snow events.
- Regularly review snow and hail predictions for the site and adapt SBMP implementation to match any changing site conditions.
- Periodically review the snow-event response and removal plan and update if necessary.

7.3.6 General BMPs

- For steep-sloped roofs, increase attic insulation, seal ceiling penetrations, and install waterproof membranes on roof decks at the roof edge (U.S. Green Building Council 2018).

7.4 Fluctuating Groundwater Elevation Levels

SBMPs for fluctuating groundwater elevation levels include those universally relevant to extreme weather events and wildfires in Section 7.1. The SBMP Tool can be used to create a site-specific summary of SBMPs and document if specific SBMPs are applicable, prioritize SBMPs, and track implementation.

7.4.1 Introduction/Applicability

Increased precipitation (Sections 7.3 and 7.5) and sea-level rise (Sections 7.9 and 7.11) may lead to increased inputs of water into local groundwater, causing isolated mounding or widespread increases in groundwater elevation levels. Conversely, decreased precipitation and/or increased pumping can lead to widespread decreases in groundwater elevation levels and changes in evapotranspiration (Section 7.10). Changes in groundwater elevation levels and changes to groundwater flow may impact the assumptions upon which the CSM and remedial design are based. Potential impacts to remedies associated with elevated groundwater levels include physical damage (such as flooding vaults and other subsurface structures, floating underground storage tanks), power outages, submerged well screens, salt-water intrusion, and decreased vadose zones. Potential impacts to remedies associated with decreased groundwater elevation levels include decreased groundwater capture, well screens no longer intercepting groundwater, and increased vadose zones. Fluctuating groundwater levels will affect the OM&M of remedial systems at high levels by flooding, damaging their components, and causing shutdowns at either high or low groundwater levels.

7.4.2 Assessing Vulnerability

The vulnerability of remediation sites to fluctuating groundwater elevations should be assessed. In addition to reviewing weather records and forecasts, trends can also be evaluated. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment.

Fluctuating groundwater level vulnerabilities may be best assessed through tools used to assess other related vulnerabilities. Sites vulnerable to fluctuating groundwater elevations may also be vulnerable to flooding (Section 7.5), sea-level rise (Section 7.9), storm surge (Section 7.11), bank and shoreline erosion (Section 7.6), increased evapotranspiration (Section 7.10), permafrost thaw (Section 7.12), or increased snow and hail (section 7.3). Review of SBMPs for those events is encouraged.

7.4.3 Planning and Prioritizing Resilience and Sustainability

- Evaluate the existing CSM or develop a new CSM to identify impacts that may occur due to groundwater elevation changes such as:
  - contaminant migration or mobilization
    release or sorption of contaminants change
    in contaminants or concentrations
  - extent of salt-water intrusion and its impact on existing infrastructure or systems that contact the groundwater
  - the effect of increased pumping on nearby groundwater supply wells under low water table levels or drought conditions
  - change in fate and transport
  - change in groundwater chemistry and microbial populations
- Evaluate the effects of lowered water levels and decreased hydraulic conductivity associated with salt-water and brackish water infiltration farther inland than normal. Consider the impacts of increase in salt concentrations on existing infrastructure or systems that contact the groundwater.
- Consult local authorities and utilities to identify existing adaptation strategies.

7.4.4 Remedy Design and Implementation

- Design monitoring and treatment systems considering potential changes due to extreme fluctuations in groundwater flow, including direction, depth, volume, and rate. Changes in these parameters could significantly change the effectiveness of the monitoring or treatment. Examples include the following:
    - changes in groundwater capture associated with pump-and-treat systems
    - reduced effectiveness of vadose zone treatments (that is, soil vapor extraction, bioventing) due to changes in vadose zone thickness
    - reduced effectiveness of in situ treatments such as bioremediation and chemical oxidation due to changes in saturated zone thickness, salt-water intrusion, groundwater chemistry, and/or the microbial population
    - impacts to monitoring due to submerged monitoring wells or groundwater table lowering to belowthe screened interval
- Design subgrade structures to remain out of contact with the increased water table level or fortify the structures to resist inundation due to flooding.
- Consider changing the size and type of culverts or stormwater conveyance channels to address impacts during high groundwater events.
    - Potential excess stormwater overland may not infiltrate into the soils or recharge the local aquifer.
    - Groundwater may flow into stormwater infrastructure.
- If groundwater levels are projected to increase, consider using well clusters targeting specific transmissive groundwater horizons or multiport well systems that have narrow screens across multiple transmissive horizons. If groundwater levels are projected to decrease, consider installing monitoring wells deeper and increasing the length of the well screen.
- Seal monitoring wells and increase the height of the well casing above ground surface.

7.5 Flooding

SBMPs for flooding include those universally relevant to extreme weather events and wildfires in Section 7.1. The SBMP Tool can be used to create a site-specific summary of SBMPs and document if specific SBMPs are applicable, prioritize SBMPs, and track implementation.

7.5.1 Introduction/Applicability

This section addresses flooding that is not specifically associated with sea-level rise, though some overlap may occur. Readers concerned with flooding at a remediation site associated with sea-level rise should also review Section 7.9.

No matter where a site is located, some risk of flooding exists (www.floodsmart.gov). As climate change continues, storm and rainfall patterns will continue to change, with some areas experiencing more storms and higher precipitation rates. Flooding can damage remedial systems that are not properly constructed or protected. As a result, contaminants may migrate or may not be treated sufficiently, operational downtime may occur and cause delays, and unexpected or additional project costs may be needed for repairs (USEPA 2013a).

Potential direct impacts of flooding include redistributing contaminated media, scouring and removal of protective caps, power interruption, physical damage, water damage, and reduced accessibility. Indirect impacts of flooding may include spills, accidental fire, explosions, and ecosystem damage. Additionally, localized, time-constrained recharge from floodwater infiltration or bank storage following flood events could perturb the groundwater system being remediated, including contaminant redistribution, LNAPL reductions, and redox condition changes.

Increased precipitation can cause otherwise permeable soil to become waterlogged, increasing the likelihood of flooding, landslides, and debris flow. Regional increases in precipitation may cause stormwater systems to become overloaded, decreasing their effectiveness to drain stormwater from the remediation site. Even if the site is not in a floodplain or lowland, lower elevation or poorly drained areas of the site may be subject to localized flooding.

Increasingly intense storms can result in flash flooding where the topography, surface soil, or geology do not allow sufficient infiltration. Although most floods can be managed by floodplains, building restrictions, and improved infiltration measures, extreme flooding can overwhelm the capacity of even large acres of floodplains and wetlands. While resilient to most weather conditions, even green infrastructure may be washed away during extreme events.

Flash flooding has the potential to cause additional impacts. Through temporary inundation and high surface-water velocities, flash flooding can damage remedial systems that are not properly constructed or protected. As a result, contaminants may migrate or may not be treated sufficiently, operational downtime may occur and cause delays, and unexpected or additional project costs may be needed for repairs (USEPA 2013a).

Green infrastructure helps mitigate the consequences of flooding by allowing rainwater to infiltrate where it lands, which benefits the wider ecosystem as the rainwater replenishes groundwater and maintains baseflow toward local rivers and streams. It is important to note that green infrastructure elements may create changes in climate, soil, and habitat at the site. Furthermore, the performance of green infrastructure can often affect the chance or intensity of flooding and landslides.

More and more communities are employing green infrastructure and conservation of surrounding watersheds to improve resilience to changing climates. For instance, increased development around Boston, Massachusetts, during past decades eliminated many wetlands and increased roadways, parking lots, and other impervious surfaces. A series of dams along the Charles River historically controlled flooding, but these dams had insufficient capacity for large precipitation events, which have become more common. Rather than build more dams at great environmental, social, and economic costs, the U.S. Army Corps of Engineers, the city and surrounding communities agreed to set aside from development and protect the remaining wetlands by creating the Charles River Natural Valley Storage Area. These wetlands provide critical green infrastructure and flood resilience to the city, and expand recreational amenities for the entire region (Cassin 2019).

In some instances, green infrastructure has been more resilient to the increased floods and droughts. One community (Napa, California) solved flooding problems by restoring the Napa River's natural channel and wetlands (that is, allowing floodplains and infiltration to mitigate flooding) instead of lining the river with concrete. The natural landscaping also benefits the local community by providing new parks and open space (Figure 7-3).

Figure 7-3. Examples of green infrastructure installed to mitigate the effects of and be resilient in the face of flooding (Napa, CA). Flood terrace restoration near the confluence of Sulfur Creek (left) and regraded bank with a wider setback and gravel/cobble bar (right) in St. Helena, CA.

Source: Napa County Stream Maintenance Manual. Used with permission.

Selecting native plants for bioretention structures will ensure the plants can tolerate typical temperature and precipitation ranges experienced in their habitat, without relying on lawncare and climate control measures to thrive. This practice allows the designed and constructed green infrastructure to be more resilient to climatic fluctuations (Figure 7-4).

Figure 7-4. Examples of green infrastructure that mitigates flooding (left: retention basin) and high temperatures (right: permeable pavement) while allowing infiltration to help replenish the local groundwater system during drought conditions.

Source: Permission pending

7.5.2 Assessing Vulnerability

The vulnerability of remediation sites to flooding should be assessed. In addition to reviewing weather records and forecasts, trends can be evaluated. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment.

In general, sites with the following features are more vulnerable to flooding and flash flooding:

- lowland areas near water bodies (Sections 7.9 and 7.11)
- areas where soil and surfaces are impermeable
- areas where there is a regional increase in precipitation (Section 7.3)
- areas vulnerable to hurricanes
- areas with high groundwater elevation levels (Section 7.4)

In 500-year and 100-year floodplains, even in areas with prolonged drought, storm events are more intense (U.S. Green Building Council 2018) and are occurring more frequently (Melillo, Richmond, and Yohe 2014). Statistically, the traditional 100-year floodplain has been found vulnerable to extreme events.

When a site is in areas other than those described above, site areas with lower elevation or poor drainage may be subject to localized flooding.

Flooding vulnerability assessment SBMPs include:

- Use federal, state, and local GIS and online map and model resources to predict the site flood risks. Some resources include:
    - FEMA flood map service center provides information on flood hazards, including flood maps and other flood hazard information for a better understanding of flood risks.
    - USEPA's Underground Storage Tank Finder web map provides information on whether a UST is within an estimated flood inundation area using a flood inundation model that estimates FEMA's Flood Insurance Rate Maps for the conterminous United States where FEMA has not mapped a 100 year floodplain.
    - Some state tools:
        - New Jersey's Flood Mapper allows users to conduct flood exposure analysis while evaluating several parameters, including total water levels, hurricane surge, sea-levelrise, and more.
        - Vermont's Flood Ready website includes community reports and map tools.
        - New Hampshire's Aquatic Restoration Mapper is an interagency collaboration that manages stream crossing assessment efforts across the state to meet the goals of aquatic restoration, infrastructure safety, and flood resiliency.
- Conduct an engineering analysis to determine the 500-year floodplain:

If information on the 500-year floodplain is not delineated, the U.S. Green Building Council recommends using the 100-year floodplain with an additional 3 ft added to it or conducting an engineering analysis to determine the 500-year floodplain (U.S. Green Building Council 2018). Similarly, the Federal Flood Risk Management Standard provides three approaches for establishing flood design elevation: 1) best-available hydrologic/hydraulic data/methods that integrate current and future changes in flooding based on climate science; 2) base flood elevation + 2 ft; and 3) 500-year flood elevation (FEMA 2015).

- Review the overall strategies and stormwater management techniques in the USEPA's Flood Resilience Checklist to help assess how well a remediation site is positioned to avoid and/or reduce flood damage and to recover from floods.
- Where GIS resources are not available, consult state or local sources to determine qualitative or quantitative likelihood of flood impacts in a specific area, especially where FEMA maps are not available, or where the data used in generating a FEMA map are outdated. The following are potential resources for more information.
    - Local authorities or utilities may know of locations and frequency of street or yard flooding.

- The state of Vermont identified inundation flooding as the second most significant natural hazard inthe 2018 Vermont State Hazard Mitigation Plan (VEM 2018).
- The Ohio Department of Transportation Infrastructure Resiliency Plan identified increases in extreme rainfall events and resulting flooding as vulnerabilities throughout the state (RSG 2016).
- The North Carolina Climate Risk Assessment and Resilience Plan (NCDEQ 2020) identified the potential for flooding to likely increase inland and in coastal areas.
- The Minnesota State Hazard plan (MDPS 2019) identified flooding as a high probability hazard.
- The Massachusetts State Hazard Mitigation and Climate Adaptation Plan identified more frequent inland flooding over a greater area, and more frequent and severe coastal flooding as predicted hazards.
- The New Hampshire Climate Change Resilience Plan (McCarthy 2014) identified the state as receiving more precipitation each year, with more falling as rain and less as snow. More of this precipitation has fallen in extreme events, there are fewer days of snow on the ground, and springoccurs earlier with earlier ice-out dates and earlier spring runoff.
- The New Jersey Scientific Report on Climate Change (NJDEP 2020) states that annual precipitation inNJ is expected to increase by 4–11% by 2050, and the size and frequency of floods will concurrently increase.
- The Denali Commission has identified communities at risk from flooding in Alaska, published in the Statewide Threat Assessment (University of Alaska Fairbanks Institute of Northern Engineering 2019).

- Consult available state or local data to determine landslide risk.
  - The Massachusetts State Hazard Mitigation and Climate Adaptation Plan found that more frequent and intense storms will result in more frequent soil saturation conditions conducive to landslides, particularly around Mount Greylock and the U.S. Highway 20 corridor near Chester.

Sites vulnerable to flooding may also be vulnerable to wind (Section 7.2), snow and hail (Section 7.3), bank and shoreline erosion (Section 7.6), sea-level rise (Section 7.9), storm surge (Section 7.11), permafrost thaw (Section 7.12), or fluctuating groundwater elevations (Section 7.4). Review of SBMPs for those events is encouraged.

7.5.3 Planning and Prioritizing Resilience and Sustainability

- Consult local authorities and utilities to identify existing adaptation strategies.
  - The Ohio Department of Transportation Infrastructure Resiliency Plan (RSG 2016) identifies adaptive measures the department is taking to address more frequent and intense floods.
  - The New Jersey Department of Environmental Protection developed a Stormwater Infrastructure Toolkit to provide long-term, sustainable, flood resiliency.

7.5.4 Remedy Design and Implementation

- Integrate flood-control measures during remedial design and construction. The American Society for Civil Engineers (ASCE 2014) has developed guidelines for flood-resistant design and construction.
- If possible, design contaminant treatment or containment to be outside the 100- and 500-year floodplains. If the 500-year floodplain is not delineated, a best practice from the U.S. Green Building Council is to use the 100-year floodplain and add 3 feet to the measurements (U.S. Green Building Council 2018).

7.5.4.1 Key SBMPs – Functional Equipment for Maintaining Remedial Performance

Key functional equipment, even if protected from floodwaters, may not be accessible for maintenance or upkeep during flooding. Key SBMPs are as follows:

- Locate the equipment at a minimum above the reported flood stage elevation plus a safety factor. Alternatively, build redundant systems or plan a backup means of getting to the critical equipment.
- Locate key functional equipment (for example, backup generators, blower fans, granular activated carbon units) above the 500-year floodplain or on platforms elevated above the predicted 500-year flood levels. Electrically powered fire protection equipment should also be located above the 500-year floodplain.
- Limit above-grade installations in the floodplain to those that can be armored, protected, or sealed and, if necessary, repaired or reinstalled at relatively low cost.
- Design buildings, tanks, and piping to withstand contact with rapidly moving, floating debris (for example, trees, appliances, cars).
- Install additional wells and aboveground pumps to extract leachate in remediation systems with leachate collection systems.
- Install insulated cover systems made of HDPE or concrete to protect monitoring equipment, control devices, and well heads from flooding (USEPA 2013a).
- Install permanent mounts that allow rapid deployment of a cable tie-down system during flood events (USEPA 2013a).
- Install supplemental anchoring systems to tanks, drums, or other containers located in flood-prone areas.
- Install electronic systems that provide workers with early flood warnings or alert workers to active flooding and enable them to suspend operations and secure system components automatically or remotely. Include remote cameras and substantial lighting or infrared imaging so that workers can assess conditions during and immediately after an event (USEPA 2013a).

7.5.4.2 Key SBMPs – Stormwater Management

- Design or modify drainage systems to handle modeled extreme precipitation events (USEPA 2013a).
- Install robust on-site stormwater management systems, including features such as vegetated and nonvegetated roofs, and limit impervious areas (Urban Green 2013).

Keep in mind that green infrastructure provides many benefits by reducing capital investment in built infrastructure for stormwater control and management, slowing erosion, improving aquifer recharge, or lowering energy use. But sociocultural changes—specifically, reliance on controlled-temperature interiors—tend to limit the usefulness of some green infrastructure measures. Vegetated roofing allows buildings to naturally regulate their thermal environment by:

- Retaining heat during the cool period by insulating the building
- Deflecting heat during the warm period by reflecting solar radiation and absorbing solar radiation through photosynthesis and evapotranspiration of the vegetation.

Extreme temperatures may bring the building interior beyond comfortable levels and require the ongoing use of heating and cooling systems (for example, HVAC, furnace, air conditioners).

- Consider green infrastructure to retain or divert flood waters, and use earthen and vegetated structures wherever possible (USEPA 2013a).
- Design the site to allow for dry site features (for example, access roads, sidewalks, and ramps) during flood events.
- Replace or install mold- and mildew-resistant insulating materials in buildings, sheds, or housing envelopes (USEPA 2013a).
- Install rain-resistant louvers to prevent wind-driven rain from entering building louvers, ductwork, or mechanical spaces and leading to dampness, mold, or microbial growth (USEPA 2013a).

7.5.4.3 Key SBMPs – Site Management

Install permanent flood-control mitigation systems for previously developed sites located within the 500-year floodplain (U.S. Green Building Council 2018).

Additional key SBMPs are as follows:

- Use flood-resistant plants when applicable (Urban Green 2013).
- Consider designing pads and foundations that can accommodate temporary flood walls (USEPA 2013a).
  Fortify concrete pads by repairing cracks, replacing pads of insufficient size or with insufficient anchorage, or integrating retaining walls along the pad perimeter (USEPA 2013a).
- Consider additional groundwater level monitoring for site areas vulnerable to flooding (Ecology 2017).
  Replace deteriorated pavement or pavement that has hindered stormwater management with permeable pavement (in the form of porous asphalt, rubberized asphalt, pervious concrete, or brick pavers) to filter pollutants, recharge aquifers, and reduce the amount of stormwater entering the storm drain system (USEPA 2013a). Also, see Chagrin River Watershed Partners website for case studies

7.5.5 OM&M

- Periodically review floodplain determinations from FEMA or other sources.
- Maintain wind- and flood-resistant and regularly pruned trees on site. Trees that are diseased, weak-wooded, or have poorly formed branching structure could fall during high winds.
- Maintain soft caps, armor and hard caps to stabilize and shield surfaces from erosion, storm surges, and tidal influence (USEPA 2013a).

7.5.6 General BMPs

- Avoid building contamination mitigation systems in areas that could be affected by flash floods or landslides.
  Maintain an inventory of raw materials and wastes at the site.
- Install secondary containment systems to capture hazardous liquids in the event of leaks (USEPA 2013a).
  Inspect and clean roof drainage at least twice a year (see the Insurance Institute for Business & Home Safety website).
- Inspect pads on a periodic basis and repair or replace if necessary.
  Perform regular vegetation maintenance.
- Perform regular site trash and debris removal.

7.5.7 Crisis Management

- Observe conditions remotely or at a safe distance.
- Safely inspect systems as conditions warrant and look for possible hazards related to damaged electrical systems, exposure to released contaminated media, increased biological hazards, and changed physical conditions (for example, those caused by inundation, siltation, and erosion).
- Conduct a post-flood inventory of raw materials and wastes and compare to the pre-flood inventory.
  Deploy contaminant release-control devices as early and safely possible (for example, adsorbent booms).
  Evaluate damage to wells, trenches, or galleries and the potential for stormwater to flow into groundwater systems through damaged or unsealed wellheads.
- Inspect underground vaults, spill containment structures, piping chases, and areas with buried pipe for siltation or erosion and possible exposure or damage.
- Inspect berms, dikes, stockpiles, and floodwalls for damage from erosion or scouring.
- Inspect surface caps, subaqueous caps, and other waste-containment structures for damage, weakness, or changes.
- Evaluate groundwater contamination for potential floodwater infiltration or bank storage following flood events.
  Reevaluate the stability of steep slopes.

7.6 Bank and Shoreline Erosion

SBMPs for bank and shoreline erosion include those universally relevant to extreme weather events and wildfires in Section 7.1. The SBMP Tool can be used to create a site-specific summary of SBMPs and document if specific SBMPs are applicable, prioritize SBMPs, and track implementation.

7.6.1 Introduction/Applicability

Flooding, storm surge (Section 7.11), and wave action may lead to bank and shoreline erosion. Many flood-related SBMPs (Section 7.5) are aimed at making a site resilient to bank and shoreline erosion.

Potential direct impacts of bank erosion include damage or loss of remediation infrastructure, reduced site accessibility, and spills or releases into water bodies. Possible indirect impacts may include insufficient treatment of contamination due to treatment system compromise or loss, ecosystem damage, and additional project costs. Bank erosion may impact access roads. Key functional equipment for maintaining remedial performance, even if protected from potential direct impacts of erosion, may not be accessible for maintenance or upkeep.

Nature-based solutions are often the most sustainable and resilient. Living shorelines can provide a habitat, improve water quality, and self-restore after an erosion event (NOAA 2015).

7.6.2 Assessing Vulnerability

The vulnerability of remediation sites to increased bank and shoreline erosion should be assessed. In addition to reviewing weather records and forecasts, trends can also be evaluated. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment.

- Consult federal, state or local sources to determine qualitative or quantitative likelihood of bank and shoreline erosion impacts in a specific area.
    - USEPA's Underground Storage Tank Finder web map application includes functionality to add ArcGIS layers of bank and coastal erosion data viewable at the national and local levels.
    - Vermont identified fluvial erosion as the most significant natural hazard in the 2018 Vermont State Hazard Mitigation Plan (VEM 2018).
    - In Alaska, the presence or absence of sea ice is an important contributor to the rate of shoreline erosion. The Alaska Climate Adaptation Science Center maintains several GIS resources for sea ice.
    - The Denali Commission has identified communities at risk from erosion and flooding in Alaska, published in the Statewide Threat Assessment (University of Alaska Fairbanks Institute of Northern Engineering 2019).
    - The Massachusetts State Hazard Mitigation and Climate Adaptation Plan identified increased coastal erosion as a predicted hazard, particularly in Eastham, Orleans, and Yarmouth.
- Consider modeling surface-water flow velocity and erosional forces along banks for future storm events.
- Consult available state or local data to determine landslide risk.

Sites vulnerable to bank and shoreline erosion may also be vulnerable to flooding (Section 7.5), sea-level rise (Section 7.9), storm surge (Section 7.11), wind (Section 7.2), snow and hail (Section 7.3), fluctuating groundwater levels (Section 7.4), or permafrost thaw (Section 7.12). Review of SBMPs for those events is encouraged.

7.6.3 Planning and Prioritizing Resilience and Sustainability

- Consider there may be changes to permitting requirements for work on banks and shorelines in the event of a flood or other natural disaster.

7.6.4 Remedy Design and Implementation

- Consider developing nature-based solutions into a living shoreline. Options include replenishing sand, planting deep-rooted or native vegetation, and incorporating more natural and locally available materials as a buffer.
    - If this is determined not to be feasible or sufficient, consider installing riprap, gabions, or segmental retaining walls to fortify streambank or shoreline slopes. Keep installations in place with netting to hold back rock elements or attach anchors and cables to rock or concrete elements placed against the slope (USEPA 2013a).
- Consider removal actions if the contamination is located in areas vulnerable to bank erosion. If removal is not possible, divert water around vulnerable banks to decrease erosion and release potential.
- Identify the annual bank or shoreline erosion rate for comparison to the design life of any structures. Use this information to identify how far to locate structures from the bank or shoreline.

7.6.5 OM&M

- Monitor available river gage data, such as that provided by the U.S. Army Corps of Engineers, to maximize preparation time so that sufficient actions can be taken and potential erosion can be minimized
- Maintain soft caps, armor, and hard caps to stabilize and shield surfaces from erosion, storm surges, and tidal influence (USEPA 2013a).
- Periodically review the annual bank or shoreline erosion rate.

7.6.6 General BMPs

- Repair cracks in concrete pads, replace pads that are not sufficient in size or anchorage, and integrate retainingwalls along the concrete pad perimeter (USEPA 2013a).
- Reinforce structures to protect buildings and equipment from foundation failures due to erosion.

7.7 Pre-Wildfire

SBMPs for increasing resilience of a site to wildfire ahead of a wildfire event include those universally relevant to extreme weather events and wildfires in Section 7.1. The SBMP Tool can be used to create a site-specific summary of SBMPs and document if specific SBMPs are applicable, prioritize SBMPs, and track implementation.

7.7.1 Introduction/Applicability

As climate change continues, wildfires are expected to increase in frequency and size. The average temperature in the United States has risen more than 2ºF over the last 50 years. In much of the Southeast and large parts of the West, the frequency of drought has increased coincident with rising temperatures (USGCRP 2009). Increased average temperature and increased extreme temperatures, as well as decreased precipitation and increased frequency of drought, can increase the risk of wildfires capable of spreading to remediation sites and affecting remedy performance (USEPA 2014). In fact, large wildfires have increased nearly fourfold in the West in recent decades, with greater fire frequency, longer fire durations, and longer wildfire seasons (USGCRP 2009). According to Community Planning Assistance for Wildfire, the U.S. fire season is now 84 days longer than it was in 1970, and of the 10 years with the largest acreage burned since 1983, nine have occurred since 2000 (USEPA 2016a).

Wildfires can create additional vulnerabilities at a site. Wildfires in upland areas above contaminated sites can reduce vegetative cover, increasing surface-water runoff and resulting in catastrophic flooding that spreads contamination or impacts remedies (USEPA 2014).

This section identifies resources and describes design and management practices to integrate resilience into the remediation strategy so that the impacts of wildfires are prevented. This section addresses SBMPs before a wildfire occurs; Section 7.8 contains information about post-wildfire SBMPs at a remediation site.

7.7.2 Assessing Vulnerability

The vulnerability of remediation sites to increased bank and shoreline erosion should be assessed. In addition to reviewing weather records and forecasts, trends can also be evaluated. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment.

It is important to note that green infrastructure elements are not fireproof. Although they are a recommended SBMP for many other extreme events, wildfire risk at the site should be part of the evaluation process prior to installation.

- Consider that, in general, the following types of remediation sites may be vulnerable to more frequent andintense wildfires:
    - sites with infrastructure (for example, abandoned mines, underground storage tanks) or treatment infrastructure (for example, pump-and-treat systems, Baker tanks)
    - landfills with planted vegetation for erosion control (Ecology 2017)
    - sites located in areas with trees or grass that are subject to drought, near the urban-forest interface,or within forested areas

  Use federal, state, and local tools to quantify the current and projected wildfire risk with available GIS resources. Some tools include:
    - the National Interagency Fire Center
    - USEPA's Underground Storage Tank Finder
    - State tools include:
        - Colorado Forest Atlas
        - Alaska Climate Adaptation Science Center.
        - New Jersey Forest Adapt online map tool

  - Where GIS resources are not available, consult federal, state, or local sources to determine qualitative or quantitative likelihood of wildfire risk in a specific area. Some resources include:
    - The Fire-Adapted Communities self-assessment tool can be used to help identify if a site or community is prepared for wildfire events by answering a series of questions.
    - The North Carolina Climate Risk Assessment and Resilience Plan (NCDEQ 2020) identified an increased likelihood of conditions conducive to wildfires throughout the state.
    - The Minnesota State Hazard plan (MDPS 2019) identified wildfire as a high probability hazard.
    - The Massachusetts State Hazard Mitigation and Climate Adaptation Plan identified Barnstable and Plymouth Counties as most vulnerable.
    - Wildfire seasons could lengthen and the frequency of large fires could increase in New Jersey, according to the New Jersey Scientific Report on Climate Change (NJDEP 2020).

Sites vulnerable to increased wildfire risk may also be vulnerable to flooding (Section 7.5), wind (Section 7.2), fluctuating groundwater elevation levels (Section 7.4), bank and shoreline erosion (Section 7.6), evapotranspiration (Section 7.10), or permafrost thaw (Section 7.12). Review of the flooding SBMPs for those events is encouraged.

7.7.3 Planning and Prioritizing Resilience and Sustainability

- Establish a wildfire management and response plan (WADNR 2019).
- Contact the local fire department that would service the remediation site to ensure that first responders are aware of the potential risks of the site during a wildfire response and receive education on local SBMPs for wildfire planning.
- Assess the potential for contamination to spread from wildfire and build controls as needed.
- Review and assess measures that the utility provider for the site is taking to reduce the likelihood of causing wildfires, as suggested by the Arizona Department of Forestry and Fire Management.
- Provide information on wildfire management and response plan to site neighbors.
- Include discussions of wildfire risks and effects in public outreach, notification, and public comment efforts and materials.

7.7.4 Remedy Design and Implementation

- Plant vegetation that is drought- and fire-resistant and can regrow quickly (USEPA 2019b, Ecology 2017). Create fire barriers (USEPA 2013a, 2019a, b) around infrastructure, treatment systems, areas of contamination, and subsurface points of entry.
- Protect heat-sensitive components from wildfire by installing manufactured systems (for example, radiant energy shields and raceway fire barriers) or enclosing vulnerable equipment or control devices in a concrete structure (USEPA 2019a, b).
- Add or replace highly flammable materials with fire-, mold-, and mildew-resistant insulation materials (USEPA 2019a, b).
- Use metal or HDPE piping, which is more resistant to burning and breakage (Ecology 2017).
  Build a retaining wall of concrete or steel sheet piles to hold back debris (USEPA 2019b).
- Relocate electricity and communication lines from overhead to underground positions to prevent power outages during and after extreme weather events (USEPA 2019b).

7.7.5 OM&M

- Inspect the alarm systems regularly.
- Inspect the heat guards regularly.
- Maintain fire barriers.
- Conduct controlled fire burns around the site to serve as a buffer (NWCG 2017).
- Regularly review fire hazard predictions for the site and adapt SBMP implementation to match any changing site conditions.
- Periodically review the wildfire management and response plan and update if necessary.

7.7.6 General BMPs

- Inspect the integrity of electrical equipment.
- Perform regular vegetation maintenance.
- Perform regular site trash and debris removal.

7.8 Post-Wildfire

SBMPs for increasing resilience of a site to wildfire after a wildfire event include those universally relevant to extreme weather events and wildfires in Section 7.1. The SBMP Tool can be used to create a site-specific summary of SBMPs and document if specific SBMPs are applicable, prioritize SBMPs, and track implementation.

7.8.1 Introduction/Applicability

This section identifies the SBMPs and resources available to manage a remediation site following a wildfire. Wildfires may damage buildings, equipment, treatment systems, and other infrastructure and increase the chance of landslides, erosion, flooding, and debris flow. Green infrastructure—and the ecosystem services it provides—is typically devastated by wildfires. Loss of fauna, flora, clean water, and habitat is often sudden and catastrophic, and may take many years to recover in a manner that will support a wide diversity of plants and animals. These impacts and the variety of other impacts following a wildfire can be compounding, which highlights the importance of a fast, efficient response. Once the immediate response is complete, review the pre-wildfire SBMPs in Section 7.7 to build resiliency into the remediation site.

7.8.2 Assessing Vulnerability

Understanding the risks (for example, landslide, erosion, and flooding) after a wildfire occurs at a remediation site can help decrease response time and increase efficiency. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment.

- The following should be considered to assess potentially compounding impacts after a wildfire: Identify areas newly exposed due to vegetation loss.
    - Review SBMPs for wind (Section 7.2) and flooding (Section 7.5).
    - Monitor surface-water and groundwater conditions (Section 7.4). Mobilization of sediments, nutrients, dissolved organic matter, impacts on municipal treatment facilities, etc., can directly impact water quality (Tecle and Neary 2015, Knoss 2018, Bladon et al. 2008).
- The following should be considered to assess the potential impacts of wildfires on contamination: Evaluate burn severity. In general, denser site vegetation corresponds with a longer fire and, therefore, a more significant impact to the soil.
    - Evaluate the permeability of soils and assess if there are any conductivity changes.
    - Monitor surface water to identify if new migration pathways were established and contaminant flowpatterns changed from vertical to lateral.
    - Reevaluate site boundaries and potential pathways for contaminant migration. Identify if key functional equipment for remedial performance was destroyed. Determine if on-site hazardous materials previously contained have been dispersed.
    - Investigate whether new contaminants were generated from burning of the on-site contaminants. Sample to determine if dioxins and furans were generated at levels of concern as a direct result ofthe fire.
    - Assess the long-term vulnerability (Section 7.1.1) of the site to wildfires. The original site characterization and design of cleanups may not reflect increasing wildfire vulnerability (USEPA 2014).
    - Reassess risk factors and rankings for risk-based cleanup strategies based on increasing wildfire risk.

Sites vulnerable to increased wildfire risk may also be vulnerable to flooding (Section 7.5), wind (Section 7.2), fluctuating groundwater elevation levels (Section 7.4), bank and shoreline erosion (Section 7.6), evapotranspiration (Section 7.10), or permafrost thaw (Section 7.12).

7.8.3 Planning and Prioritizing Resilience and Sustainability

Although it is important to immediately respond after a wildfire to reduce additional site impacts (Section 7.8.4), it is also important to consider long-term site conditions and develop a plan to reduce the chances of another fire and help reestablish the ecosystem of the site. When rebuilding a site or a treatment system or redesigning the treatment system, SBMPs for wildfire resilience should be integrated in the planning phase.

- At a minimum, the first two items below should be performed as part of the long-term post-wildfire response plan at a site:Review pre-wildfire SBMPs (Section 7.7).
    - Document site-specific lessons learned to ensure that the site and remedial treatment rebuild are resilient. Assess if site conditions have changed. For example, land cover that is altered can result in the need to modify stormwater controls, manage invasive species, and rebalance the hydrologic system (Vaillant, Kolden, and Smith 2016).
    - Perform an integrity inspection of infrastructure, keeping in mind that anything on the ground surface thatpenetrates the subsurface is a potential conduit of subsurface and groundwater contamination.
        - Surface—above-grade equipment, aboveground storage tanks, and electrical equipment (for example, electrical panels, transformers, bushings)
        - Subsurface—wells, subgrade piping and electrical conduit, and underground storage tanks
- Reevaluate site boundaries and potential pathways for contaminant migration. Sites that have achieved remedy completion may need to be reevaluated if wildfires have changed the underlying risk assessment.
    - Reassess current monitoring and sampling protocols to ensure continued effectiveness.
    - Revise safety procedures as necessary to reflect the likelihood or intensity of surrounding conditions. Assess alternative utility and transportation options in case default options are not available.

7.8.4 Remedy Design and Implementation

If the remediation area is susceptible to erosion, landslides, or flooding, the following modifications to the remedy design should be implemented to reduce post-wildfire impacts:

- Install dams and channel treatments (Colorado State Forest Service) to reduce the velocity of water runoff (for example, install straw wattles in a shallow trench to form a continuous barrier and intercept water running down a slope) (USAID 2017).
- Install gabions, bulkheads, retaining walls, and other slope-stabilization treatments (for example, seeding and mulching, Colorado State Forest Service) to help restore soil and reduce impact from rains.
- Install berms, gabions, vegetated swales, and other soil and sediment traps to help reduce soil loss and increase water dispersion (for example, silt fences and log felling, Colorado State Forest Service).
- Till and scarify to help increase infiltration (Colorado State Forest Service).

7.9 Sea-Level Rise

SBMPs for sea-level rise include those universally relevant to extreme weather events and wildfires in Section 7.1. The SBMP Tool can be used to create a site-specific summary of SBMPs and document if specific SBMPs are applicable, prioritize SBMPs, and track implementation.

7.9.1 Introduction/Applicability

Wave action and sea-level rise are associated with increased risk of flooding (Section 7.5) and erosion (Section 7.6). Rising sea levels inundate low-lying lands, erode shorelines, contribute to coastal flooding, and increase the flow of salt water into estuaries and nearby groundwater aquifers. Higher sea levels also make coastal infrastructure more vulnerable to damage from storms due to an increased likelihood of flooding from higher storm surges (USEPA 2016a). An extensive list of tools to help understand and assess site vulnerability to sea-level rise and storm surges, as well as adaptation strategies, are available in the state and federal resource map. Some resources include:

- the coastal flooding section of data.gov
- the USEPA's Climate Smart Brownfields Manual (USEPA 2016b)
- the contaminated lands section of Adapting to Rising Tides, a program of the San Francisco Bay Conservation and Development Commission
- Sea-Level Rise Adaptation Training at USEPA's Clu-In.org
- Adaptation Strategies for Resilient Cleanup Remedies from the Washington Department of Ecology (2017)
- New Jersey's Flood Mapper

Nature-based solutions are often the most sustainable and resilient. Living shorelines can provide a habitat, improve water quality, self-restore, and may even adapt to sea-level rise (NOAA 2015).

7.9.2 Assessing Vulnerability

The vulnerability of remediation sites to sea-level rise should be assessed. In addition to reviewing weather records and forecasts, trends can also be evaluated. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment.

- Use federal, state, and local tools to quantify the current and projected sea-level rise risk with available GIS resources. Some tools include:
  - sea-level change curve calculator from the U.S. Army Corps of Engineers. The middle three trendlines may be the most likely scenarios.
  - NOAA sea level rise visualization tool, which shows what sea-level rise will look like at high tideNASA Sea-Level Change Portal
  - USEPA's Underground Storage Tank Finder includes functionality to add ArcGIS layers of sea levelride data, viewable at the national and local levels
  - state-specific sea-level rise tools:
    - Sea-Level Rise and Coastal Flood Web Tools Comparison Matrix was developed by the Nature Conservancy, NOAA Office for Costal Management, and Climate Central.
    - The Delaware Department of Natural Resources and Control published a statewide sea-level rise vulnerability assessment with maps and models (DNREC 2012).
    - The Hawaii Climate Change Mitigation and Adaptation Commission developed the Hawai'i Sea-Level Rise Vulnerability and Adaptation Report and viewer tool.
    - The New Hampshire Department of Environmental Services created the New HampshireSea-Level Rise, Storm Surge, and Groundwater Rise Mapper to be a screening tool to plan for future coastal inundation scenarios.
    - The New Jersey Flood Mapper allows users to conduct flood exposure analysis whileevaluating several parameters, including sea-level rise.

- Washington State maintains an interactive Sea-Level Rise Data Visualization tool. The Denali Commission has identified communities at risk from flooding in Alaska,
- published in the Statewide Threat Assessment (University of Alaska Fairbanks Institute of Northern Engineering 2019).
- Align the projected sea-level rise timeline with the site timeline—for example, if a site will have a 30-year cap,look at sea-level rise predictions at least 30 years out.
- If GIS resources are not available, consult state or local sources to determine qualitative or quantitativelikelihood of sea-level rise in a specific area.
- The North Carolina Climate Risk Assessment and Resilience Plan identified with virtual certainty that sea level along the coast will continue to rise (NCDEQ 2020).
- The New Hampshire Climate Change Resilience Plan stated that sea-level rose about 5.3 inches from1926 to 2001 (McCarthy 2014).
- The New Jersey Scientific Report on Climate Change states that by 2050 there is a 50% chance that sea-level rise will meet or exceed 1.4 feet, and the entire coastal area of NJ will experience more frequent flooding not associated with precipitation. Atlantic City is particularly vulnerable to flooding due to sea-level rise. Overpumped aquifers are vulnerable to salt-water intrusion (NJDEP 2020).
- Georgia Department of Natural Resources reports that the sea level in Georgia's coastal areas hasrisen at a rate of 3mm/year for the past 70 years.
- If the site is vulnerable to sea-level rise, quantify the current and projected associated risks, including flooding,storm surge, and shoreline encroachment.
- Use available extreme water-level predictions to understand flooding risk during a storm surge.
- The NOAA Extreme Water Levels tool provides 1% annual exceedance probability levels for specific locations. This value can be added to the predicted sea-level rise value to predict flood water heights during storm surges.
- Use available modeling resources, such as the NOAA Sea-Level Rise Viewer, to evaluate shorelineencroachment in contaminated areas.

Sites vulnerable to sea-level rise may also be vulnerable to flooding (Section 7.5), storm surge (Section 7.11), bank and shoreline erosion (Section 7.6), wind (Section 7.2), fluctuating groundwater elevation levels (Section 7.4), or permafrost thaw (Section 7.12). Review of the SBMPs for those events is encouraged.

7.9.3 Planning and Prioritizing Resilience and Sustainability

- Determine the tolerance for flood risk.
- Contact local and regional planning agencies and infrastructure owners who may service the site, such as the local transportation agency and utilities, to learn if they have any sea-level rise mitigation plans specific to thelocal area that can be used on site and ensure the site plans are compatible with other regional plans.
- Establish sea-level rise management and mitigation plan (Miller et al. 2019).
- Plan habitat restoration to span a wide range of elevations from subtidal to upland (Ecology 2017).
- Proactively plan and budget for increasingly frequent floods.
- Consider resilient uses for the site, such as park space.
- Monitor water temperature and pH to determine the conditions the remedy should be designed to.

7.9.4 Remedy Design and Implementation

- If possible, design contaminant treatment or containment to be outside the 100- and 500-year floodplains. Statistically, the traditional 100-year floodplain has been found vulnerable to sea-level rise even in areas with prolonged drought. If the 500-year floodplain is not delineated, a best practice from the U.S. Green Building Council is to use the 100-year floodplain and add 3 feet to the measurements (U.S. Green Building Council 2018).

- Consider developing nature-based solutions into a living shoreline. Options include replenishing sand, planting deep-rooted or native vegetation, and incorporating more natural and locally available materials as a buffer to stabilize shorelines. Swamps, marshes, bogs, or other areas vegetated with plants that thrive in saturated soil can reduce the height and speed of floodwaters and provided a buffer from wind or wave action and storm surge(Ecology 2017).
    - If this is determined not to be feasible or sufficient, consider installing riprap, gabions, or segmental retaining walls to fortify streambank or shoreline slopes. Keep installations in place with netting tohold back rock elements or attach anchors and cables to rock or concrete elements placed against the slope (USEPA 2013a).
- Monitor groundwater elevations, salinity, pH, sea level, and long-term shoreline impacts such as wave erosion, flooding, or overtopping of seawalls or groundwater barrier walls to design remedial treatment resilient to the impacts of sea-level rise. A drop in groundwater and river flows can lead to decreased hydraulic head, resultingin salt-water and brackish water infiltrating farther inland and potential groundwater quality degradation.
- Consider the increasing prevalence of seasonal and monthly high-tide flooding when planning access to sites and facilities.
- Seal monitoring wells and increase the height of the well casing above the ground surface.
- Build treatment systems at a higher elevation or on platforms elevated above future sea-level projections(Ecology 2017) or build floodable structures.
- Consider that increasing water temperature, increasing acidification, and salinity changes may affect natural attenuation mechanisms, the integrity of the equipment, and the efficacy of the treatment method (Ecology 2017).
- Use materials that are corrosion resistant and compatible with brackish groundwater and surface water for engineered system components.
- Identify the annual bank or shoreline erosion rate for comparison to the design life of any structures. Use this information to identify how far to locate structures from the bank or shoreline.

7.9.5 OM&M

- Periodically review the sea-level rise management and mitigation plan and update if necessary.
  Monitor for the mobilization of contaminants.
- Monitor site conditions to evaluate changes in sea and groundwater temperature, salinity, pH, and elevation.
- Monitor long-term shoreline impacts such as wave erosion, flooding, or overtopping of seawalls or groundwater barrier walls.
- Consider that monitoring may be required indefinitely for alternative remedies that rely on containment and are vulnerable to sea-level rise (Nuttle and Portnoy 1992).
- Maintain soft caps, armor, and hard caps to stabilize and shield surfaces from erosion, storm surges, and tidal influence (USEPA 2013a).
- Periodically review the annual bank or shoreline erosion rate.
- Periodically review floodplain determinations from FEMA or other sources.

7.9.6 General BMPs

- Perform regular vegetation maintenance.
- Perform regular site trash and debris removal.

7.10 Evapotranspiration

SBMPs for evapotranspiration (ET) include those universally relevant to extreme weather events and wildfires in Section 7.1. The SBMP Tool can be used to create a site-specific summary of SBMPs and document if specific SBMPs are applicable, prioritize SBMPs, and track implementation.

7.10.1 Introduction/Applicability

Recent studies conducted by the U.S. Geological Survey (USGS) and NASA's Earth Observing System Project Science office showed that due to increases in temperature, there has been an increase in the flow between the various stages of the water cycle over most of the United States in the past seven decades. Water has been moving more quickly and intensely through the various stages (Huntington et al. 2018, Kramer et al. 2015). "As the planet warms, we anticipate that the warmer air, which holds more moisture, will lead to more evaporation and precipitation," said Tom Huntington, a research hydrologist at USGS. If those processes are increasing, it is evidence for an intensifying water cycle" (Patel 2019, page 1).

Furthermore, as temperatures increase, plant transpiration increases, which in turn reduces soil moisture and lowers shallow groundwater elevations. This increase in ET (defined as the sum of evaporation and plant transpiration) poses both short-term and long-term risks for selected remediation projects throughout North America, particularly constructed treatment wetlands, phytoremediation, retention basins, and other surface water–based remediation.

U.S. Department of Agriculture (USDA) Evaporative Stress Index (ESI), USEPA's Evapotranspiration Calculator Desktop Modeling Tool, and the National Drought Mitigation Center are valuable resources for ET information.

The USDA ESI can be used to identify geographic areas subject to drought.

According to USDA, this model identifies "temporal anomalies in evapotranspiration highlighting areas with anomalously high or low rates of water use across the land surface. It also captures early signals of 'flash drought,' brought on by extended periods of hot, dry and windy conditions leading to rapid soil moisture depletion. It is implemented at a 4-km resolution real-time model of evapotranspiration stress over the Continental United States." More information, including relevant USDA research, can be found at the USDA-ARS Hydrology and Remote Sensing Laboratory website.

The USEPA ET Calculator Desktop Modeling Tool can be used to evaluate the site vulnerability to ET and specific risks associated with a given site. This tool estimates ET time series data for hydrologic and water quality models. It was developed specifically for the Hydrologic Simulation Program – Fortran (HSPF) and the Stormwater Management Model, but can be used with other models if they use time series ET data as input.

The National Drought Mitigation Center maintains the U.S. Drought Monitor through a multiagency partnership at the University of Nebraska-Lincoln. It is a map released every Thursday, showing parts of the United States that are in drought. The website includes maps, tabular data, and weekly drought summaries.

7.10.2 Assessing Vulnerability

The vulnerability of remediation sites to increased ET should be assessed. In addition to reviewing weather records and forecasts, trends can also be evaluated. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment.

- Use federal, state, and local tools to quantify the current and projected ET risk with available GIS resources. Some tools include:
  - USDA Evaporative Stress Index
  - USEPA ET Calculator Desktop Modeling Tool
  - USEPA's Underground Storage Tank Finder includes functionality to add ArcGIS layers ofevapotranspiration data viewable at the national and local levels
  - the National Drought Monitor out of the University of Nebraska-Lincoln
  - New Jersey Forest Adapt allows users to generate maps with a variety of climate projection data, including temperature and precipitation
- Where GIS resources are not available, consult state or local sources to determine qualitative or quantitative likelihood of ET risk in a specific area.

    - The Ohio Department of Transportation Infrastructure Resiliency Plan identified increases in drought and related flash flooding as vulnerabilities throughout the state (RSG 2016).
    - The North Carolina Climate Risk Assessment and Resilience Plan identified that severe droughts are likely to be more intense and frequent (NCDEQ 2020).
    - The Minnesota State Hazard plan identified drought as a high probability hazard (MDPS 2019).
    - The Massachusetts State Hazard Mitigation and Climate Adaptation Plan identified the entire commonwealth as vulnerable to drought, with the frequency and intensity projected to increaseduring summer and fall.
    - The New Jersey Scientific Report on Climate Change states that New Jersey is warming faster than the rest of the Northeast region, with average annual temperatures increasing by 4.1°F to 5.7°F by2050. Droughts may occur more frequently due changes in precipitation patterns (NJDEP 2020).

- Sites vulnerable to increased ET may also be vulnerable to wildfires (Sections 7.7 and 7.8), wind (Section 7.2), or fluctuating groundwater levels (Section 7.4). Review of the flooding SBMPs for those events is encouraged.

7.10.3 Planning and Prioritizing Resilience and Sustainability

- Consult local authorities and utilities to identify existing adaptation strategies.
    - The Ohio Department of Transportation Infrastructure Resiliency Plan identifies adaptive measures the department is taking to address more frequent and intense droughts (RSG 2016)
    - New Hampshire maintains a Drought Assessment and Response Annex to coordinate the state'sassessment and response activities in the case of a drought emergency (NHDES 2016).
- Monitor surface-water and groundwater elevations for decreasing levels using transducers or other means to plan a design resilient to this impact.
- Monitor for salinity and pH of water systems to plan a design resilient to these impacts.
- Develop protocols to conduct regular checks for plant disease and invasive insect species (for example, fungus, termites, bees, fire ants).

7.10.4 Remedy Design and Implementation

- Install low-level alarm float switches in surface water–based systems (for example, retention ponds, evaporation ponds).
- Select hardy, drought-resistant, local vegetation for covers, phytoremediation projects, and wetlands.
- Install spray-irrigation areas.
- Use dry rot–resistant materials when practical.

7.10.5 OM&M

- Monitor surface-water and groundwater elevations for decreasing levels using transducers or other means.
- Monitor for salinity and pH of water systems.
- Regularly check rubber fittings for dry rot.
- Follow site-specific protocols to regularly check for plant disease and invasive insect species (for example, fungus, termites, bees, fire ants).
- During confluence of extreme conditions (for example, drought, increased temperature, increased ET), conduct regular checks of vegetation for fire potential.

7.10.6 General BMPs

- Perform regular vegetation maintenance.

7.11 Storm Surge

SBMPs for storm surge include those universally relevant to extreme weather events and wildfires in Section 7.1. The SBMP Tool can be used to create a site-specific summary of SBMPs and document if specific SBMPs are applicable, prioritize SBMPs, and track implementation.

7.11.1 Introduction/Applicability

Storm surges occur when high storm winds (Section 7.2) raise the seawater level above the normal anticipated tide. They cause destructive coastal flooding (Section 7.5) and pose a serious risk to people, property, and ecosystems. Depending on the severity of the storm and coastal elevations, storm surges can threaten low-lying, inland areas miles from the shoreline.Rising sea levels (Section 7.9) and greater storm frequency are projected to increase the threat of storm surges in the future.

Storm-surge magnitude depends on many factors, including but not limited to storm intensity, wind speed, and coastal features. The impacts of storm surges are exacerbated by eroded shorelines (Section 7.6), which do not provide an adequate buffer for diffusing wave energy. Over the years, coastal development has reduced natural sediment accretion and beach width, making communities more vulnerable to waves and wind. Storm surges further erode shorelines and limit the buffer potential against future storms (USACE 2007).

In addition to posing an immediate risk to people and property, storm surges damage critical infrastructure, threaten ecosystems, and compromise remediation systems. Transportation infrastructure, wastewater treatment facilities, and drinking water systems may fail. Wetlands and estuary ecosystems are threatened by sediment deposition and salt-water infiltration. Existing remediation systems may be compromised and ongoing remediations disrupted.

Nature-based solutions are often the most sustainable and resilient. Living shorelines can provide a habitat, improve water quality, and self-restore after an erosion event (NOAA 2015).

7.11.2 Assessing Vulnerability

The vulnerability of remediation sites to storm surge should be assessed. In addition to reviewing weather records and forecasts, trends can be evaluated. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment.

- Use federal, state, and local tools to quantify the current and projected ET risk with available GIS resources. Some tools include:
    - the USEPA Storm Surge Inundation Map, an interactive map that illustrates hurricane frequency, storm-surge flooding, and FEMA flood zones
    - NOAA's national storm-surge hazard maps showing coastal areas that are at risk of storm surge, as well as the potential magnitude of the storm surge based on the storm category. In Alaska the presence or absence of sea ice is an important contributor to the impact of storm surges. The AlaskaClimate Adaptation Science Center maintains several GIS resources for sea ice.
    - USEPA's Underground Storage Tank Finder web map application includes functionality to add ArcGIS layers of storm surge data viewable at the national and local levels.
    - the New Jersey Flood Mapper, which allows users to conduct flood exposure analysis while evaluating several parameters, including storm surge
- Where GIS resources are not available, consult state or local sources to determine qualitative or quantitative likelihood of storm-surge risk in a specific area.
    - The North Carolina Climate Risk Assessment and Resilience Plan identified virtual certainty for increased storm-surge flooding in coastal areas (NCDEQ 2020).
    - The Denali Commission has identified communities at risk from erosion and flooding in Alaska, published in the Statewide Threat Assessment (University of Alaska Fairbanks Institute of Northern Engineering 2019).

Sites vulnerable to storm surge may also be vulnerable to bank and shoreline erosion (Section 7.6), flooding (Section 7.5), fluctuating groundwater levels (Section 7.4), sea-level rise (Section 7.9), snow and hail (Section 7.3), wind (Section 7.2), or permafrost thaw (Section 7.12). Review of the SBMPs for those events is encouraged.

7.11.3 Planning and Prioritizing Resilience and Sustainability

- Incorporate wetland and estuary protection into infrastructure and remedy planning to provide a buffer against storm surges and coastal erosion (USEPA 2009).
- If possible, design contaminant treatment or containment to be outside the 100- and 500-year floodplains. Statistically, the traditional 100-year floodplain has been found vulnerable to sea-level rise even in areas with prolonged drought. If the 500-year floodplain is not delineated, a best practice from the U.S. Green Building Council is to use the 100-year floodplain and add 3 feet to the measurements (U.S. Green Building Council 2018).

7.11.4 Remedy Design and Implementation

- Consider developing nature-based solutions into a living shoreline. Options include replenishing sand, planting deep-rooted or native vegetation, and incorporating more natural and locally available materials as a buffer to stabilize shorelines. Swamps, marshes, bogs, or other areas vegetated with plants that thrive in saturated soil can reduce the height and speed of floodwaters and provide a buffer from wind or wave action and storm surge (Ecology 2017).
    - If this is determined not to be feasible or sufficient, consider installing riprap, gabions, or segmental retaining walls to fortify streambank or shoreline slopes. Keep installations in place with netting tohold back rock elements or attach anchors and cables to rock or concrete elements placed against the slope (USEPA 2013a).
- Preserve coastal lands such as dunes, wetlands, sea grass beds, and oyster reefs as recommended by USEPA's Green Infrastructure-Coastal Resiliency website.
- Install flood and storm-surge controls and drainage structures to protect critical site and remedy components.
- Green infrastructure and earthen structures such as seawalls, vegetated berms or swales, detention wetlands, tree trenches, and stormwater ponds, dams, or levees can be used to prevent inundation (USEPA 2013a).
- Identify the annual bank or shoreline erosion rate for comparison to the design life of any structures. Use this information to identify how far to locate structures from the bank or shoreline.
- Move or locate key functional equipment for remedial performance away from potential storm surge or coastal flooding areas (USEPA 2013a).
- Install or relocate overhead communication and electric lines underground to prevent power outages during storms (USEPA 2013a).
- Storm-proof infrastructure by repairing, retrofitting, or relocating facilities and equipment to prevent damage and disruptions during extreme weather events. The USEPA's Climate Impacts on Water Utilities website (USEPA ARC-X) contains resources and information pertaining to climate impacts on infrastructure.
- Develop off-grid alternate power sources that can supply power during storms. Locate new and backup electrical power above the floodplain (USEPA 2013a).
- Secure storage areas above the 100- and 500-year floodplains. If the 500-year floodplain is not delineated, a best practice from the U.S. Green Building Council is to use the 100-year floodplain and add 3 feet to the measurements (U.S. Green Building Council 2018).
- Use pervious materials instead of impervious surfaces to improve drainage and stormwater flow.

7.11.5 OM&M

- Monitor storm conditions through the National Hurricane Center.
- Regularly review storm-surge predictions for frequency and elevation of surge waters at the site and adapt SBMP implementation to match any changing site conditions.
- Periodically review the annual bank or shoreline erosion rate.
- Maintain soft caps, armor, and hard caps to stabilize and shield surfaces from erosion, storm surges, and tidal influence (USEPA 2013).
- Periodically review floodplain determinations from FEMA or other sources.

7.11.6 General BMPs

- Perform regular vegetation maintenance.
- Perform regular site trash and debris removal.

7.12 Permafrost Thaw

SBMPs for permafrost include those universally relevant to extreme weather events and wildfires in Section 7.1. The SBMP Tool can be used to create a site-specific summary of SBMPs and document if specific SBMPs are applicable, prioritize SBMPs, and track implementation.

7.12.1 Introduction/Applicability

This section is designed to help practitioners identify key SBMPs for designing or adapting remediation sites so that they are resilient to thawing permafrost. Permafrost is defined by the United States Permafrost Association and the U.S. Army Corps of Engineers (USACE) as earth materials that remain continuously at or below 0ºC for at least 2 consecutive years. Surface activity generally causes some damage to thermal stability in the active layer, causing some degree of permafrost degradation, the main exception being snow compaction in the winter. All tundra types are more sensitive to both chemical and physical damage when the soil is thawed (Cater 2010). Unlike the SBMP guidance for other extreme weather events or wildfires, which address well understood climate phenomena occurring on a more frequent basis or at a higher intensity, large-scale thawing permafrost is a relatively new phenomenon. Arctic air temperatures are rising at approximately twice the rate compared to the rest of the United States (USEPA 2016a, Schnabel, Goering, and Dotson 2020). The Alaska *Department*of *Environmental Conservation* (ADEC) noted, “Climate change is introducing additional complexity for contaminated site cleanup in the Arctic” (ADEC 2019, page 3).

Permafrost has warmed throughout much of the Northern Hemisphere, with colder permafrost sites warming more rapidly since the 1980s (Jones et al. 2013). As air temperatures warm, the active layer warms and deepens, and the top of the permafrost also warms and degrades. The degree of warming and degradation depends on the mean annual air temperature, ground ice content, vegetation (in particular, mosses), snow cover and depth, soil moisture, soil type, and exposure to sun.

“The resilience and vulnerability of permafrost to climate change depends on complex interactions among topography, water, soil, vegetation, and snow” (Torre-Jorgenson et al. 2010). At any cleanup site in the tundra, responsible parties should understand the current thermal regime and ground ice types and content and expect that it will change over time (Jorgenson et al. 2015). This understanding is relevant at even small-scale cleanups of only a few cubic meters of spilled diesel fuel on a remote roadway (Barnes 2015). ADEC recommends that remedy design undergo evaluation to account for this change during the life of the remedy, and make modifications where applicable (ADEC 2019).

The science of evaluating vulnerability to permafrost thaw, measuring it, understanding it, planning for it, and adapting to it is still developing. Compared to the other extreme events, very few documents exist as a resource to a party responsible for conducting cleanup where permafrost, and the potential for permafrost thaw, exist. We have compiled what information is available from the general literature into the SBMPs below and discussed them with people in the state of Alaska well versed in permafrost remedial activities, from both the state government and academia. As the understanding of permafrost thaw continues to evolve, published scientific articles are collated by the U.S. Permafrost Association, together with the American Geosciences Institute, and distributed as permafrost monthly alerts to members of the U.S. Permafrost Association. The monthly permafrost citations are added to the searchable Cold Regions Bibliography that contains additional historic references.

7.12.2 Permafrost Primer

Feedback from the state of Alaska indicated that remediation personnel who come to work from the Lower 48 are often not well versed in the unique challenges permafrost and thawing permafrost present. Therefore, a separate section was added to provide a primer on permafrost. The primer is intended to help underscore the value of the SBMPs presented below in providing sustainable resilience to permafrost thaw for a remediation site. The primer should not be used in place of specialized training to work in permafrost. Also be aware that the state of Alaska has special regulations for working in the tundra, and early and frequent communication with ADEC and the Alaska Department of Natural Resources (ADNR) is encouraged. The Permafrost Primer, including where to find the applicable regulations, can be accessed by clicking on the Read More below.

7.12.2.1 Regulatory Framework

The state of Alaska has some regulations specific to the Arctic zone, defined in 18 AAC 75.990 as areas north of latitude 68 North. Areas south of that latitude will be considered an Arctic zone on a site-specific basis, based on a demonstration that the site is underlain by continuous permafrost. ADEC issued a technical memorandum on April 4, 2019, titled “Establishing Arctic Zone Cleanup Levels” (ADEC 2019). This guidance clarifies the implementation of cleanup levels established in the Alaska Administrative Code (18 AAC 75) for sites located in the Arctic zone. The guidance acknowledges that the cleanup levels may not be applicable to all sites, given site-specific considerations, such as whether the spill was to undisturbed tundra, pad, or active layer porewater that is connected to the subpermafrost aquifer, or if there is supra-permafrost flow to surface waters, etc. The guidance directs the reader to also use the Tundra Treatment Guidelines, 3rd edition (Cater 2010). The Tundra Treatment Guidelines are the primary strategic resource for managing a spill cleanup in tundra, with specific tactics provided by the Alaska Clean Seas Technical Manual (Lukin et al. 1999). A technical discussion of petroleum movement and remediation in frozen soils is given in Barnes and Biggar (2008) and Barnes and Chuvilin (2008).

7.12.2.2 Permafrost Features

Tundra strata and its influence on hydraulic conductivity in the Arctic are unique. The presence of ice in Arctic soils, the influence seasonal freeze and thaw cycling has on fluid movement, and the typically shallow active layers found in these environments all impact the movement of fluids in these soils in a manner not found in temperate soils (Barnes and Chuvilin 2008).

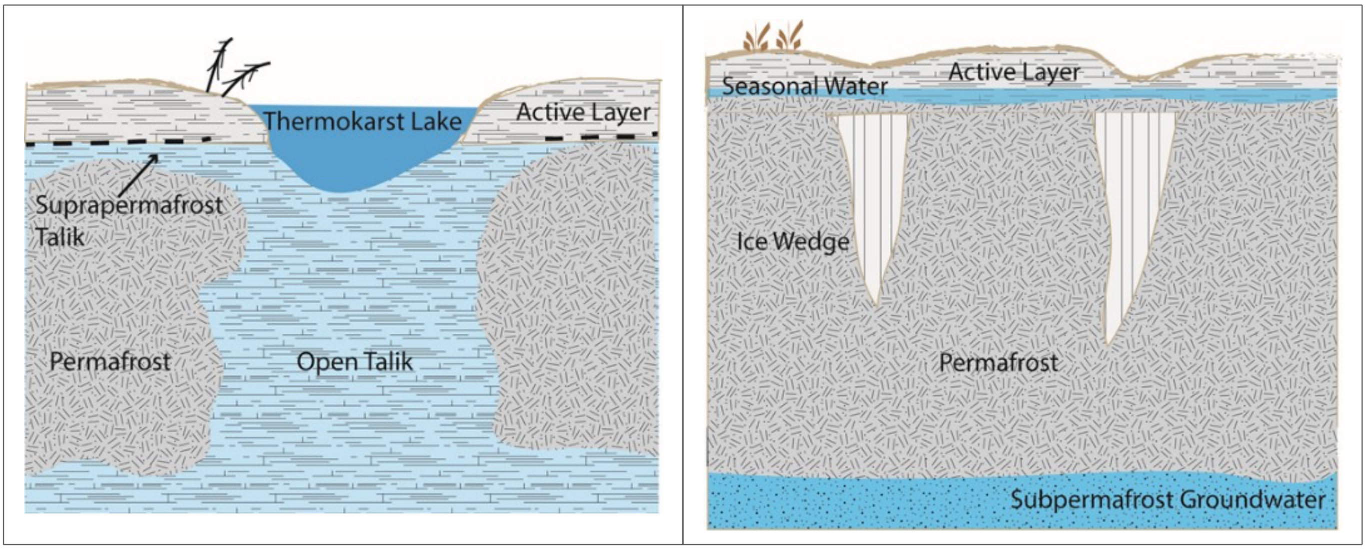


Figure 7-5. Cross sections of some permafrost and thermokarst lithology.

Source: Dr. Barnes. Permission pending.

Figure 7-6. A typical gravel pad supporting operations in Alaska's North Slope oilfield.

Source: Bill O'Connell, ADEC. Used with permission.

The active layer is the upper layer of the soil starting at the soil/air interphase to the depth of maximum annual thaw. The active layer of soil in the tundra supports a generally slow-growing, unique ecosystem not easily replaced (Cater 2010). It reflects annual changes in air temperature and thaws each summer, refreezing each winter (USACE CRREL Permafrost Tunnel Research Center website, see the Temperature Profile section).Because the underlying permafrost limits water infiltration, surface water is abundant in many types of tundra despite low annual precipitation (Cater 2010). Groundwater may exist in the active layer, in a talik, or under the Permafrost (Figure 7-6). When groundwater is in the active layer or a talik, it is referred to as supra-permafrost. When it is under the permafrost, it is referred to as subpermafrost. Talik is a layer or body of unfrozen ground occurring in a permafrost area due to a local anomaly in thermal, hydrologic, hydrogeologic, or hydrochemicalconditions. Talik may be between the active layer and the top of the permafrost (when winter freezing does not penetrate deeper than the active layer), an isolated mass of unfrozen ground within the permafrost, a closed body below a thermokarst lake, or an open body with connection to the regional groundwater (see Figure 7-5 forexamples) (USGS 1993, Müller-Petke and Yaramanci 2015). Taliks can conduct water between areas of other thawed zones, channeling water through permafrost (Carlson and Barnes 2011). Surface water and supra- permafrost groundwater can follow ice wedges in permafrost and create beaded streams, with beads on the intersections of ice wedges (USACE CRREL Permafrost Tunnel Research Facility website, see Pseudomorphs andThermal Erosions section).

Figure 7-7. Beaded stream in the North Slope.

Source: Bill O'Connell

Generally, below the active layer, ground temperatures depend on the geothermal gradient and, if they are lower than freezing, the soil is permanently frozen or permafrost. Continuous permafrost in Alaska can be found in the North Slope beginning at approximately the Brooks Range (USACE CRREL Permafrost Tunnel Research Center website, see the Permafrost Zones section) as depicted in Figure 7-7. Discontinuous, sporadic, and isolated permafrost covers nearly the entire rest of the state of Alaska (Jorgenson et al. 2008). Underlying permafrost may be subpermafrost groundwater.

Ice-rich permafrost found in the Arctic Coastal Plain can contain up to 90% ice by volume (Schnabel, Goering, and Dotson 2020, Kanevskiy et al. 2011). Thermokarst is the process of massive ice degradation that creates large voids leading to subsidence. This can lead to widespread terrain collapse. The National Park Service created a video discussing thermokarst, associated terrain features, and how they monitor thermokarst activity in Alaska.

Freeze and thaw cycles tend to increase the downward migration of contaminants through cryogenic expulsion and influence the distribution of disconnected petroleum blobs (Barnes and Chuvilin 2008).

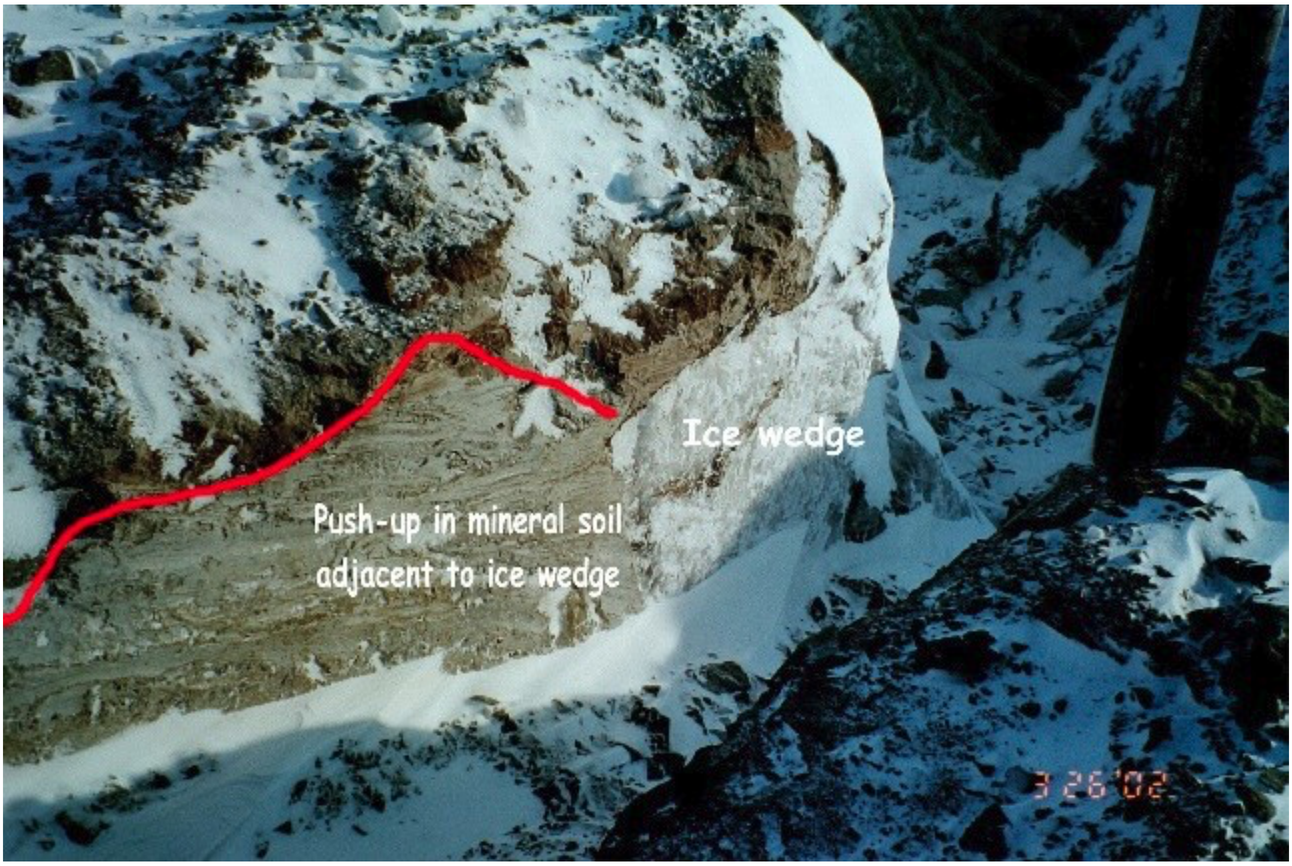


Figure 7-8. Ice wedge intrusion

Source: Lori Aldrich, ADEC

Permafrost discontinuities can be caused by differential thawing due to changes in the thermal regime at the ground surface (Carlson and Barnes 2011). The cumulative effects of climate change and construction in the permafrost can result in substantial increased degradation of permafrost (SEARCH 2018).

2.12.2.3 Effect of Permafrost Thaw and Temperature Instability on Contaminated Sites

Subsidence and terrain instability add complications to remedial design and implementation. They can diminish the load-bearing capacity of structures (Schnabel, Goering, and Dotson 2020, Jones et al. 2013) or reveal old, buried contaminants not previously identified. Subsidence can create new migration pathways for the contaminants, and exposure pathways for human health and the environment. Subsidence and erosion are accelerated by surface-water movement and can change surface drainage patterns (Figure 7-10) (SEARCH 2018).

Figure 7-9. Ice wedge polygons.

Source: Bill O'Connell, ADEC

Permafrost thaw can thin the permafrost barrier to subpermafrost groundwater. Surface water infiltrates deeper and contaminant migration to the vegetative rooting zone is more likely (Cater 2010). Deeper drainage allows surface soil and vegetation to dry out (NOAA 2016). Once the contaminant has migrated to this depth and at concentrations toxic to plants, remediation is limited to soil excavation for off-site disposal (Barnes 2015).

Permafrost can affect water distribution, movement, and storage capacity, controlling zones of recharge and groundwater flow pathways (Carlson and Barnes 2011). The Alaska DEC Contaminated Sites Program has made a general determination that the presence of continuous permafrost is a barrier to the downward migration of contaminants to groundwater (ADEC 2019). But as continuous permafrost thaws, the amount of frozen ground decreases, the permafrost becomes discontinuous, and this conceptual model becomes less reliable.

Water can move laterally through taliks, or vertically migrate into an ice wedge then laterally tunnel within the ice wedge and surrounding permafrost (USACE CRREL Permafrost Tunnel Research Facility). Migration can occur through cracks, or macropores left when the ice melts. The intrusion of water may mobilize contaminants, saturated sediments, and dissolved minerals and cause thermal erosion of the permafrost, or it could re-freeze and form thermokarst-cave ice and deposit the sediments around the ice.

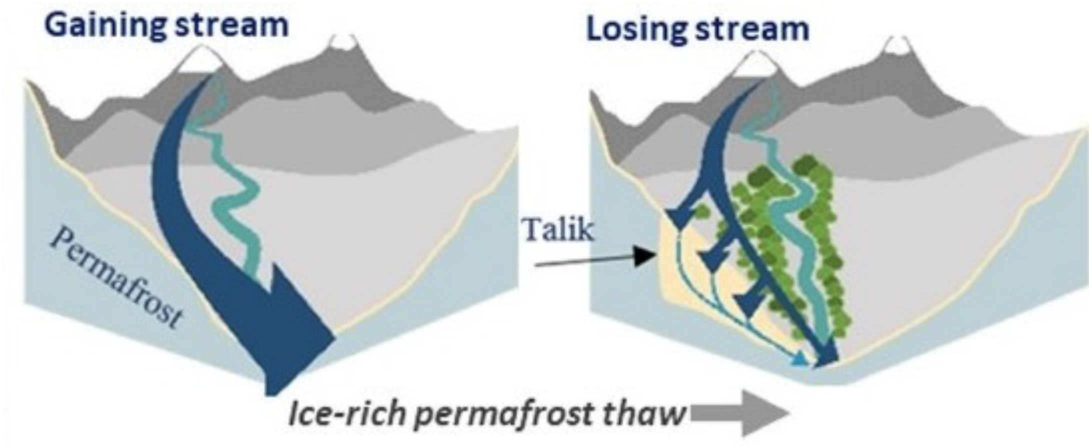


Figure 7-10. Vertical movement of groundwater through a talik.

Source: *Liljedahl et al. (2020)*

Once supra-permafrost and subpermafrost groundwater are connected, vertical mixing can occur in both directions. As shown in Figure 7-12, subpermafrost groundwater can even recharge supra-permafrost groundwater, diluting plume concentrations locally and changing plume flow (Carlson and Barnes 2011). Melt water comingled with the contaminant plume may also create a larger plume than originally identified. In short, plume configuration may be substantially different from what the regional hydrology trends would predict due to localized variations in the groundwater flow direction and even the potential for channeling in a direction other than regional groundwater trends (Carlson and Barnes 2011). Channeling or other changes in groundwater flow direction may move contaminant plumes from an area with relatively low potential exposures to an area with relatively high potential exposures. As the permafrost and ice conditions change over time, the plume location and dynamics may respond and change, making it difficult to design effective treatment and monitoring systems (Barnes and Biggar 2008).

Infrastructure in these areas can survive only if the underlying permafrost is protected. Protection includes reducing risk of thaw and ensuring the permafrost that remains frozen does not increase in temperature. Often engineering designs are created using 30 years of historical climate data for estimating future impacts of infrastructure with a service life of the same duration (SEARCH 2018). This approach is not sustainable or climate-resilient, as warming in the Arctic is happening more rapidly than is represented by the historical data (SEARCH 2018). For most infrastructure, engineering designs with a 15-year rehabilitation and replacement cycle allow engineers to adapt to changing conditions (NOAA 2016). Incorporating adaptation into rehabilitation cycles could save 10–45% of the expected costs of climate change (NOAA 2016).

Cold soil temperatures will slow the weathering of compounds in the subsurface, and cold groundwater temperatures reduce the solubility of some contaminants (Barnes and Biggar 2008). Cleanup levels in the Arctic are often developed with temperature effects on contaminant dispersal and breakdown in mind. As the site thermal regime changes, the contaminants may become more available, change phase, or convert into more toxic versions, potentially warranting an adjustment of cleanup levels and remedial goals.

7.12.2.4 Effect of Remedy Implementation on Thawing Permafrost

Any disturbance of the active layer can change the thermal regime. Removal of the vegetated topsoil drastically changes the overall thermal conductivity of the soil, resulting in thawing of underlying permafrost soils (Linell 1973). Excavation and backfill is a common remedial activity. If the thaw depth exceeds the lower boundary of the excavation over ice-rich permafrost, the ice features may thaw (Barnes 2015). Large quantities of clean native soil for backfilling may not be easily accessible, but backfilling with soil that is characteristically different from the native soil will further alter the thermal regime (Barnes 2015). Both may change the underlying permafrost condition or create thermokarsting (Barnes 2015). Barnes (2015) found that this can be mitigated in part by adding native soil on top of nonnative fill to the depth of tundra roots, about 1.6 feet (Barnes 2015). Capping with a relatively thin layer of native fill reduces the maximum depth of thaw by at least 3.6 feet (Barnes 2015), and aids in establishing native vegetation, a natural insulator, which will further reduce the maximum thaw depth over time.

Disturbance of the active layer through excavation creates a negative feedback loop, encouraging more permafrost thaw, which can create deeper drainage, moving contaminants to the rooting zone, leaving excavation as the primary effective remedial technique. This possibility should be part of any land-use or engineering planning considerations.

7.12.2.5 Secondary Impacts from Thawing Permafrost

Changes in the landscape due to permafrost thaw can create new habitat for some flora and fauna and attract them to the site, while also encouraging existing animals to leave the area (SEARCH 2018). Saturated soils resulting from permafrost thaw and ice melt can lead to slowly moving landslides (SEARCH 2018). Thermokarst development can result in erosion. Thawing permafrost near a coastline combined with increases in sea-level rise (Section 7.9) and storm surge (Section 7.11), and decreases in sea ice can lead to dramatically increased rates of coastal erosion (Section 7.6) and flooding (Section 7.5) (NOAA 2016). Salt-water intrusion into supra- and subpermafrost groundwater could affect the freezing point of the water and melting point of the surrounding ice. Increasingly warm permafrost and drying vegetation and soil can lead to increased wildfire risk (Sections 7.7 and 7.8) (NOAA 2016).

Remedial projects in streams or other water bodies near permafrost may be vulnerable to the effects of permafrost thaw, even though the contaminant and/or infrastructure for treatment is not directly in the permafrost. Permafrost thaw and accompanying bank erosion (Section 7.6) deliver more sediment into streams and rivers, impacting invertebrate productivity, water temperature, and water chemistry (SEARCH 2018) and therefore altering the degradation potential of the contaminant, and potentially the migration of the contaminant.

7.12.3 Assessing Vulnerability

The vulnerability of remediation sites to permafrost thaw should be assessed. See Sections 6.1.3 and 6.1.4.1 for an overview of how to conduct an exposure assessment, and Sections 6.2.3 and 6.2.5.1 for an overview of when and how to conduct a vulnerability assessment. In addition to reviewing weather records and forecasts, trends can be evaluated.

- Identify the permafrost characteristics and thaw stability of the soil across the entire footprint of planned or existing infrastructure and known contaminant location (Schnabel, Goering, and Dotson 2020).
- Use online resources for digital elevation models and permafrost predictive maps.
    - Elevation data can be found at Alaska's Division of Geological & Geophysical Surveys or the University of Minnesota's Polar Geospatial Center.
    - The University of Alaska Fairbanks Geophysical Institute Permafrost Laboratory maintains a near real-time data set and interactive online graphs available to the public of temperatures (both air/surface and borehole), soil pit temperature and water content, and snow depth for various locations across Alaska, along with links to many other resources and maps.
    - Temperature and precipitation projections, frequency of extreme temperature, and permafrost risksand hazards are accessible as GIS data sets through the Alaska Climate Adaptation Science Center.
    - The Denali Commission has identified communities at risk from thawing permafrost in Alaska, published in the Statewide Threat Assessment (University of Alaska Fairbanks Institute of Northern Engineering 2019).

    - By 2023, the Permafrost Discovery Gateway will provide a browser-based platform for visualizing and exploring data in Arctic regions—from the historical and predictive modeling perspectives down to the submeter scale (Schnabel, Goering, and Dotson 2020).
- Sites vulnerable to permafrost thaw may also be vulnerable to storm surge (Section 7.11), evapotranspiration (Section 7.10), bank and shoreline erosion (Section 7.6), flooding (Section 7.5), fluctuating groundwater elevation levels (Section 7.4), sea-level rise (Section 7.9), wind (Section 7.2), or wildfires (Sections 7.7 and 7.8). Review of the SBMPs for those events is encouraged.
- If the cleanup site is near but not overlying permafrost, evaluate vulnerability to secondary impacts from permafrost thaw (Section 7.12.2.5).

7.12.4 Planning and Prioritizing Resilience and Sustainability

- Assume the permafrost at the site will thaw over time and design the remedy and any infrastructure with flexibility to withstand destabilizing ground conditions or adapt the existing design.

7.12.4.1 Site Characterization

- Characterize the tundra terrain. Walker (1983) is a well-regarded reference for tundra characterization.
- Characterize the boreal forest type.
- Characterize the presence, abundance, type, and location of subsurface ice (Jorgenson et al. 2015). Use remote sensing methods, such as Lidar, or historical data as much as possible to avoid physically disturbing the terrain.
- Use geophysical surveys over the entire footprint of the remedial site at the beginning of the investigation to identify optimal locations for investigative boreholes to minimize destructive activity in the tundra (Schnabel, Goering, and Dotson 2020). Ground penetrating radar is a common method for identifying the top of the permafrost layer.
- Use electrical resistivity to identify subsurface ice bodies and characterize the physical state of interstitial water (Schnabel, Goering, and Dotson 2020). Electrical resistivity surveys can show the health of permafrost and in particular, taliks in the subsurface or salty liquids in permafrost. Direct current electrical resistivity tomography (ERT) is recommended for a shallow survey. When deeper information is required, the very low frequency electromagnetic tools are very useful.
- Consider conducting fly-over electromagnetic surveys by helicopter for large-scale cleanups or infrastructure planning (Daanen et al. 2016, USGS 2011).
- Characterize the local groundwater flow using stable isotope tracers with a monitoring well network.
- Decommission boreholes in a manner that preserves the thermal regime.
- Sample nearby surface water for the contaminants of concern to determine if supra-groundwater flow to the water body has occurred. This is important even if the water body is not downgradient from the source or in alignment regional hydrology.

7.12.4.2 CSMs

- Evaluate which landscape-scale changes are anticipated in the vicinity of and over the design life of the infrastructure component (Schnabel, Goering, and Dotson 2020).
    - Include the likelihood for thermokarst development, subsidence, and thermal erosion at the site.
    - Consider that subsidence may modify topography and hydrology and change the surface-water drainage patterns for the site.
    - Include drying surface soil and vegetation in the evaluation of contaminant availability andmigration.
- Consider how contaminant migration might be affected by permafrost thaw and secondary impacts (Section 7.12.2.5).
    - Weigh the risks of contaminant migration after thaw against the risks of destroying tundra andcreating additional thaw.

    - If contamination is on the coast, determine if the coastline is subject to sea-level rise (Section 7.9) or increased erosion (Section 7.6) and whether more aggressive remediation of the contaminant is warranted prior to failure of the coastline and release into the open ocean.
    - Evaluate in situ treatment techniques to eliminate the ongoing need for containment.
    - Evaluate how the landscape is expected to change (for example, from dry to wet) and consider howthe expected changes over time may impact exposure pathways and mitigation measures, whether planned or already installed.
- Consider the soil and groundwater temperature and whether they are likely to increase over time, affecting the contaminant cleanup levels. Use the Alaska Climate Adaptation Science Center Climate and Weather Tools.
- Consider that methane may become an additional contaminant of concern at the site, and/or create additional site hazards if released from permafrost as it thaws.

7.12.5 Remedy Design and Implementation

- To the extent practical and allowed by regulating entities, complete all work in the winter.
  Minimize surface disturbances, including compaction and the footprint of any construction.
    - Retain the active layer and vegetation where possible to serve as insulation for the underlying permafrost.
    - Locate structures in areas of the site least sensitive to thermokarst—for example, on coarse-grained soil, such as gravels free of ice wedges, which will have minimal settlement and maintain foundationstrength when the pore ice melts. Dry tundra or fine-grained soil will also generally have minimal settlement (USACE CRREL Permafrost Tunnel Research Facility, see Permafrost Thaw-Stability section).
- Minimize soil compaction to avoid affecting site drainage pattern and thermal changes. The following protective measures are from Cater (2010):
    - Limit foot and vehicle travel on all tundra types as much as possible, especially in the same area, byusing a different pathway to enter and exit the site.
    - Use snow ramps to access tundra from gravel roads and pads.
    - Use existing infrastructure and roads whenever possible.
    - When existing infrastructure is not available:
        - For high foot-traffic areas plan to use boardwalks light enough to be moved manually, sothey can be easily moved around the site as needed, and removed at project completion.
        - Use snowshoes when repeated trips on foot cannot be avoided.
        - For light equipment consider using compressed snow or ice pads or other workingplatforms as appropriate.
        - For heavy equipment consider using appropriately designed ice pads and/or interconnected rig mats as appropriate.
- Follow the guidelines provided by ADNR for tundra travel and obtain a permit for construction of snow ramps, ice roads, and ice pads, and for any vehicle traveling on tundra on state-owned land on the North Slope during any season. Visit the ADNR Tundra Travel website to view current tundra conditions, sign up to receive email notifications about travel in the tundra, and find appropriate contacts to obtain off-road travel permits.
    - Do not use vehicles to cross ponds, lakes, or the wetlands immediately bordering these areas.
    - Avoid crossing areas where more than 3 inches of standing water are present.
    - Avoid making minimum-radius turns with sharp articulations with vehicles.
- Develop an infrastructure rehabilitation cycle of 15 years maximum and incorporate climate adaptation into it.
- Install barriers to replace permafrost where contaminants are water-soluble to prevent subsurface migration.
- For surficial spills where permafrost has thawed, evaluate whether cleanup methods other than flooding and flushing are appropriate (Lukin et al. 1999). If flooding or flushing are used, consider using naturally occurring surface waters pumped from strategic points to the spill, and/or cool the water to 0°C.
- Design for cleanup levels appropriate for soil and groundwater with warmer temperatures. Identify the infrastructure thermal processes and minimize or insulate them to the extent practicable.

- Identify if any trails through the tundra exist on the site, which may be used by wildlife or for harvest activities (SEARCH 2018).
    - Locate infrastructure or equipment away from trails.
    - Consider incorporating trail hardening and stabilization into the site design to add a social benefit (Section 5.9) to the cleanup.
- Use thermal modeling software to understand heat transfer in Arctic soil beneath planned infrastructure. There are models capable of simulating the progression of permafrost thaw that may occur as a response to either climate change or the placement of warm infrastructure (Schnabel, Goering, and Dotson 2020).
- Heated buildings, warm pipelines, or other warm structures should be separated from ice-rich permafrost to avoid inducing thawing (Schnabel, Goering, and Dotson 2020). Separate them from the ground surface by
    - placing them on a foundation with pilings that are frozen into the permafrost
    - creating a ventilated space under the structure
    - placing them on a thermal pile with passive cooling systems such as thermosiphons or an active cooling system such as a heat pump or solar energy. [Note: Be aware that pilings and thermosiphons are less effective where permafrost temperatures are warmer (Schnabel, Goering, and Dotson 2020). One advantage to thermal pilings is that they can be adjusted as the ground surface elevation changes over time from subsidence or heave (SEARCH 2018).
- If constructing the building on grade, install insulation and a cooling system (for example, mechanical refrigeration, ventilation ducts, thermosiphon cooling system) below the building footprint.
    - Design linear structures, like a road, with an embankment height that ensures that the annualsummer thaw will not penetrate the permafrost (Schnabel, Goering, and Dotson 2020).
    - Remove or pack snow to help release heat from the ground or conduct cold into the ground, respectively, and stabilize the permafrost prior to construction.
    - Use insulated Arctic pipe or heavily insulated utility corridors above the ground surface to protect permafrost from any warm flowing liquid in pipes.
- Install sensors to monitor the extent of changing pressures and stresses on structures or to monitor subsurface geophysical conditions relevant to infrastructure performance and failure (DOD 2019, NOAA 2016).
- Locate infrastructure and key equipment away from any potential path for a slow-moving frozen debris landslide.
- Consider permafrost with high ice content as thaw-unstable with the likelihood to cause structural failure for anything built on top of it (Schnabel, Goering, and Dotson 2020).
- Evaluate alternatives to trenching to limit the lateral extent of flow. Trenching may have drawbacks of disrupting the thermal regime and may cause thermokarst (Cater 2010). Trenching may also lead to further disturbances and contaminant migration if the trench intercepts a natural stream, river, or swale (Cater 2010).
- Do not use equipment larger than necessary.
- Remove soil only to the depth to which contaminants have infiltrated.
    - Where excavation is required in locations with ground ice, or suspected of containing ground ice, over-excavate to ensure the thaw depth does not exceed the lower boundary of the backfilled soils (Barnes 2015). This depth changes dramatically when the vegetation and organic layer are removed. We recommend using thermal modeling to find the appropriate depth of backfill.
- Complete excavations and backfilling before the active layer thaws (Barnes and Biggar 2008).
- Backfill excavations with material of similar particle size and relative amounts of organic matter, gravel, sand, and silt to the surrounding area (Barnes 2015, Cater 2010).
    - If large enough quantities of native fill are not available for backfilling, at a minimum place 1.6 feet of native fill on top of the fill material to finish bringing the excavation to grade. If native or local organic soils are not available, import nonnative peat soil in compressed bales for this purpose.
    - Place organic material on top of mineral soil for the maximum effect on the thermal regime.
    - Use cold soils and allow the backfill to freeze completely. Ensure cooling by removing snow cover if it accumulates after completion.

- Replace displaced tundra sod back into original divot, or transplant tundra sod to replace soil and vegetation that have been removed. Traditional ecological knowledge (TEK) for sodding techniques based on techniques for roofs and ice cellars may be applicable (Cater 2010).
- Maintain existing natural contours and surface-water flow patterns.
- Consider the microclimate of the area you are revegetating and choose appropriate native plants and/or local seed sources.

7.12.8 OM&M

- Continue monitoring site soil temperature, soil moisture content, ice, and hydrologic conditions, including periodic sampling of nearby surface waters for contaminants of concern.
- Continue monitoring groundwater for changes in temperature, flow direction, or contaminant distribution.
- Consider monitoring for methane as a new contaminant of concern if permafrost thaw progresses or subsurface conditions warm.
- Evaluate landscape changes periodically. Containment strategies and/or cleanup levels may need to be revisited and/or refined over time due to landscape changes.
- Monitor infrastructure for frost heaving and/or subsidence.
- Implement the infrastructure rehabilitation cycle every 15 years at the most.
- Monitor sensors to identify the extent of changing pressures and stresses on structures or subsurface geophysical conditions relevant to infrastructure performance and failure and conduct rehabilitation when a threshold is reached (DOD 2019, NOAA 2016).
- Minimize surface disturbances, including compaction, and retain the active layer and vegetation where possible to serve as insulation for the underlying permafrost.

8. Recommendations for the Future

This document has captured a great deal of information and resources available with regard to SRR at the time of its publication, but it is by no means comprehensive in its scope. In discussion with the members of the SRR Team as to what areas they believed could use further research, the following topics were indicated:

- Local discussion of tradeoffs and the balance between the prongs of sustainability (economic/social/environmental). Site decisions vary from site to site, community to community, and understanding the local acceptance of risks can lead to a better decision overall.
- Implementation of more of a risk management approach, bringing in more relevant local information wherepossible to more thoroughly evaluate site actions.
- Demonstration of the value that SRR techniques can bring—publish additional case studies to show that value/success. Also show case studies where remedy has been confounded by extreme events (weather, wildfire, climate change, etc.). Research and publish evaluation of extreme events on existing remedial systemsto assist others in making sound decisions.
- Additional research/examples and focus on adaptive capacity. Publish the research to increase knowledge and awareness so that others can make a case for using SRR techniques.
- Development of metrics to track progress on goals of SRR actions.
- Development of further guidance or standardized methods for conducting vulnerability assessments.
- Better examples of intentional *resiliency* implementation in case studies. Provide less than perfect examples ofresiliency planning and show how partial success can be measured.
- Encouragement of periodic site reviews that include an evaluation of resiliency.
- Encouragement of greater focus on SRR in design phase of site work.

9. References

ADEC. 2019. “Establishing Arctic Zone Cleanup Levels.” Alaska Department of Environmental Conservation, Division of Spill Prevention and Response. Technical Memorandum. http://dec.alaska.gov/media/15699/arctic-zone-cleanup-levels-tech-memo-april-2019.pdf.

Alexander, Sasha, James Aronson, Oliver Whaley, and David Lamb. 2016. “The relationship between ecological restoration and the ecosystem services concept.” Ecology and Society 21 (1). doi: 10.5751/ES-08288-210134.

ASCE. 2014. “Flood Resistant Design and Construction.” ASCE/SEI 24-14. American Society of Civil Engineers. https://doi.org/10.1061/9780784413791.

ASCE. 2016. “Minimum Design Loads and Associated Criteria for Buildings and Other Structures.” ASCE 7. American Society of Civil Engineers.

ASTM. 2013a. “Standard Guide for Integrating Sustainable Objectives into Cleanup.” E2876-13. American Society for Testing and Materials. https://www.astm.org/Standards/E2876.htm.

ASTM. 2013b. “Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process.” E1527-13. West Conshohocken, PA: ASTM International. https://www.astm.org/Standards/E1527.htm.

ASTM. 2015. “Standard Guide for Climate Resiliency Planning and Strategy.” E3032-15e1. American Society for Testing and Materials. https://www.astm.org/Standards/E3032.htm.

ASTM. 2016. “Standard Guide for Greener Cleanups.” E2893-16. American Society for Testing and Materials. https://www.astm.org/Standards/E2893.htm.

ATSDR. 2011. “Principles of Community Engagement, 2nd edition.” NIH Publication 11-7782. Agency for Toxic Substances and Disease Registry. https://www.atsdr.cdc.gov/communityengagement/.

Bardos, R. P., S. Jones, I. Stephenson, P. Menger, V. Beumer, F. Neonato, L. Maring, U. Ferber, T. Track, and K. Wendler. 2016. “Optimising value from the soft re-use of brownfield sites.” Sci Total Environ 563-564:769-82. doi: 10.1016/j.scitotenv.2015.12.002.

Barnes, D.L. , and E. Chuvilin. 2008. “Petroleum migration in permafrost affected regions.” In Permafrost Soils, edited by R. Margesin, 263-278. Springer Verlag.

Barnes, David L. 2015. “Soil thermal regime after fuel spill cleanup response in a continuous permafrost zone.” Polar Record 52 (1):98-107. doi: 10.1017/S0032247415000297.

Barnes, David L., and Kevin Biggar. 2008. “Movement of petroleum through freezing and frozen soils.” In Bioremediation of Petroleum Hydrocarbons in Cold Regions, edited by David L. Barnes, Dennis M. Filler and Ian Snape, 55-68. Cambridge, UK: Cambridge University Press.

Bhargava, M, and R Sirabian. 2013. “SiteWise™ version 3 users guide.” UG-0000-ENV. Batelle Memorial Institute, Naval Facilities Engineering Command.

Bladon, Kevin D., Uldis Silins, Michael J. Wagner, Micheal Stone, Monica B. Emelko, Carl A. Mendoza, Kevin J. Devito, and Sarah Boon. 2008. “Wildfire impacts on nitrogen concentration and production from headwater streams in southern Alberta’s Rocky Mountains.” Canadian Journal of Forest Research 38 (9):2359-2371. doi: 10.1139/x08-071.

California Governor’s Office of Planning and Research. 2018. “Planning and Investing for a Resilient California. AGuidebook for State Agencies.” California Governor’s Office. https://www.opr.ca.gov/docs/20180313-Building_a_Resilient_CA.pdf.

Carlson, Andrea E., and David L. Barnes. 2011. “Movement of trichloroethene in a discontinuous permafrost zone.” Journal of Contaminant Hydrology 124 (1):1-13. doi: 10.1016/j.jconhyd.2010.11.002.

Cassin, Jan. 2019. “Color coordinating: How urban green infrastructure can build resilience.” https://www.greenbiz.com/article/color-coordinating-how-urban-green-infrastructure-can-build-resilience.

Cater, Timothy C. 2010. “Tundra Treatment Guidelines: A Manual for Treating Oil and Hazardous Substance Spills To Tundra, 3rd ed.”. Juneau, Alaska: Alaska Department of Environmental Conservation. https://dec.alaska.gov/spar/ppr/response-resources/tundra-treatment/.

CL:AIRE. 2020. “CL:AIRE Leading sustainable land reuse.” https://www.claire.co.uk/home/about-us/sharing-knowledge-and-developing-people.

Claypool, John E., and Scott Rogers. 2012. An Overview of Public Domain Tools for Measuring the Sustainability of Environmental Remediation – 12060, Conference: WM2012: Waste Management 2012 conference on improving the future in waste management, Phoenix, AZ (United States), 26 Feb – 1 Mar 2012; Other Information: Country of input: France; 10 refs.: ; WM Symposia, 1628 E. Southern Avenue, Suite 9-332, Tempe, AZ 85282 (United States).

CNT. 2011. “The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits.” Center for Neighborhood Technology https://www.cnt.org/publications/the-value-of-green-infrastructure-a-guide-to-recognizing-its-economic-environmental-and.

Comberti, C., T. F. Thornton, V. Wyllie de Echeverria, and T. Patterson. 2015. “Ecosystem services or services to ecosystems? Valuing cultivation and reciprocal relationships between humans and ecosystems.” Global Environmental Change 34:247-262. doi: https://doi.org/10.1016/j.gloenvcha.2015.07.007.

CRCCARE. 2018. “Guideline on Performing Cost-Benefit and Sustainability Analysis of Remediation Options.” Cooperative Research Centre for Contamination Assessment and Remediation of the Environment. https://www.crccare.com/files/dmfile/GuidelineonpeformingCBandSAofremediationoptions_Rev0.pdf.

Cundy, A. B., R. P. Bardos, A. Church, M. Puschenreiter, W. Friesl-Hanl, I. Müller, S. Neu, M. Mench, N. Witters, and J. Vangronsveld. 2013. “Developing principles of sustainability and stakeholder engagement for “gentle” remediation approaches: The European context.” Journal of Environmental Management 129:283-291. doi: 10.1016/j.jenvman.2013.07.032.

Daanen, R.P., A.M. Emond, A.K. Liljedahl, Katey Walter-Anthony, D.L. Barnes, Vladimir Romanovsky, and G.R.C. Graham. 2016. “Use of airborne electromagnetic geophysical survey to map discontinuous permafrost in Goldstream Valley (poster).” American Geophysical Union Fall Meeting, San Francisco, California. https://doi.org/10.14509/29814.

DNREC. 2012. “Preparing for Tomorrow’s High Tide. Sea Level Rise Vulnerability Assessment for the State of Delaware.” Delaware Department of Natural Resources and Environmental Control. http://www.dnrec.delaware.gov/coastal/Documents/SeaLevelRise/AssesmentForWeb.pdf.

DNREC. 2020. “State of Delaware. Brownfields Grant Funding Eligible Expenses. Guidance and Reimbursement Application Instructions.” New Castle, DE: Delaware Department of Natural Resources and Environmental Control. http://www.dnrec.delaware.gov/dwhs/SIRB/Documents/BFG%20Funding%20ExpenseGuidance%20072720.pdf.

DOD. 2012. “Manual Number 4715.20: Defense Environmental Restoration Program (DERP) Management.”. Washington, D.C.: United States Department of Defense. https://www.denix.osd.mil/fuds/front-page-documents/dodm-4715-20/01_DoDM_471520_DERP-Manual_9March2012.pdf.

DOD. 2019. “Report on Effects of a Changing Climate to the Department of Defense. January 2019.” United States Department of Defense. Office of the Under Secretary of Defense for Acquisition and Sustainment.

DTSC. 2018. “DTSC Interim Summary Report of Woolsey Fire. Impacts at SSFL & Surrounding Communities Sampling Results.” Sacramento, CA: California Department of Toxic Substances Control and California Environmental Protection Agency. https://dtsc.ca.gov/wp-content/uploads/sites/31/2019/03/DTSC-Interim-Summary-Report-for-Woolsey-Fire-complete-12-18-18.pdf.

Ecology. 2017. “Adaptation Strategies for Resilient Cleanup Remedies: A Guide for Cleanup Project Managers to Increase the Resilience of Toxic Cleanup Sites to the Impacts from Climate Change. Toxics Cleanup Program. Publication no. 17-09-052.” Olympia, WA: Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/documents/1709052.pdf.

Ellis, D., and P. Hadley. 2009. “Sustainable Remediation White Paper Integrating Sustainable Principles, Practices, and Metrics Into Remediation Projects.” Remediation 19 (3):5-114. doi: 10.1002/rem.20210.

ESTCP. 2011. “Final Report. Assessing Alternative Endpoints for Groundwarer Remediation at Contaminated Sites.” ESTCP Project ER-200832. Environmental Security Technology Certification Program.

Farkas, Alan L., and Christopher S. Frangione. 2010. “Growth for design and construction markets stops in 2009.” Environmental Engineer 46 (1):21-24.

Favara, Paul, Dick Raymond, Matthew Ambrusch, Arianna Libera, Gerlinde Wolf, John A. Simon, Barbara Maco, Elizabeth R. Collins, Melissa A. Harclerode, Amanda D. McNally, Reanne Ridsdale, Maile Smith, and Lyndsey Howard. 2019. “Ten years later: The progress and future of integrating sustainable principles, practices, and metrics into remediation projects.”

Remediation Journal 29 (4):5-30. doi: 10.1002/rem.21612.

FEMA. 2013. “Risk Management Series Snow Load Safety Guide.” FEMA P-957. Washington, D.C.: Federal Emergency Management Agency. https://www.fema.gov/sites/default/files/2020-07/fema_snow_load_2014.pdf.

FEMA. 2015. “Federal Flood Risk Management Standard.” Federal Emergency Management Agency.

Fidler, Courtney. 2010. “Increasing the sustainability of a resource development: Aboriginal engagement and negotiated agreements.” Environment, Development and Sustainability 12 (2):233-244. doi: 10.1007/s10668-009-9191-6.

GAO. 2019. “SUPERFUND: EPA Should Take Additional Actions to Manage Risks from Climate Change.” GAO-20-73. Washington, D.C.: US Government Accountability Office. https://www.gao.gov/products/GAO-20-73.

Greenberg, Michael, and M. Jane Lewis. 2000. “Brownfields redevelopment, preferences and public involvement: A case study of an ethnically mixed neighbourhood.” Urban Studies 37:2501-2514. doi: 10.1080/00420980020080661.

Hadley, Paul W., Peter Gathungu, Juan T. Koponen, Perry Myers, and Jesus I. Sotelo. 2014. “Improving objectives for cleanup sites.” Remediation Journal 24 (4):7-26. doi: 10.1002/rem.21401.

Harclerode, Melissa A., Tamzen W. Macbeth, Michael E. Miller, Christopher J. Gurr, and Teri S. Myers. 2016. “Early decision framework for integrating sustainable risk management for complex remediation sites: Drivers, barriers, and performance metrics.” Journal of Environmental Management 184:57-66. doi: 10.1016/j.jenvman.2016.07.087.

Harclerode, Melissa, D. Reanne Ridsdale, Dominique Darmendrail, Paul Bardos, Filip Alexandrescu, Paul Nathanail, Lisa Pizzol, and Erika Rizzo. 2015. “Integrating the social dimension in remediation decision-making: State of the practice and way forward.” Remediation Journal (Winter 2015):11-42. doi: 10.1002/rem.21447.

Holland, Karin, Raymond Lewis, Karina Tipton, Stella Karnis, Carol Dona, Erik Petrovskis, Louis Bull, Deborah Taege, and Christopher Hook. 2011. “Framework of integrating sustainability into remediation projects.” Remediation Journal 21:7-38. doi: 10.1002/rem.20288.

Hu, Winnie. 2018. “A Billion-dollar investment in New York’s water. New York City’s water system moves over a billion gallons a day, nearly all of it unfiltered. A major investment aims to keep it that way.” The New York Times. https://www.nytimes.com/2018/01/18/nyregion/new-york-city-water-filtration.html.

Huntington, Thomas G., Peter K. Weiskel, David M. Wolock, and Gregory J. McCabe. 2018. “A new indicator framework for quantifying the intensity of the terrestrial water cycle.” Journal of Hydrology 559:361-372. doi: 10.1016/j.jhydrol.2018.02.048.

ISO. 2010. “Social Responsibility.” ISO 2600. International Standards Organization. https://www.iso.org/iso-26000-social-responsibility.html.

ITRC. 2000. “Emerging Technologies for Enhanced In Situ Biodenitrification (EISBD) of Nitrate-Contaminated Ground Water.” EISBD-1. Washington, D.C.: Interstate Technology and Regulatory Council. https://itrcweb.org/GuidanceDocuments/EISBD-1.pdf.

ITRC. 2002. “A Systematic Approach to In Situ Bioremediation in Groundwater, Including Decision Trees on In Situ Bioremediation for Nitrates, Carbon Tetrachloride, and Perchlorate.” ISB-8. Washington, D.C. : Interstate Technology and Regulatory Council. https://itrcweb.org/GuidanceDocuments/ISB-8.pdf.

ITRC. 2004. “Remediation Process Optimization: Identifying Opportunities for Enhanced and More Efficient Site Remediation.” RPO-1. Washington, D.C. : Interstate Technology and Regulatory Council. https://www.itrcweb.org/GuidanceDocuments/RPO-1.pdf.

ITRC. 2005. “Overview of In Situ Bioremediation of Chlorinated Ethene DNAPL Source Zones.” BIODNAPL-1. Washington, D.C. : Interstate Technology and Regulatory Council. https://itrcweb.org/GuidanceDocuments/BioDNAPL-1.pdf.

ITRC. 2006. “Technology Overview. Life Cycle Cost Analysis.” RPO-2. Washington, D.C.: Interstate Technology and Regulatory Council. https://www.itrcweb.org/GuidanceDocuments/RPO-2.pdf.

ITRC. 2007. “In Situ Bioremediation of Chlorinated Ethene DNAPL Source Zones: Case Studies.” BIODNAPL-2. Washington, D.C. : Interstate Technology and Regulatory Council. https://itrcweb.org/GuidanceDocuments/bioDNPL_Docs/BioDNAPL-2.pdf.

ITRC. 2008a. “Enhanced Attenuation: Chlorinated Organics.” EACO-1. Washington, D.C. : Interstate Technology and Regulatory Council. https://itrcweb.org/GuidanceDocuments/EACO-1.pdf.

ITRC. 2008b. “In Situ Bioremediation of Chlorinated Ethene: DNAPL Source Zones.” BIODNAPL-3. Washington, D.C. :

Interstate Technology and Regulatory Council. https://itrcweb.org/GuidanceDocuments/bioDNPL_Docs/BioDNAPL3.pdf.

ITRC. 2009. “Phytotechnology Technical and Regulatory Guidance and Decision Trees, Revised.” PHYTO-3. Washington, D.C. : Interstate Technology and Regulatory Council. https://itrcweb.org/GuidanceDocuments/PHYTO-3.pdf.

ITRC. 2011a. “Green and Sustainable Remediation: A Practical Framework.” GSR-2. Washington, D.C.: Interstate Technology & Regulatory Council, Green and Sustainable Remediation Team. https://itrcweb.org/GuidanceDocuments/GSR-2.pdf.

ITRC. 2011b. “Green and Sustainable Remediation: State of the Science and Practice.” GSR-1. Washington, D.C.: Interstate Technology Regulatory Council. https://www.itrcweb.org/GuidanceDocuments/GSR-1.pdf.

ITRC. 2011c. ” Project Risk Management for Site Remediation.” Interstate Technology & Regulatory Council, Remediation Risk Management Team: RRM-1. Washington D.C. https://itrcweb.org/GuidanceDocuments/RRM-1.pdf.

ITRC. 2017. “Remediation Management of Complex Sites.” RMCS-1. Washington, D. C.: Interstate Technology & Regulatory Council, Complex Sites Team. https://rmcs-1.itrcweb.org/.

ITRC. 2018a. “LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies.” LNAPL-3. Washington, D.C.: Interstate Technology Regulatory Council, Light, Non-Aqueous Phase Liquid Team. https://lnapl-3.itrcweb.org/.

ITRC. 2018b. “Stormwater Best Management Practices Performance Evaluation.” Stormwater-1. Washington, D.C. : Interstate Technology and Regulatory Council. Stormwater Team. https://stormwater-1.itrcweb.org/.

ITRC. 2020a. “Optimizing Injection Strategies and In-situ Remediation Performance.” OIS-ISRP-1. Washington, D.C. : Interstate Technology and Regulatory Council. https://ois-isrp-1.itrcweb.org/.

ITRC. 2020b. “Risk Communication Toolkit.” RCT-1. Washington, D.C. : Interstate Technology Regulatory Council. https://rct-1.itrcweb.org/.

Jenkins, Robin, Elizabeth Kopits, and David Simpson. 2006. “Measuring the Social Benefits of EPA Land Cleanup and Reuse Programs. Working Paper #06-03.” Washington, D.C.: U.S. Environmental Protection Agency. National Center for Environmental Economics https://19january2017snapshot.epa.gov/sites/production/files/2014-12/documents/measuring_the_social_benefits_of_epa_land_cleanup_and_reuse_programs.pdf.

Jones, Benjamin M., Courtney L. Amundson, Joshua C. Koch, and Guido Grosse. 2013. Thermokarst and thaw-related landscape dynamics — an annotated bibliography with an emphasis on potential effects on habitat and wildlife. In Open-File Report. Reston, VA. doi: 10.3133/ofr20131161.

Jorgenson, M. T., M. Kanevskiy, Y. Shur, N. Moskalenko, D. R. N. Brown, K. Wickland, R. Striegl, and J. Koch. 2015. “Role of ground ice dynamics and ecological feedbacks in recent ice wedge degradation and stabilization.” Journal of Geophysical Research: Earth Surface 120 (11):2280-2297. doi: 10.1002/2015JF003602.

Jorgenson, M., Kenji Yoshikawa, Mikhail Kanevskiy, Y. Shur, Vladimir Romanovsky, Sergey Marchenko, and Benjamin Jones. 2008. Permafrost Characteristics of Alaska + Map.

Kanevskiy, Mikhail, Yuri Shur, M. Jorgenson, Chien-Lu Ping, Daniel Fortier, Eva Stephani, and Matthew Dillon. 2011. “Permafrost of Northern Alaska.” Proceedings, Twenty-first International Offshore and Polar Engineering Conference:1179-1186.

Knoss, Trent. 2018. “How wildfires contaminate drinking water sources.” CU Boulder Today. https://www.colorado.edu/today/2018/06/19/how-wildfires-contaminate-drinking-water-sources.

Kramer, Ryan J., Lahouari Bounoua, Ping Zhang, Robert E. Wolfe, Thomas G. Huntington, Marc L. Imhoff, Kurtis Thome, and Genevieve L. Noyce. 2015. “Evapotranspiration trends over the eastern United States during the 20th century.” Hydrology 2 (2):93-111. doi: 10.3390/hydrology2020093.

Kumar, Girish , and Krishna R. Reddy. 2020. “Addressing climate change impacts and resiliency in contaminated site remediation.” Journal of Hazardous, Toxic, and Radioactive Waste 24 (4):04020026. doi: 10.1061/(ASCE)HZ.2153-5515.0000515.

LARWQCB. 2019. “Los Angeles Region Framework for Climate Change Adaptation and Mitigation. Potential Regulatory Adaptation and Mitigation Measures. April 2019.”. Los Angeles Regional Water Quality Control Board. https://www.waterboards.ca.gov/losangeles/water_issues/programs/climate_change/docs/2019/FrameworkPart2-PotentialReg ulatoryAdaptation_MitigationMeasures-final.pdf.

Letang, Shevon. 2017. “Community participation in brownfields redevelopment decision-making under the microscope: an analysis of three processes in Passaic County, New Jersey.” Psychosociological Issues in Human Resource Management 5 (2):51-95.

Libera, A., F. P. J. de Barros, B. Faybishenko, C. Eddy-Dilek, M. Denham, K. Lipnikov, D. Moulton, B. Maco, and H. Wainwright. 2019. “Climate change impact on residual contaminants under sustainable remediation.” Journal of Contaminant Hydrology 226:103518. doi: 10.1016/j.jconhyd.2019.103518.

Liljedahl, Anna K., Ina Timling, Gerald V. Frost, and Ronald P. Daanen. 2020. “Arctic riparian shrub expansion indicates a shift from streams gaining water to those that lose flow.” Communications Earth & Environment 1 (1):50. doi: 10.1038/s43247-020-00050-1.

Linell, K. A. 1973. “Long-term effects of vegetative cover on permafrost stability in an area of discontinuous permafrost.” Proceedings of Permafrost: North American Contribution to the Second International Conference, Yakutsk, USSR.

Lukin, James, Ron Hocking, Fred McAdams, Bruce McKenzie, Mary Cocklan-Vendl, and Alan Schuyler. 1999. “The Alaska Clean Seas Technical Manual.” International Oil Spill Conference Proceedings 1999 (1):905-908. doi: 10.7901/2169-3358-1999-1-905.

Maco, Barbara, Paul Bardos, Frederic Coulon, Emerald Erickson-Mulanax, Lara J. Hansen, Melissa Harclerode, Deyi Hou, Eric Mielbrecht, Haruko M. Wainwright, Tetsuo Yasutaka, and William D. Wick. 2018. “Resilient remediation: Addressing extreme weather and climate change, creating community value.” Remediation Journal 29 (1):7-18. doi: 10.1002/rem.21585.

Marchese, Dayton, Erin Reynolds, Matthew E. Bates, Heather Morgan, Susan Spierre Clark, and Igor Linkov. 2018. “Resilience and sustainability: Similarities and differences in environmental management applications.” Science of The Total Environment 613-614:1275-1283. doi: https://doi.org/10.1016/j.scitotenv.2017.09.086.

MassDEP. 2020. “310 CMR 40.0000: Massachusetts Contingency Plan (2020 proposed). 40.1005: Defining “Foreseeable Period of Time” for Purposes of a Permanent Solution.” Massachusetts Department of Environmental Protection. https://www.mass.gov/files/documents/2020/04/02/jud-lib-310cmr40.pdf.

McCarthy, Bethann. 2014. “Climate Change Resilience Plan. Resilience & Preparedness in State Government Project.” WD-14-02. New Hampshire Department of Environmental Services, Drinking Water & Groundwater Bureau.

MDPS. 2019. “Minnesota State Hazard Mitigation Plan Including Recommended Actions for Climate Change Adaptation.” St. Paul, MN: Minnesota Department of Public Safety. https://dps.mn.gov/divisions/hsem/hazard-mitigation/Documents/2019-mn-hmp-only.pdf.

Melillo, Jerry M., Terese Richmond, and Gary Yohe. 2014. “Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.” U.S.Global Change Research Program. http://nca2014.globalchange.gov.

Mielbrecht, Eric, and Katelyn Tarrio. 2019. “Massachusetts Climate Change and Hazardous Waste Site Screening.” Climate Adaptation Knowledge Exchange. https://www.cakex.org/documents/massachusetts-climate-change-and-hazardous-waste-site-screening.

Miller, I.M., Z. Yang, N VanArendonk, E. Grossman, G. S. Mauger, and H. Morgan. 2019. “Extreme Coastal Water Level in Washington State: Guidelines to Support Sea Level Rise Planning. A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, Pacific Northwest National Laboratory and U.S. Geological Survey.” Prepared for the Washington Coastal Resilience Project. https://cig.uw.edu/publications/extreme-coastal-water-level-in-washington-state-guidelines-to-support-sea-level-rise-planning/.

Milly, P. C. D., Julio Betancourt, Malin Falkenmark, Robert M. Hirsch, Zbigniew W. Kundzewicz, Dennis P. Lettenmaier, and Ronald J. Stouffer. 2008. “Stationarity is dead: Whither water management?” Science 319 (5863):573-574. doi: 10.1126/science.1151915.

Moore, Beth, Josh Silverman, Eric Bradley, and Yoel Rotterman. 2016. “DOE Climate Change Vulnerability and Adaptation Planning: Three Relevant Case Studies, 16056.” WM2016: 42. Annual Waste Management Symposium, Phoenix, AZ.

MSO. 2013. “Minneapolis Climate Action Plan.” City of Minneapolis Sustainability Office. http://www2.minneapolismn.gov/sustainability/climate-action-goals/climate-action-plan.

Müller-Petke, M., and U. Yaramanci. 2015. “11.13 – Tools and Techniques: Nuclear Magnetic Resonance.” In Treatise on

Geophysics (2nd ed), edited by Gerald Schubert, 419-445. Oxford: Elsevier.

NARA. 1994. “Executive Order 12898 – Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations.” Washington, D.C.: National Archives and Records Administration. https://www.archives.gov/files/federal-register/executive-orders/pdf/12898.pdf.

NARA. 2015. “Presidential Documents. Executive Order 13693—Planning for Federal Sustainability in the Next Decade.” Washington, D. C.: National Archives and Records Administration. https://www.fedcenter.gov/programs/eo13693/.

NARA. 2017. “Presidential Documents. Executive Order 13783 of March 28, 2017 Promoting Energy Independence and Economic Growth.” Washington, D. C.: National Archives and Records Administration. https://www.federalregister.gov/documents/2017/07/06/2017-14100/promoting-energy-independence-and-economic-growth-request-for-information.

NARA. 2018. “Presidential Documents. Executive Order 13834 of May 17, 2018 Efficient Federal Operations.” Washington, D. C.: National Archives and Records Administration. https://www.federalregister.gov/documents/2018/05/22/2018-11101/efficient-federal-operations.

NCDEQ. 2020. “North Carolina Climate Risk Assessment and Resilience Plan. Impacts, Vulnerability, Risks, and Preliminary Actions.” North Carolina Department of Environmental Quality. https://files.nc.gov/ncdeq/climate-change/resilience-plan/2020-Climate-Risk-Assessment-and-Resilience-Plan.pdf.

NHDES. 2016. “Drought Management Plan.” New Hampshire Department of Environmental Services. https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/drought-managementplan.pdf.

NIBS. 2018. “Natural Hazard Mitigation Saves: 2017 Interim Report.” Washington, D.C.: National Institute of Building Sciences.

NJDEP. 2018. “N.J.A.C. 7:26E. Technical Requirements for Site Remediation.” New Jersey Department of Environmental Protection. https://www.nj.gov/dep/rules/rules/njac7_26e.pdf.

NJDEP. 2019. “Technical Guidance for Preparation and Submission of a Conceptual Site Model.” New Jersey Department of Environmental Protection. https://www.nj.gov/dep/srp/guidance/srra/csm_tech_guidance.pdf.

NJDEP. 2020. “Scientific Report on Climate Change.” New Jersey Department of Environmental Protection. https://www.nj.gov/dep/climatechange/docs/nj-scientific-report-2020.pdf#page=6.

NOAA. 2015. “Guidance for Considering the Use of Living Shorelines.” National Atmospheric and Oceanic Administration. https://www.habitatblueprint.noaa.gov/wp-content/uploads/2018/01/NOAA-Guidance-for-Considering-the-Use-of-Living-Shorelines_2015.pdf.

NOAA. 2016. “Arctic Development and Transport. U. S. Climate Resilience Toolkit.” National Artmospheric and Oceanic Administration. https://toolkit.climate.gov/regions/alaska-and-arctic/arctic-development-and-transport.

NRC. 2003. Environmental Cleanup at Navy Facilities: Adaptive Site Management. Washington, D.C.: The National Academies Press. National Research Council.

NRC. 2005. “Contaminants in the Subsurface: Source Zone Assessment and Remediation.” Washington, D.C.: National Academies Press.

NRC. 2013. Alternatives for Managing the Nation’s Complex Contaminated Groundwater Sites. Washington, D.C.: National Research Council, The National Academies Press.

Nuttle, William K., and John W. Portnoy. 1992. “Effect of rising sea level on runoff and groundwater discharge to coastal ecosystems.” Estuarine, Coastal and Shelf Science 34 (2):203-212. doi: 10.1016/S0272-7714(05)80106-4.

NWCG. 2017. “Interagency Prescribed Fire Planning and Implementation Procedures Guide.” PMS 484. National Wildfire Coordinating Group. https://www.nwcg.gov/sites/default/files/publications/pms484.pdf.

O’Connell, Shannon, and Deyi Hou. 2015. “Resilience: A new consideration for environmental remediation in an era of climate change.” Remediation Journal 26 (1):57-67. doi: 10.1002/rem.21449.

Patel, K. 2019. “Water Cycle is Speeding Up Over Much of the U.S.” NASA Earth Observatory. https://earthobservatory.nasa.gov/images/145357/water-cycle-is-speeding-up-over-much-of-the-us.

Purvis, Ben, Yong Mao, and Darren Robinson. 2019. “Three pillars of sustainability: in search of conceptual origins.” Sustainability Science 14. doi: 10.1007/s11625-018-0627-5.

Reddy, K. R., and J.A. Adams. 2015. Sustainable Remediation of Contaminated Sites. New York: Momentum Press.

Reddy, K.R., G. Kumar, and Y.J. Du. 2019. “Risk, Sustainability and Resiliency Considerations in Polluted Site Remediation.” Proceedings of the 8th International Congress on Environmental Geotechnics: Volume 1. ICEG 2018 Environmental Science and Engineering.

Reddy, Krishna R., Claudio Cameselle, and Jeffrey A. Adams. 2019. Sustainable Engineering: Drivers, Metrics, Tools, and Applications. Hoboken, NJ: John Wiley & Sons, Inc.

Reddy, Krishna R., Bala Yamini Sadasivam, and Jeffrey A. Adams. 2014. “Social Sustainability Evaluation Matrix (SSEM) to Quantify Social Aspects of Sustainable Remediation.” In ICSI 2014, 831-841.

Ridsdale, D. Reanne, and Melissa Harclerode. 2019. “Stakeholder roadmap: A guide to effective active engagement using social methodologies (Platform Presentation).” Tenth International Conference on Remediation and Management of Contaminated Sediments, New Orleans, LA.

Ridsdale, D. Reanne, and Bram F. Noble. 2016. “Assessing sustainable remediation frameworks using sustainability principles.” Journal of Environmental Management 184 (Pt 1):36-44. doi: 10.1016/j.jenvman.2016.09.015.

RSG. 2016. “Final Report: Ohio DOT Infrastructure Resiliency Plan.” Ohio Department of Transportation. http://www.dot.state.oh.us/Divisions/Planning/Environment/Documents/Ohio%20DOT%20Infrastructure%20Resiliency%20Plan.pdf.

Schnabel, William E., Douglas J. Goering, and Aaron D. Dotson. 2020. “Permafrost engineering on impermanent frost.” The Bridge 50 (1). doi: https://www.nae.edu/228948/Permafrost-Engineering-on-Impermanent-Frost.

SEARCH. 2018. “How Is Permafrost Degradation Affecting Infrastructure? SEARCH Science Brief AA-018.” Fairbanks, AK: Study of Environmental Arctic Change. https://www.searcharcticscience.org/arctic-answers/permafrost-and-infrastructure/briefs#:~:text=Degradation%20of%20permafrost%E2%80%94perennially%20frozen,jeopardizing%20infrastructure%20at%20the%20surface.

SURF. 2009. “Sustainable remediation white paper—Integrating sustainable principles, practices, and metrics into remediation projects.” Remediation Journal 19 (3):5-114. doi: 10.1002/rem.20210.

Tecle, Aregai, and Daniel Neary. 2015. “Water quality impacts of forest fires.” Journal of Pollution Effects and Control 3 (3):1-7. doi: 10.4172/2375-4397.1000140.

Thun, R.I. 2019. “Remedy Resiliency to Extreme Weather Events.” Battelle Fifth International Symposium on Bioremediation and Sustainable Environmental Technologies, Baltimore, Maryland.

Torre-Jorgenson, M.T. , V. Romanovsky, J. Harden, Y. Shur, J. O’Donnell, E.A.G. Schuur, M. Kanevskiy, and S. Marchenko. 2010. “Resilience and vulnerability of permafrost to climate change.” Canadian Journal of Forest Research 40 (7):1219-1236. doi: 10.1139/x10-060.

U.S. Green Building Council. 2018. “RELi 2.0 Rating Guidelines for Resilient Design and Construction.”. U.S. Green Building Council. https://www.usgbc.org/resources/reli-20-rating-guidelines-resilient-design-and-construction.

UCCCRJ. 1987. “Toxic Wastes and Race in the United States. A National Report on the Racial and Socio-Economic Characteristics of Communities with Hazardous Waste Sites.” United Church of Christ, Commission for Racial Justice. https://www.nrc.gov/docs/ML1310/ML13109A339.pdf.

University of Alaska Fairbanks Institute of Northern Engineering. 2019. “Statewide Threat Assessment: Identification of Threats from Erosion, Flooding, and Thawing Permafrost in Remote Alaska Communities. Report # INE 19.03.” Prepared for the Denali Commission by the University of Alaska Fairbanks Institute of Northern Engineering, U.S. Army Corps of Engineers Alaska District, U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory. https://www.denali.gov/wp-content/uploads/2019/11/Statewide-Threat-Assessment-Final-Report-November-2019-1-2.pdf.

Urban Green. 2013. “Building Resiliency Task Force Report to Mayor Michael R. Bloomberg & Speaker Christine C. Quinn.”

USACE. 2007. “Beach Nourishment, How Beach Nourishment Projects Work. Shore Protection Assessment.” United States Army Corps of Engineers. https://www.iwr.usace.army.mil/Portals/70/docs/projects/HowBeachNourishmentWorksPrimer.pdf.

USACE. 2010. “Decision Framework for Incorporation of Green and Sustainable Practices into Environmental Remediation Projects. Interim Guidance 10-01.” United States Army Corps of Engineers. https://www.usace.army.mil/Portals/65/doc/Directorates/EMCX/DECISION%20FRAMEWORK%20FOR%INCORPORATION.pdf.

USAF. 2020. “Memorandum. Air Force Guidance Memorandum to AFI 32-7001. Environmental Management.” Department of the Air Force.

USAID. 2017. "Green Infrastructure Resource Guide." United States Agency for International Development. https://www.usaid.gov/sites/default/files/documents/1865/green-infrastructure-resource-guide.pdf.

USDOE. 2014. "DOE Climate Change Adaptation Plan." United States Department of Energy. https://www.energy.gov/sites/prod/files/2014/10/f18/doe_ccap_2014.pdf.

USDOE. 2016. "Climate Change Adaptation Plan – 2016 Interim Update." United States Department of Energy. https://www.energy.gov/sites/prod/files/2017/01/f34/2016%20DOE%20Climate%20Adaptation%20Plan_0.pdf.

USDOE. 2017. "DOE Climate Change Vulnerability Screening Guidance ". United States Department of Energy. https://www.energy.gov/management/spo/articles/does-vulnerability-screening-guidance-published.

USDOE. 2018. "Fiscal Year 2019 Site Sustainability Plan Guidance." United States Department of Energy. https://sustainabilitydashboard.doe.gov/PDF/Resources/2019%20Site%20Sustainability%20Plan%20Guidance.pdf.

USEPA. 2004. "Cleaning Up the Nation's Waste Sites: Markets and Technology Trends. 2004 Edition." EPA 542-R04-015. Washington, D.C.: United States Environemtal Protection Agency, Office of Solid Waste Emergency Response. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=30006II3.txt.

USEPA. 2007. "Risk Communication in Action. The Risk Communication Workbook." EPA 625/R-05/003. Washington, D.C.: United States Environmental Protection Agency. https://www.epa.gov/sites/production/files/2020-12/documents/risk-communication-risk-communication-workbook.pdf.

USEPA. 2008. "Green Remediation: Incorporating Sustainable Environmental Practices into Remediation at Contaminated Sites." EPA 542-R-08-002. Washington, D.C. : United States Environmental Protection Agency, Office of Solid Waste and Emergency Response. https://www.epa.gov/sites/production/files/2015-04/documents/green-remediation-primer.pdf.

USEPA. 2009. "Synthesis of Adaptation Options for Coastal Areas." Washington, D.C.: United States Environemtal Protection Agency, Climate Ready Estuaries Program. https://www.epa.gov/sites/production/files/2014-04/documents/cre_synthesis_1-09.pdf.

USEPA. 2011. "Environmental Cleanup Best Management Practices: Effective Use of the Project Life Cycle Conceptual Site Model." EPA 542-F-11-011. United States Environmental Protection Agency. https://www.epa.gov/sites/production/files/2015-04/documents/csm-life-cycle-fact-sheet-final.pdf.

USEPA. 2013a. "Climate Change Adaptation Technical Fact Sheet: Groundwater Remediation Systems." EPA 542-F-13-004. United States Environmental Protection Agency. https://semspub.epa.gov/work/HQ/175851.pdf.

USEPA. 2013b. "Implementing Stormwater Infiltration Practices at Vacant Parcels and Brownfield Sites." EPA 905-F-13-001. Washington, D.C.: United States Environmental Protection Agency. https://www.epa.gov/sites/production/files/2015-10/documents/brownfield_infiltration_decision_tool.pdf.

USEPA. 2013c. "Sustainable Materials Management in Site Cleanup. Technical Support Project Engineering Forum." EPA 542-F-13-001. United States Environmental Protection Agency. https://clu-in.org/greenremediation/docs/materials_management_issue%20paper.pdf.

USEPA. 2014. "Climate Change Adaptation Plans." EPA 100-K-14-001. Washington, D.C. : United States Environmental Protection Agency. https://www.epa.gov/sites/production/files/2015-08/documents/adaptationplans2014_508.pdf.

USEPA. 2015a. "Green Remediation Best Management Practices: An Overview." EPA 542-F-16-001. United States Environmental Protection Agency. https://clu-in.org/greenremediation/docs/GR_BMP_factsheet_overview.pdf.

USEPA. 2015b. "Green Remediation Best Management Practices: Site Investigation and Environmental Monitoring." EPA 542-F-16-002. United States Environmental Protection Agency. https://clu-in.org/greenremediation/docs/GR_Fact_Sheet_SI&EM.pdf.

USEPA. 2016a. "Climate Change Indicators in the United States." United States Environmental Protection Agency. https://www.epa.gov/climate-indicators/downloads-indicators-report.

USEPA. 2016b. "Climate Smart Brownfields Manual." EPA 560-F-16-005. United States Environmental Protection Agency. https://www.epa.gov/sites/production/files/2017-01/documents/final_climate_smart_brownfields_manual_online_version.pdf.

USEPA. 2016c. "EJ 2020 Action Agenda. The U.S. EPA's Environmental Justice Strategic Plan for 2016-2020." United States Environmental Protection Agency.

https://www.epa.gov/sites/production/files/2016-05/documents/052216_ej_2020_strategic_plan_final_0.pdf.

USEPA. 2017a. “Development of a Climate Resilience Screening Index (CRSI): An Assessment of Resilience to Acute Meteorological Events and Selected Natural Hazards.” EPA600/R-17/238. Washington, D.C.: U. S. Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100SSN6.txt.

USEPA. 2017b. “Ecosystem Services at Contaminated Site Cleanups.” EPA 542-R-17-004. United States Environmental Protection Agency. https://www.epa.gov/remedytech/ecosystem-services-contaminated-site-cleanups.

USEPA. 2017c. “Memorandum. Considering Traditional Ecological Knowledge (TEK) During the Cleanup Process.” United States Environmental Protection Agency. https://www.epa.gov/sites/production/files/2018-02/documents/considering_traditional_ecological_knowledge_tek_during_the_cleanup_process.pdf.

USEPA. 2019a. “Climate Resilience Technical Fact Sheet: Contaminated Waste Containment Systems, October 2019 Update.” EPA 542-F-19-004. United States Environemtnal Protection Agency. https://www.epa.gov/sites/production/files/2019-12/documents/cr_containment_fact_sheet_2019_update.pdf.

USEPA. 2019b. “Climate Resilience Technical Fact Sheet: Groundwater Remediation Systems. October 2019 Update.” EPA 542-F-19-005. United States Environmental Protection Agency. https://www.epa.gov/superfund/climate-resilience-technical-fact-sheet-groundwater-remediation-systems.

USEPA. 2020a. “Superfund Community Involvement Handbook.” OLEM 923.0.-51. Washington, D.C.: United States Environmental Protection Agency. https://www.epa.gov/superfund/superfund-community-involvement-tools-and-resources.

USEPA. 2020b. “Sustainable and Healthy Communities. Strategic Research Action Plan 2019-2022.” EPA 601-K-20-004. Washington, D.C.: United States Environmental Protection Agency, Office of Research and Development. https://www.epa.gov/research/sustainable-and-healthy-communities-strategic-research-action-plan-2019-2022.

USFWS. 2011. “Traditional Ecological Knowledge for Application by Service Scientists.” United States Fish and Wildlife Service. https://www.fws.gov/nativeamerican/pdf/tek-fact-sheet.pdf.

USGCRP. 2009. “Global Climate Chage Impacts in the United States.” United States Global Change Research Program. https://nca2009.globalchange.gov/index.html.

USGCRP. 2017. “Climate Science Specal Report: Fourth National Climate Assessment, Volume 1.” In, ed D.J. Wuebbles, D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart and T. K. Maycock. Washington, D. C. : U.S. Global Change Research Program. doi:10.7930/J0J964J6.

USGCRP. 2018. “Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II “. Washington, D.C. : U.S. Global Change Research Program. doi:10.7930/NCA4.2018.

USGS. 1993. “Permafrost.” United States Geological Survey. https://pubs.usgs.gov/gip/70039262/report.pdf.

USGS. 2011. “A Promising Tool for Subsurface Permafrost Mapping: An Application of Airborne Geophysics from the Yukon River Basin, Alaska.” Fact Sheet 2011-3133. United States Geologic Survey. https://pubs.usgs.gov/fs/2011/3133/pdf/fs20113133.pdf.

USN. 2012. “Department of the Navy Guidance on Green and Sustainable Remediation. Rev. 1.” United States Department of the Navy, Naval Facilities Engineering Command.

Vaillant, N.M., C. A. Kolden, and A. M. S. Smith. 2016. “Assessing landscape vulnerability to wildfire in the USA.” Current Forestry Reports 2 (3):201-213. doi: 10.1007/s40725-016-0040-1.

VEM. 2018. “Vermont Stronger: 2018 Vermont State Hazard Mititgation Plan.” Burlington, VT: Vermont Emergency Management. https://vem.vermont.gov/sites/demhs/files/documents/2018%20Vermont%20State%20Hazard%20Mitigation%20Plan%20-%20Final%20Adopted_Interactive.pdf.

Vogel, Cathy M. 2015. “Defense Environmental Restoration Program Study. Presentation to the Interstate Technology & Regulatory Council Remediation Management of Complex Sites (RMCS) Team. Study performed by Noblis Inc. for the DOD Strategic Environmental Research and Development Program (SERDP)/Environmental Security Technology Certification Program (ESTCP) Offices under Contract Number GS10F0048X, Delivery Order FA8903-12-F-0073. June 10.”

WADNR. 2019. “Washington State Wildland Fire Protection 10-Year Strategic Plan. 2nd ed.” Washington State Department of Natural Resources. https://www.dnr.wa.gov/publications/rp_wildfire_strategic_plan.pdf.

Walker, D. A. 1983. “A hierarchical tundra vegetation classification especially designed for mapping in Northern Alaska.” Fourth International Permafrost Conference Proceedings, University of Alaska-Fairbanks.

Appendix A. Case Study Matrix

Click **here** to download the Case Study Matrix.

Appendix B. State Survey and State Survey Results

In the fall of 2019, the SRR team conducted a state survey. The survey asked for information on green and sustainable regulations, policies, guidance; and activities; extreme weather and fire events; and information on what resources would be helpful to the state. The team received 52 responses to the survey. The survey instrument is presented in section B.1 andthe results are presented section B.2.

B.1 State Survey

GSR & Resiliency State Priorities Survey

The ITRC Green and Sustainable Remediation with Resiliency to Extreme Weather Event and Wildfires Team (GSR/R) has justbegun updating the 2011 GSR guidance to support sustainable, resilient remediation and redevelopment of contaminatedsites.

States' needs are foremost and your response to this survey will guide how we develop resources for you. For further background please review the Team Page and the associated fact sheet, both found HERE.

GSR is the site-specific employment of products, processes, technologies, and procedures that mitigate contaminant risk to receptors while making decisions that are cognizant of balancing community goals, economic impacts, and environmental effects.

Extreme weather events (such as heat waves, droughts, tornadoes, and hurricanes) are defined as lying in the outermost ("most unusual") 10 percent of a place's history. Analyses are available at the national and regional levels.

Resilience is the capacity of a community, business, or natural environment to prevent, withstand, respond to, and recoverfrom a disruption.

SURVEY PERIOD: October 8, 2019 through November 6, 2019

If you have any questions, please contact the Team's Program Advisor, Barbara Maco (barbara.maco@sustainableremediation.org)

1. Please provide your contact information:

Name:	
State and Department:	
Job Title:	
Email Address:	
Phone Number:	

2. Does your state have any existing GSR regulation, policy, or guidance? (See GSR definition above)

- Yes
- No
- Unsure / Do Not Know

If YES, please provide the reference/link:

3. Check all of the following extreme weather/climate or **wildfire** events that have or might impact your state. Please note any related impact such as increased/decreased stormwater runoff in the comment box.

- ☐ Sustained changes in average **temperature**
- ☐ Increased extreme temperatures
- ☐ Decreased precipitation days, increasing drought intensity
- ☐ Increased heavy precipitation events
- ☐ Increased intensity of hurricanes
- ☐ Other (please specify)
- ☐ Increased flood risk
- ☐ Decreased **permafrost**
- ☐ Sea level rise
- ☐ Increased frequency and/or intensity of wildfires

4. At which stages is your state planning for resiliency to address extreme weather events and wildfires? If you have NONE, please put NA in the category box. If YES, please provide a reference and/or web link.

Assessment / Identification:

State-Managed Climate Change Information Clearinghouse or Data Resource:

State Agency or Department Lead:

Comprehensive Plan:

Executive Order:

Regulation / Statue:

Other (please specify):

5. Does your state have any policy, strategy, regulatory framework, requirements, or guidance for addressing the impacts of extreme weather events and wildfires at remediation sites, both active and closed?

- ○ Yes
- ○ No
- ○ Unsure / Do Not Know

If YES, please provide a reference/link. If NO, is your state planning on this in the future?

6. Does your state have an emergency response plan for extreme weather events and wildfire impacts at contaminated sites?

- ○ Yes
- ○ No
- ○ Unsure / Do Not Know

7. Has your state seen GSR applied in any of the following site cleanup programs? Provide key information in comment section.

- ☐ State lead
- ☐ CERCLA NPL
- ☐ RCRA
- ☐ Time critical removal
- ☐ Brownfields

Please note key elements of implementation here.

8. What are the GSR implementation barriers for your state? Please note what they are in the comment box below.

- [ ] Regulatory barriers
- [ ] Technical barriers
- [ ] Lack of information
- [ ] Cost

List the barriers

9. Rate the following items that might lead to a more **sustainable resilient remediation** and redevelopment in your state.

	Rating
State or Federal legislation/regulatory mandate	
State or Federal grant incentives	
Local permits, regulations, or ordinances	
Private certification (e.g. LEED, Envision)	
Land use/**institutional controls**	

10. **Metrics** provide a basis for evaluating actions being considered throughout the site cleanup and redevelopment process and can apply to more than one component of GSR… environmental, economic and or social. Please indicate if these metrics have been used at cleanup projects in your state or their potential value for future cleanups.

	Rating
Environmental metrics (greenhouse gas emissions created or energy consumed)	
Economic metrics (such as job creation/preservation)	
Social metrics (parkland or open space created)	

11. Does your state recommend/encourage GSR best management practices (BMPs) at contaminated site cleanup and redevelopment.

- Yes
- No
- Unsure / Do Not Know

12. What types of BMP resources would your state like to see in the ITRC GSR/R guidance?

Remedial technology/approach evaluation (such as a feasibility study)

- [ ] Remedial technology/approach **optimization**
- [ ] Remedial technology/approach implementation
- [ ] **Risk management**
- [ ] Long-term monitoring
- [ ] **stakeholder** engagement
- [ ] Other (please specify):

13. Would a sustainable remediation guidance/framework that also addresses extreme weather events and wildfire impacts at contaminated sites be useful for your state?

- Yes
- No
- Unsure / Do Not Know

14. Rate each case study topic based on its usefulness to support sustainable resilient remediation and redevelopment implementation in your state.

	Rating
technology/approach evaluation (such as a feasibility study)	
technology/approach optimization	
technology/approach implementation	
Return on investment, including cost of externalities (e.g. social cost of carbon, **ecosystem services**)	
Regulator collaboration and/or support	
Community engagement with the impacted public	
Stakeholder engagement to define sustainability metrics and tools	
Risk management	
Water conservation and reuse	
Materials use/management	
Circular economy	

15. Does your state have any case studies/site examples that could be included in the ITRC GSR/Resiliency guidance?

- Yes
- No
- Unsure / Do Not Know

16. Do you have any additional feedback that you would like to provide to help the ITRC GSR/R Team develop its guidance and other resources?

B.2 State Survey

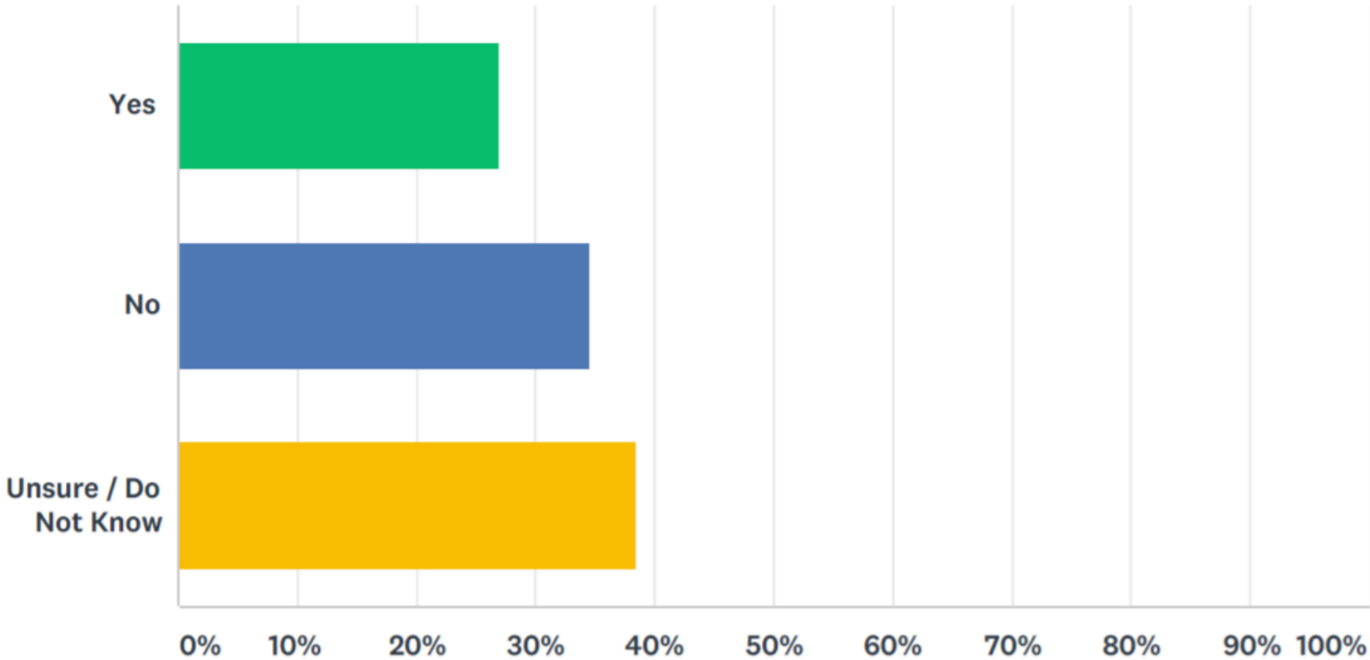
Q1 Please provide your contact information:

Answered: 52, Skipped: 0

ANSWER CHOICES	RESPONSES	
Name:	100.00%	52
State and Department:	100.00%	52
Job Title:	92.31%	48
Email Address:	100.00%	52
Phone Number:	98.08%	51

Q2 Does your state have any existing GSR regulation, policy, or guidance? (See GSR definition above)

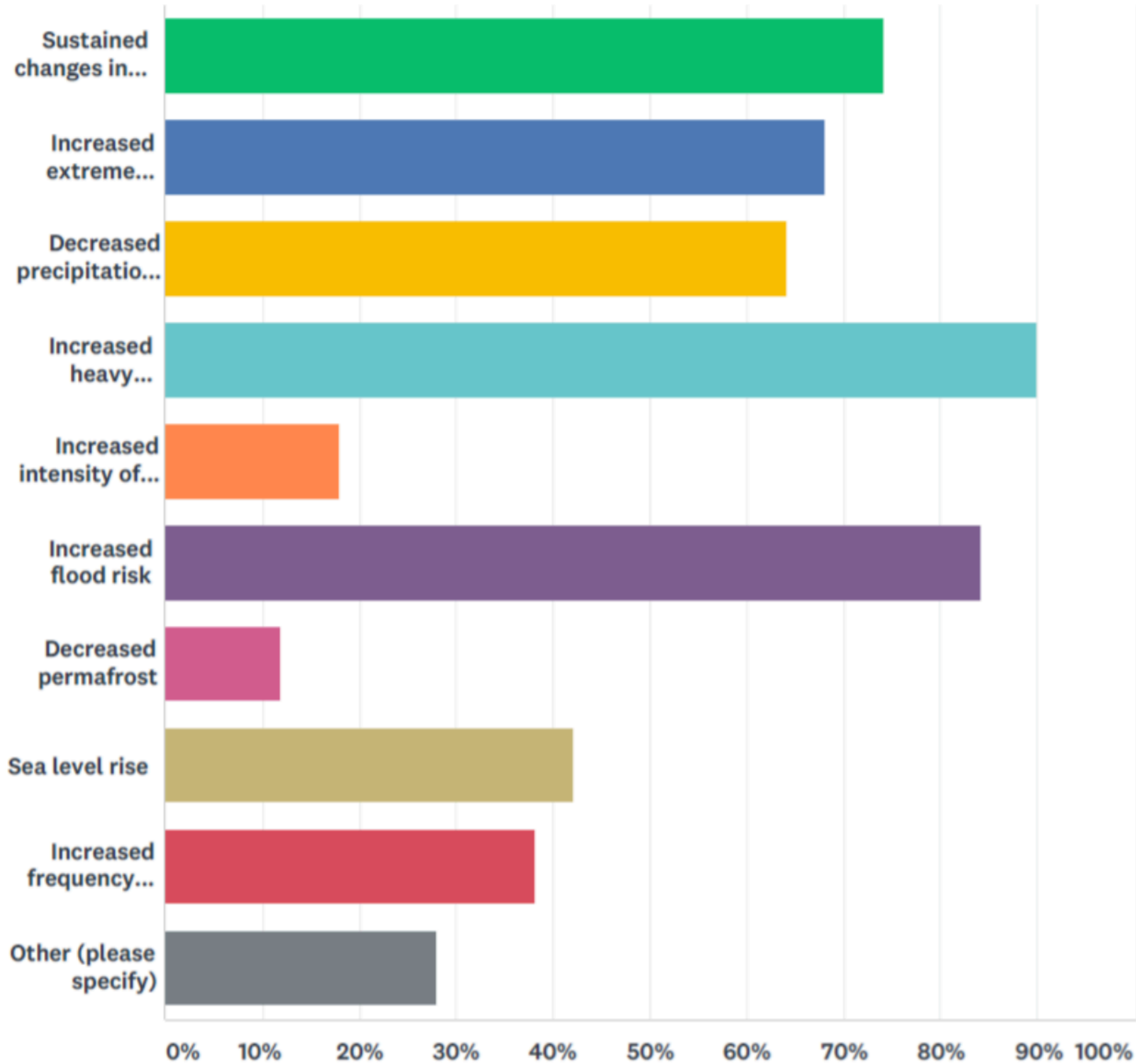
Answered: 52 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	26.92%	14
No	34.6%	18
Don't know/Unsure	38.4%	20
TOTAL		52

Q3 Check all of the following extreme weather/climate or wildfire events that have or might impact your state. Please note any related impact such as increased/decreased stormwater runoff in the comment box.

Answered: 50 Skipped: 2



ANSWER CHOICES	RESPONSES	
Sustained changes in average temperature	74.00%	37
Increased extreme temperatures	68.00%	34
Decreased precipitation days, increasing drought intensity	64.00%	32
Increased heavy precipitation events	90.00%	45
Increased intensity of hurricanes	18.00%	9
Increased flood risk	84.00%	42
Decreased permafrost	12.00%	6
Sea level rise	42.00%	21
Increased frequency and/or intensity of wildfires	38.00%	19
Other (please specify)	28.00%	14
Total Respondents:		50

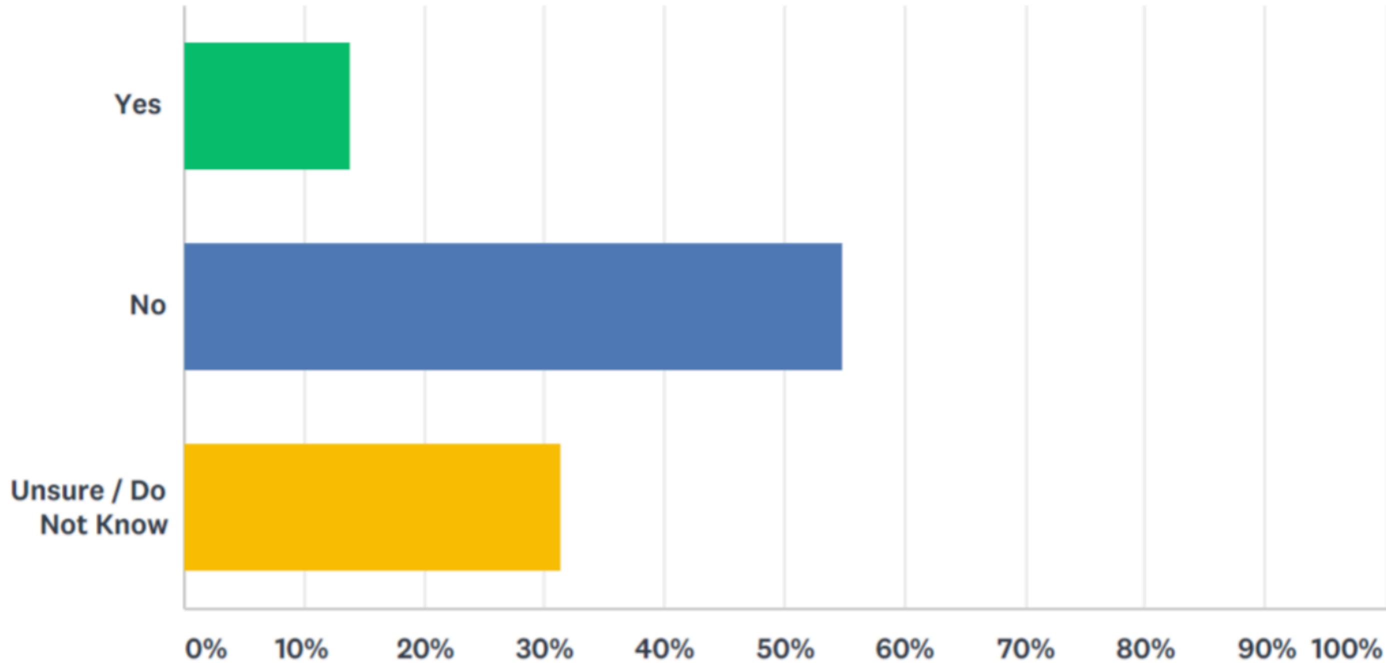
Q4 At which stages is your state planning for resiliency to address extreme weather events and wildfires? If you have NONE, please put NA in the category box. If YES, please provide a reference and/or web link.

Answered: 50 Skipped: 2

ANSWER CHOICES	RESPONSES	
Assessment / Identification:	84.00%	42
State-Managed Climate Change Information Clearinghouse or Data Resource:	76.00%	38
State Agency or Department Lead:	66.00%	33
Comprehensive Plan:	62.00%	31
Executive Order:	62.00%	31
Regulation / Statue:	56.00%	28
Other (please specify):	32.00%	16

Q5 Does your state have any policy, strategy, regulatory framework, requirements, or guidance for addressing the impacts of extreme weather events and wildfires at remediation sites, both active and closed?

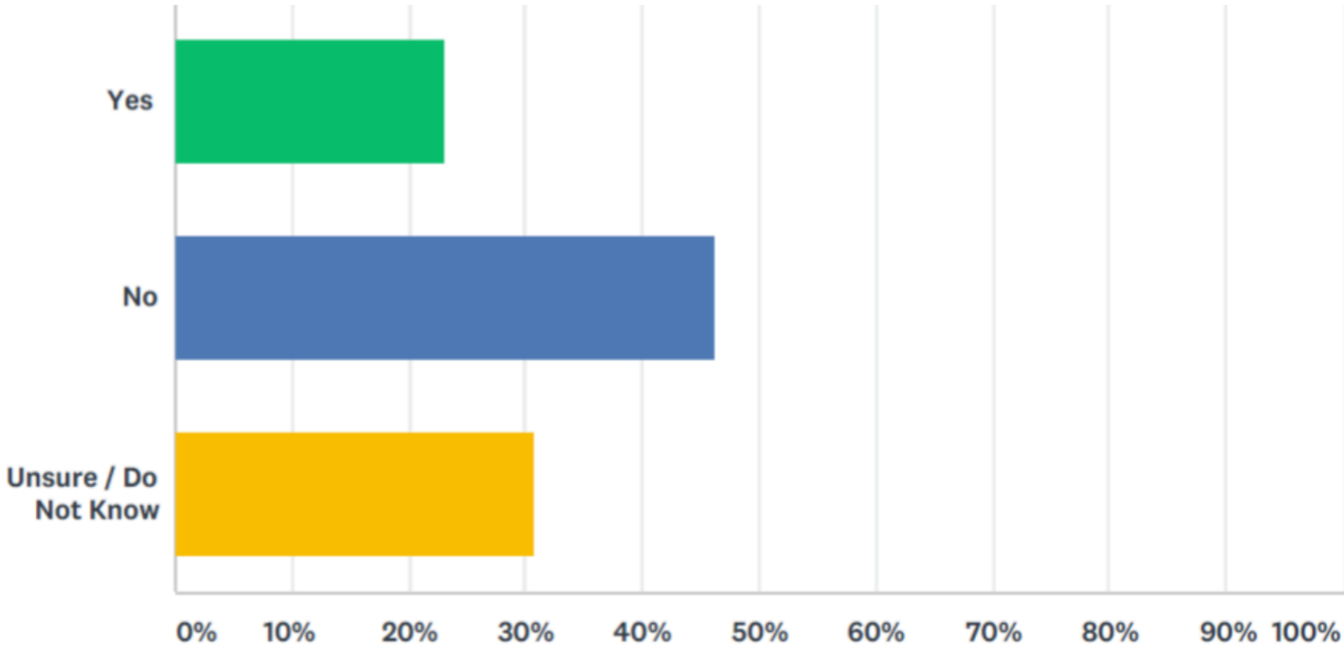
Answered: 51 Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	13.73%	7
No	54.90%	28
Unsure / Do Not Know	31.37%	16
TOTAL		51

Q6 Does your state have an emergency response plan for extreme weather events and wildfire impacts at contaminated sites?

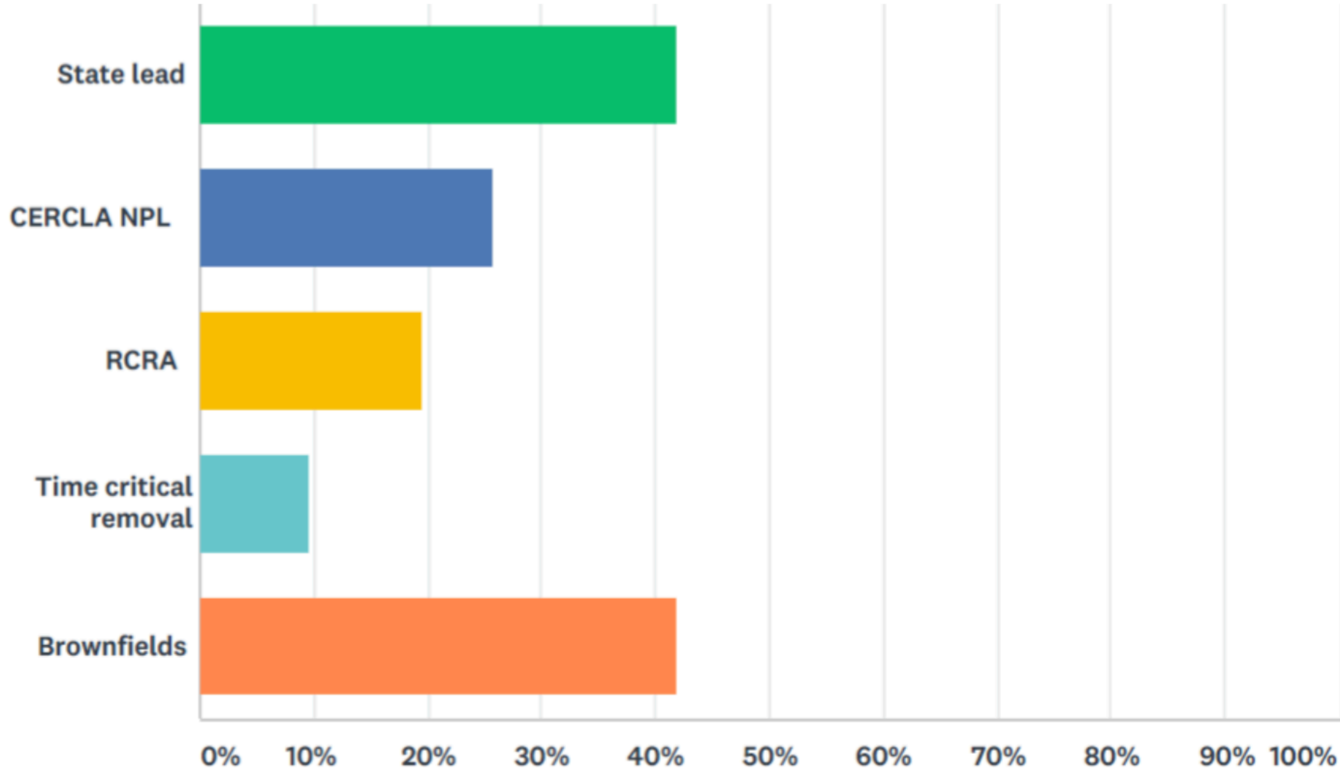
Answered: 52 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	23.08%	12
No	46.15%	24
Unsure / Do Not Know	30.77%	16
TOTAL		52

Q7 Has your state seen GSR applied in any of the following site cleanup programs? Provide key information in comment section.

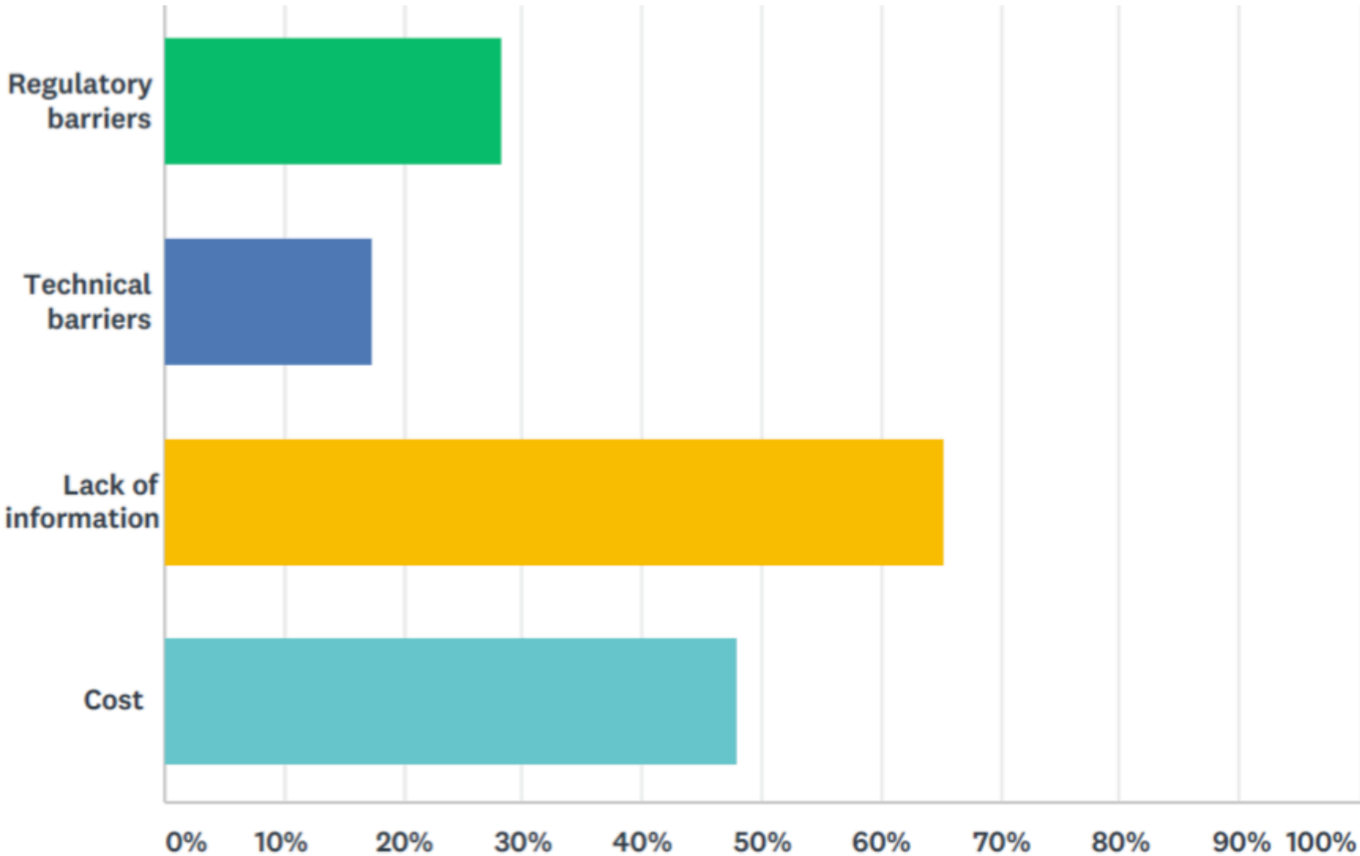
Answered: 31 Skipped: 21



ANSWER CHOICES	RESPONSES	
State lead	41.94%	13
CERCLA NPL	25.81%	8
RCRA	19.35%	6
Time critical removal	9.68%	3
Brownfields	41.94%	13
Total Respondents:		31

Q8 What are the GSR implementation barriers for your state? Please note what they are in the comment box below.

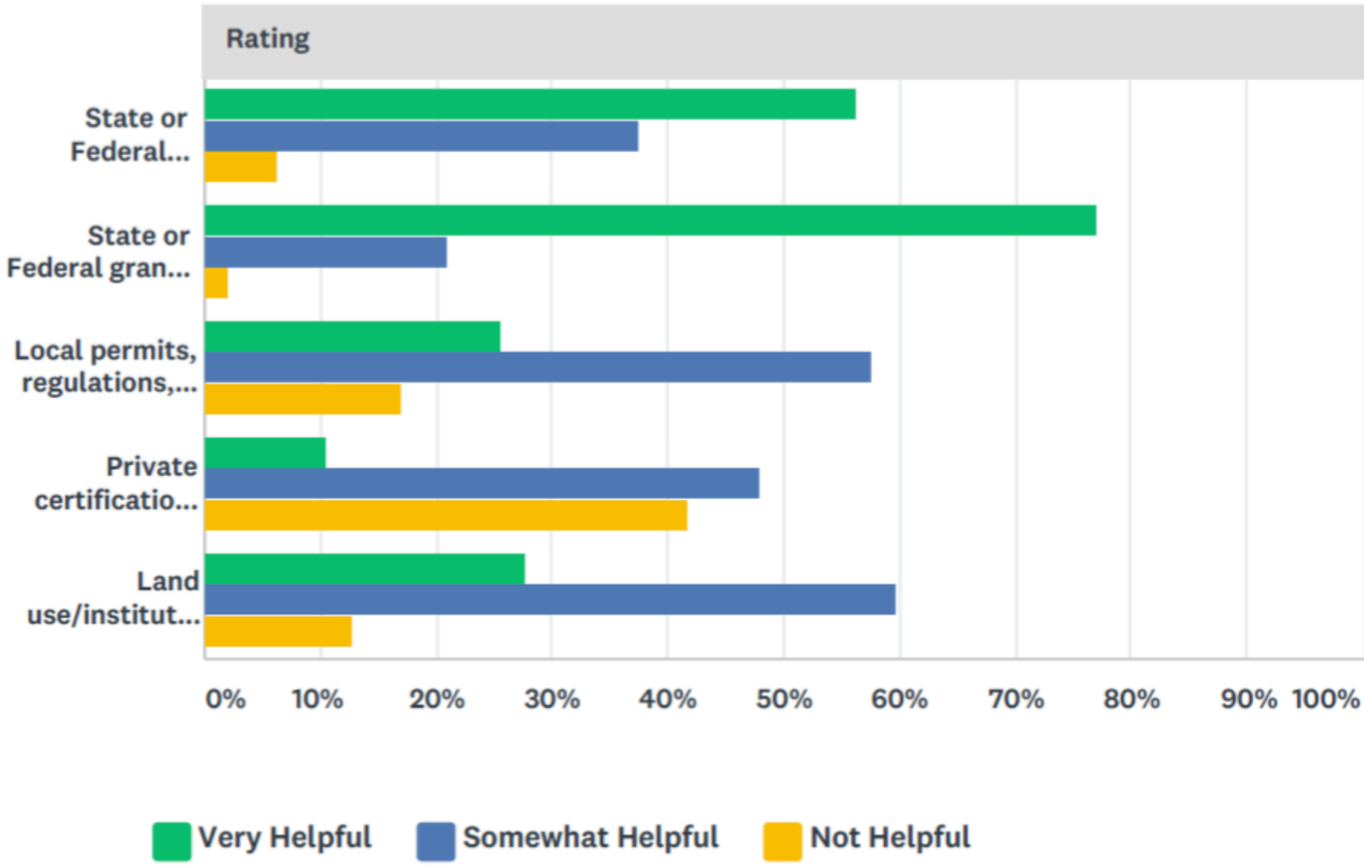
Answered: 46 Skipped: 6



ANSWER CHOICES	RESPONSES	
Regulatory barriers	28.26%	13
Technical barriers	17.39%	8
Lack of information	65.22%	30
Cost	47.83%	22
Total Respondents:		46

Q9 Rate the following items that might lead to a more sustainable resilient remediation and redevelopment in your state.

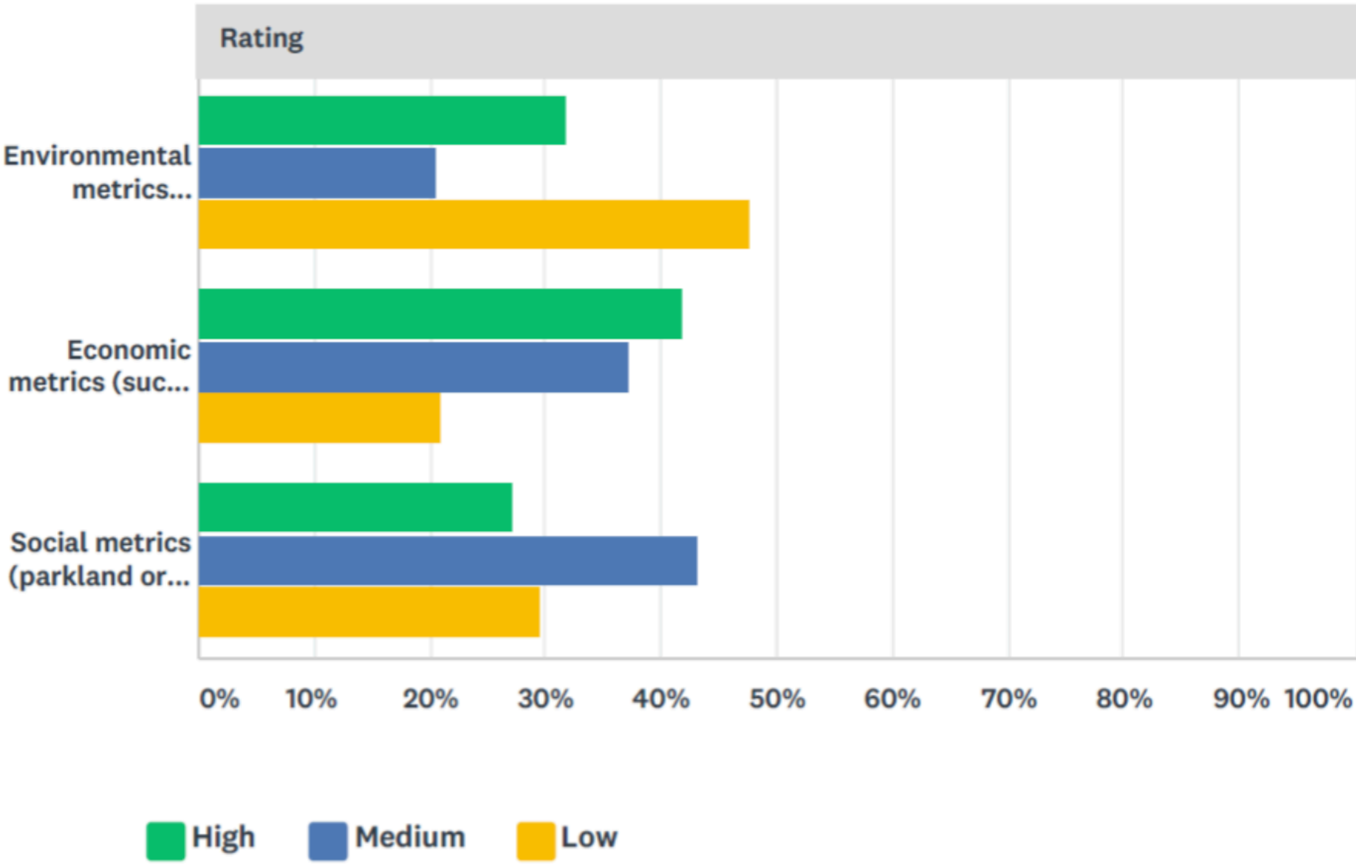
Answered: 48 Skipped: 4



Rating	VERY HELPFUL	SOMEWHAT HELPFUL	NOT HELPFUL	TOTAL
State or Federal legislation/regulatory mandate	56.25% 27	37.50% 18	6.25% 3	48
State or Federal grant incentives	77.08% 37	20.83% 10	2.08% 1	48
Local permits, regulations, or ordinances	25.53% 12	57.45% 27	17.02% 8	47
Private certification (e.g. LEED, Envision)	10.42% 5	47.92% 23	41.67% 20	48
Land use/institutional controls	27.66% 13	59.57% 28	12.77% 6	47

Q10 Metrics provide a basis for evaluating actions being considered throughout the site cleanup and redevelopment process and can apply to more than one component of GSR… environmental, economic and or social. Please indicate if these metrics have been used at cleanup projects in your state or their potential value for future cleanups.

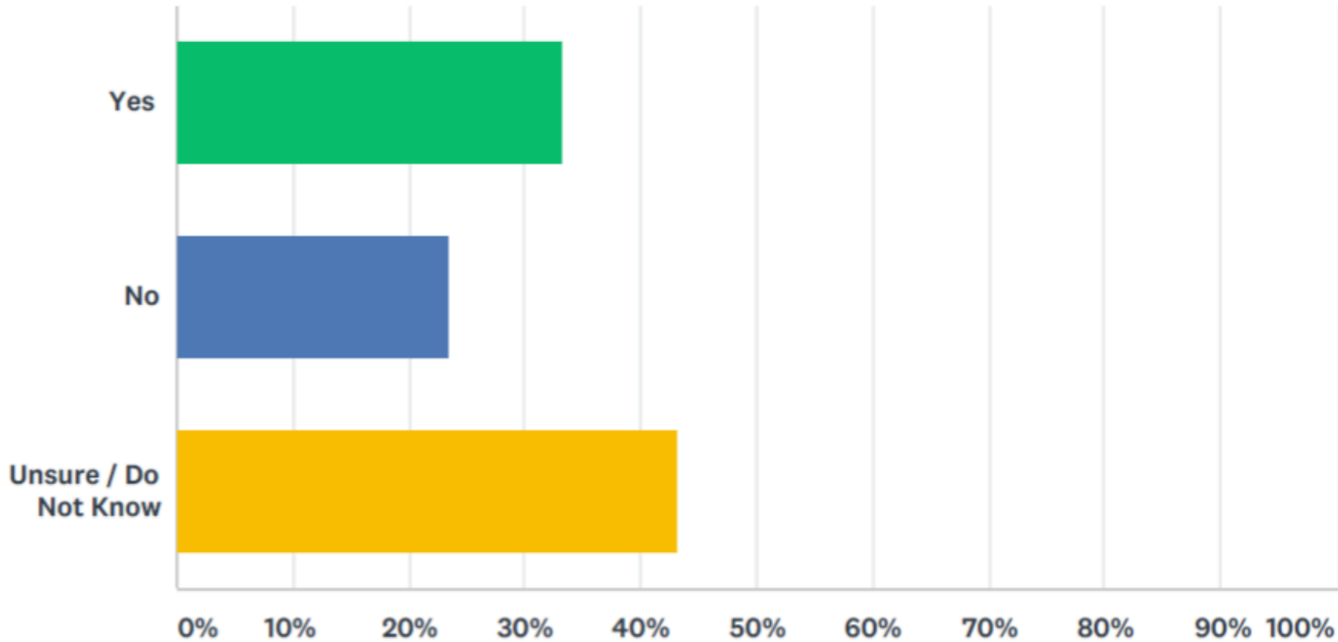
Answered: 45 Skipped: 7



Rating	High	Medium	Low	Total
Environmental metrics (greenhouse gas emissions created or energy consumed)	31.82% 14	20.45% 9	47.73% 21	44
Economic metrics (such as job creation/preservation)	41.86% 18	37.21% 16	20.93% 9	43
Social metrics (parkland or open space created)	27.27% 12	43.18% 19	29.55% 13	44

Q11 Does your state recommend/encourage GSR best management practices (BMPs) at contaminated site cleanup and redevelopment.

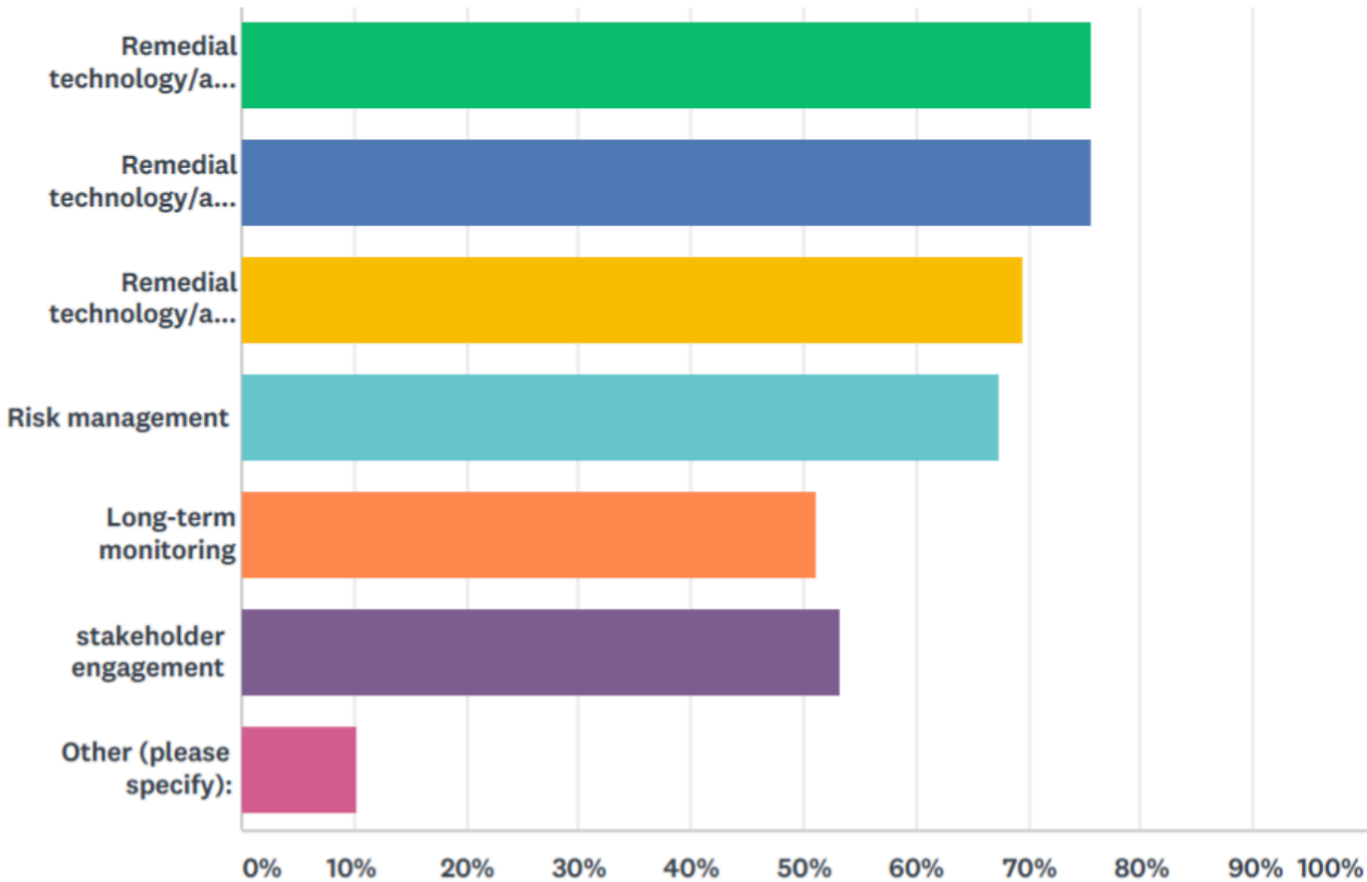
Answered: 51 Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	33.33%	17
No	23.53%	12
Unsure / Do Not Know	43.14%	22
TOTAL		51

Q12 What types of BMP resources would your state like to see in the ITRC GSR/R guidance?

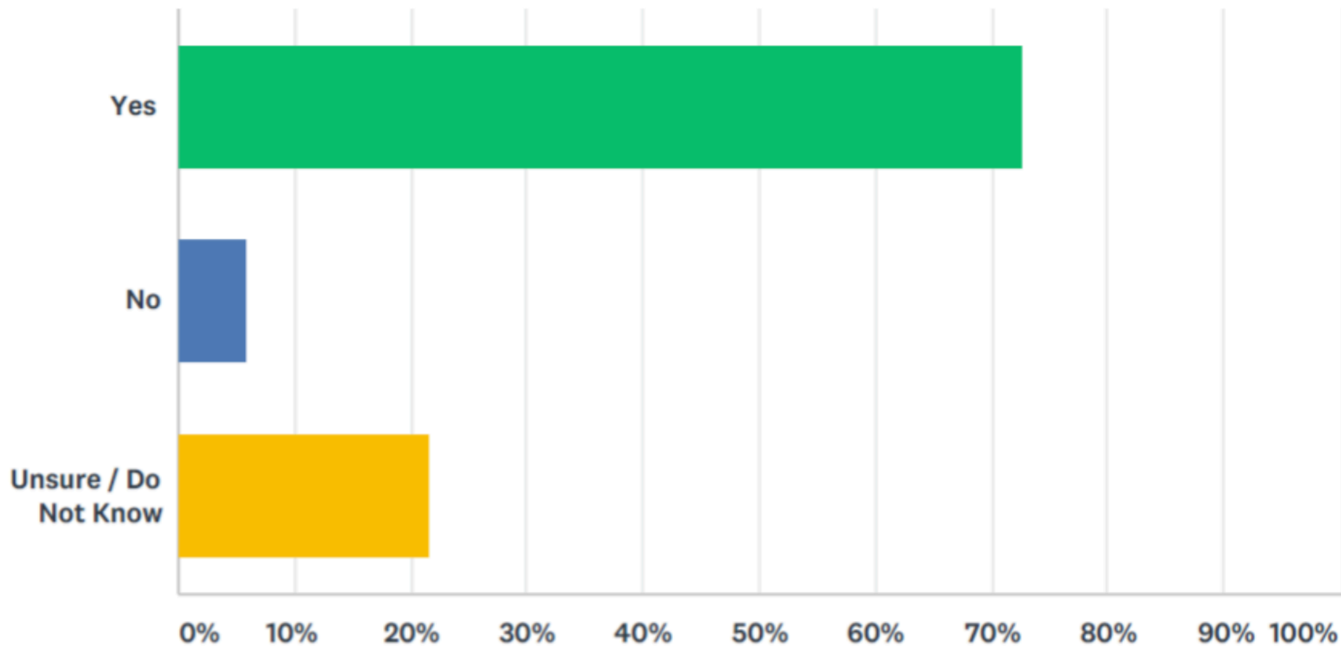
Answered: 49 Skipped: 3



ANSWER CHOICES	RESPONSES	
Remedial technology/approach evaluation (such as a feasibility study)	75.51%	37
Remedial technology/approach optimization	75.51%	37
Remedial technology/approach implementation	69.39%	34
Risk management	67.35%	33
Long-term monitoring	51.02%	25
stakeholder engagement	53.06%	26
Other (please specify):	10.20%	5
Total Respondents:		49

Q13 Would a sustainable remediation guidance/framework that also addresses extreme weather events and wildfire impacts at contaminated sites be useful for your state?

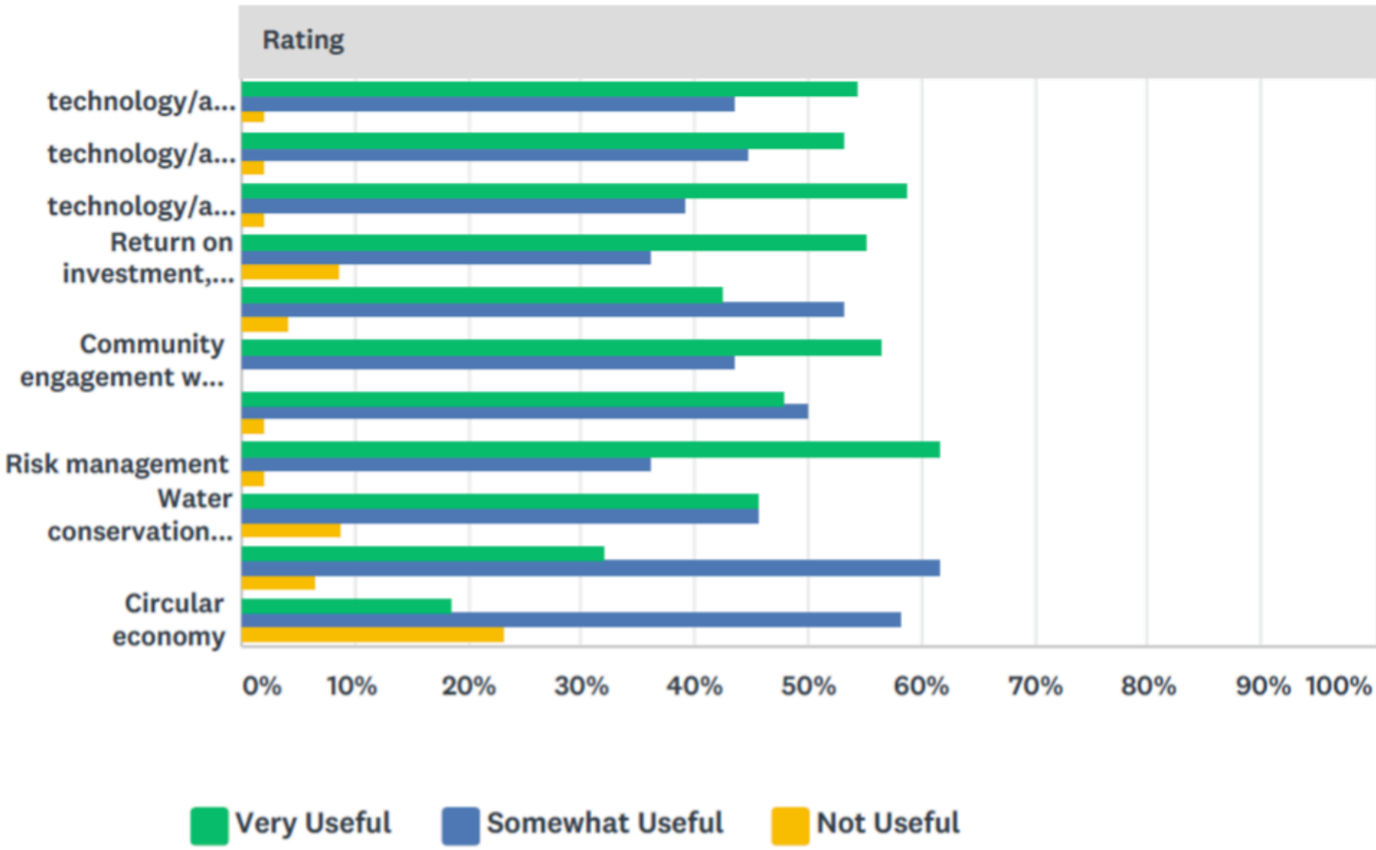
Answered: 51 Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	72.55%	37
No	5.88%	3
Unsure / Do Not Know	21.57%	11
TOTAL		51

Q14 Rate each case study topic based on its usefulness to support sustainable resilient remediation and redevelopment implementation in your state.

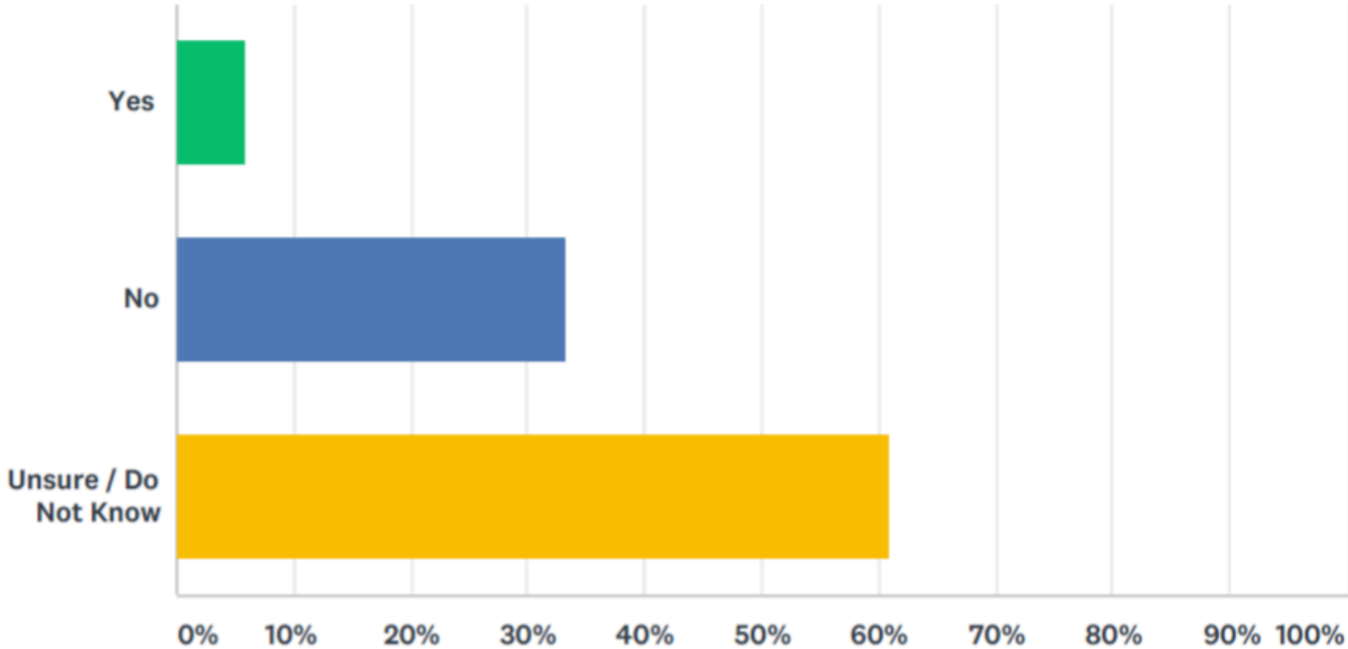
Answered: 48 Skipped: 4



Rating	Very Useful	Somewhat Useful	Not Useful	Total
technology/approach evaluation (such as a feasibility study)	54.35% 25	43.48% 20	2.17% 1	46
technology/approach optimization	53.19% 25	44.68% 21	2.13% 1	47
technology/approach implementation	58.70% 27	39.13% 18	2.17% 1	46
Return on investment, including cost of externalities (e.g. social cost of carbon, ecosystem services)	55.32% 26	36.17% 17	8.51% 4	47
Regulator collaboration and/or support	42.55% 20	53.19% 25	4.26% 2	47
Community engagement with the impacted public	56.52% 26	43.48% 20	0.00% 0	46
Stakeholder engagement to define sustainability metrics and tools	47.83% 22	50.00% 23	2.17% 1	46
Risk management	61.70% 29	36.17% 17	2.13% 1	47
Water conservation and reuse	45.65% 21	45.65% 21	8.70% 4	46
Materials use/management	31.91% 15	61.70% 29	6.38% 3	47
Circular economy	18.60% 8	58.14% 25	23.26% 10	43

Q15 Does your state have any case studies/site examples that could be included in the ITRC GSR/Resiliency guidance?

Answered: 51 Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	5.88%	3
No	33.33%	17
Unsure / Do Not Know	60.78%	3
TOTAL		51

Q16 Do you have any additional feedback that you would like to provide to help the ITRC GSR/R Team develop its guidance and other resources?

Answered: 20 Skipped: 32

Appendix C. Tech Sheets for Selected State SRR Resources

Tech sheets describing SRR resources are included in this appendix for the states of California, Massachusetts, and New Jersey.

Tech Sheet: California SRR Resources

Sustainable resilient remediation (SRR) is an optimized solution for the cleanup and reuse of hazardous waste sites that limits the negative environmental impacts, maximizes social and economic benefits, and creates resilience againstthe increasing threat of extreme weather events,sea-level rise, and wildfires.
This tech sheet describes how California is promoting and integrating sustainability andresilience in remediation.

To quickly find examples and best practices fromother states and federal agencies, visit the ITRC SRR Team's webpage and click on the state resources map. California has several laws, regulations, executive orders (EOs), and policies in place for climate adaptation and resilience, environmental justice, wildfires, and green remediation. This techsheet summarizes these efforts.

Climate Resilience

In 2015, Governor Brown established EO B-30-15, which aims to reduce greenhouse gas (GHG) emissions and incorporate climate change impacts into planning and investment decisions. Further, this order requires the state Natural Resources Agency to update the state's climate adaptation strategy every 3 years. To read thecomplete EO and for more information, click here.
The Natural Resources Agency's climate adaptation strategy, mentioned above, is called Safeguarding California. The last update was in 2018 and the next will be published in 2021. As stated in the2018 update, the plan "builds on nearly a decade of adaptation strategies to communicate current and needed actions state government should take to build climate change resiliency."
The Governor's Office of Planning and Research (OPR) published a climate resilience report titled Planning and Investing for a Resilient California: A Guidebook for State Agencies (2018). This report includes accounting for current and future climate conditionsin infrastructure investment. OPR was directed to convene a technical advisory group to develop guidance to support implementation of the executive order (EO B-30-15).

Hazardous Waste Management Resilience Initiatives

Three hazardous waste management resilience initiatives inCalifornia are summarized below. The California Department of Toxic Substances Control (DTSC) and a team of federal, state, and local agencies evaluated impacts of the Woolsey Fire on conditions at the Santa Susana Field Laboratory site (state-led cleanup) and in nearby communities. Theinterim report summarizes work done to address concerns about the impact of the Woolsey Fire on the site and surrounding communities (DTSC 2018). The Los Angeles Region Framework for Climate Change Adaptation and Mitigation: Potential Regulatory Adaptation and Mitigation Measures report looks at the impact of the effects of climate change on contaminated sites and undergroundstorage tanks and how these effects can be considered in the agency's actions (LARWQCB 2019). The San Francisco Bay Conservation and Development Commission's Adapting to Rising Tides project evaluated the current condition of shoreline and community assets and the stressors affecting them.

Wildfires

The State of California has multiple resources for wildfire prevention and response.

In 2019, the Governor's Office released a report called Wildfires and Climate Change: California's Energy Future. The strike force report sets out steps the state must take to reduce the incidence and severity of wildfires, including the significant wildfire mitigation and resiliency efforts the governor has already proposed. It renews the state's commitment to clean energy. It outlines actions to hold the state's utilities accountable for their behavior and potential changes to stabilizeCalifornia's utilities to meet the energy needs of customers and the economy.

The California Public Utilities Commission requires wildfire mitigation plans from large or small and multijurisdictional utility companies and independent transmission owners in SB 901. Each of the participants also provides final action statements and resolutions. The commission issued a ruling on the wildfire mitigation plan templates and other related materials. Utilities also submitted progress reports in 2019.

Additionally, the Bureau of Land Management created a Microsoft PowerPoint presentation of its wildland fire response in 2015. The presentation includes details on organization and immediate response to wildland fires, emergency stabilization and rehabilitation responses, and case examples. A request for access may be required to view this document.

Green Remediation

The Department of Toxic Substances Control has a green remediation website to promote green remediation whenever possible. The site also explains green remediation and the DTSC's interim advisory (2009), which introduces sustainability and life-cycle thinking and shows how these concepts can be incorporated into any stage of a cleanup project. The website provides additional resources as well.

Tech Sheet: Massachusetts SRR Resources

Sustainable resilient remediation (SRR) is an optimized solution for the cleanup and reuse of hazardous waste sites that limits the negative environmental impacts, maximizes social and economic benefits, and creates resilience against the increasing threat of extreme weather events, sea-level rise, and wildfires

This tech sheet describes how Massachusetts is promoting and integrating sustainability and resilience in remediation.

To quickly find examples and best practices from other states and federal agencies, visit the ITRC SRR Team's webpage and click on the state resources map.

The Sustainable Remediation FAQs answers basic questions about sustainable remediation and state programs that support SSR, including the Massachusetts Contingency Plan (MCP) and Brownfields programs.

The Massachusetts Department of Environmental Protection (MassDEP) issues postclosure use permits for solar and wind installations on closed and capped landfills. To date, the agency has approved more than 100 projects rated more than 220 megawatts, the largest Brightfields program in the U.S. Massachusetts has established laws and executive orders (EOs) with ambitious goals to combat climate change and incorporate resilience in infrastructure and remediation. The state maintains a climate action website with links to supporting regulations, programs, and policies.

Laws

In 2008, Massachusetts enacted the Green Communities Act and the Global Warming Solutions Act (GWSA). The GWSA made Massachusetts one of the first states with a comprehensive regulatory program to address climate change and one of the most robust climate change laws in the nation.

Executive Orders

In 2014, an EO was enacted requiring secretariats to take action in promoting environmental justice. The EO requires new strategies that promote positive impacts in environmental justice communities and focus on several environmental justice initiatives. In 2016, Massachusetts Governor Charlie Baker issued EO 569, Establishing An Integrated Climate Change Strategy For The Commonwealth. Among other things, the EO required the state to "make new and existing efforts to mitigate and reduce greenhouse gas (GHG) emissions and build resilience and adapt to the impacts of climate change," as well as to "coordinate efforts…to strengthen the resilience of our communities, prepare for the impacts of climate change, and prepare for and mitigate damage from extreme weather events."

Regulations

In 2014, the Massachusetts Contingency Plan (MCP) was amended and included the promotion of green approaches for the assessment and remediation of regulated sites. The relevant provisions include eliminating or reducing total energy use, air emissions, water use, materials consumption, and damage to ecosystems. Although there are no specific sustainability
The Sustainable Remediation FAQs answers basic questions about sustainable remediation and state programs that support SSR, including the Massachusetts Contingency Plan (MCP) and Brownfields programs. The Massachusetts Department of Environmental Protection (MassDEP) issues postclosure use permits for solar and wind installations on closed and capped landfills. To date, the agency has approved more than 100 projects rated more than 220 megawatts, the largest Brightfields program in the U.S.requirements in the MCP, the MCP recognizes energy consumption and other factors that are relevant to sustainability as considerations in remedy selection. In particular, 310 CMR 40.0858(4) requires an evaluation of the following:

- "the relative consumption of energy resources in the operation of the alternatives, and the externalities associated with the use of those resources"
- "costs of environmental restoration, potential damages to natural resources, including consideration of impacts to surface waters, wetlands, wildlife, fish and shellfish habitat."

The promotion and application of green approaches for the assessment and remediation of oil and hazardous disposal sites (per the 2014 amendments to the MCP) are consistent with the commonwealth's mandates to improve energy efficiency, reduce emissions, and expand renewable energy resources where practicable.

In 2019, additional MCP amendments were proposed to require the consideration of "anticipated impacts associated with climate change" on "risk of harm to health, safety, public welfare or the environment during any foreseeable period of time" at waste sites. These changes will be final in 2021, and further guidance is being developed.

Guidance

MassDEP provides guidance on recommended approaches to maximize the net environmental benefit when conducting remediation under the MCP. Signed in 2014, the purpose of the guidance is to support environmental professionals in their consideration and use of greener approaches for site assessment and remediation that eliminate or reduce the environmental footprint of cleanup activities to the maximum extent possible. The focus of such approaches includes addressing five core elements or factors for reducing the environmental footprint of a cleanup:

- minimizing total energy use while maximizing renewable energy
- minimizing emissions of GHGs and other air pollutants
- minimizing water use and impacts to water resources
- reducing, reusing, and recycling materials and waste
- avoiding or reducing adverse impacts to ecosystems and land resources

Funding Sources

The Municipal Vulnerability Preparedness grant program provides support for communities to identify climate change vulnerabilities, prioritize critical actions, and build community resiliency and follow-on grants to fund projects.

State Projects

Charles River Natural Valley Storage Area

More and more communities are employing green infrastructure and conserving surrounding watersheds to improve resilience to changing climates. Increased development around Boston, Massachusetts, in the past decades eliminated many wetlands and increased roadways, parking lots, and other impervious surfaces. A series of dams along the Charles River historically controlled flooding, but these dams had insufficient capacity for large precipitation events, which have become more common. Rather than build more dams at greatenvironmental, social, and economic costs, the U.S. Army Corps of Engineers, the city, and surrounding communities agreed to protect the remaining wetlands by creating the Charles River Natural Valley Storage Area. These wetlands provide critical green infrastructure, deliver flood resilience to the city, and expand recreational amenities for the entire region (Cassin 2019).

Massachusetts Climate Change and Hazardous Waste Site Screening

The Sustainable Remediation Forum (SURF), EcoAdapt, MassDEP, and researchers at Boston University collaborated to develop a simple model and GIS tools to evaluate the potential vulnerability of a subset of 6,001 high-interest MassDEP-listed sites based on their locations relative to FEMA flood hazard map zones, NOAA hurricane surge zones, and NOAA sea-level rise projections. The assessment also included site remediation status, key environmental parameters, and community parameters such as population density, proportions of elderly and children, percent of minority populations and median household income, and proximity of schools and hospitals. Vulnerability results include a unique combination of site exposure, site sensitivity, and community sensitivity parameters. The research marks a first step in informing community leaders, state agencies, and remediation managers of the potential vulnerabilities of hazardous waste sites due to climate change impacts (Mielbrecht and Tarrio 2019).

Resilient MA – Climate Change Clearinghouse for the Commonwealth

Resilient MA – Climate Change Clearinghouse for the Commonwealth is a web portal to thousands of resources on climate change and resilience. Documents and links available include, but are not limited to, the following:

- Massachusetts Clean Energy and Climate Plan for 2020 is an implementation plan for reducing GHG emissions (dated 12/31/2015).
- Massachusetts State Hazard Mitigation and Climate Adaptation Plan, dated September 2018, accounts for projected changes in precipitation, temperature, sea-level rise, and extreme weather events to position Massachusetts to effectively reduce the risks associated with natural hazards and the effects of climate change.
- Massachusetts Climate Change Projections – Statewide and for Major Drainage Basis, March 2018, provides simulations on temperature, precipitation, and sea-level rise through the end of the century using the latest climate models.
- Global Warming Solutions Act Dashboard: Massachusetts' Progress towards Reducing Greenhouse Gas Emissions by 2020 shows Massachusetts' progress toward the goals of the act, which was signed in August 2008.

Tech Sheet: New Jersey SRR Resources

Sustainable resilient remediation (SRR) is an optimized solution for the cleanup and reuse of hazardous waste sites that limits the negative environmental impacts, maximizes social and economic benefits, and creates resilience against the increasing threat of extreme weather events, sea-level rise, and wildfires.

This tech sheet describes how New Jersey is promoting and integrating sustainability and resilience in remediation.

To quickly find examples and best practices from other states and federal agencies, visit the ITRC SRR Team's webpage and click on the state resources map.

On October 29, 2012, the Northeast was hit by Superstorm Sandy. The storm caused major flooding in several cities along the northeast coastline, including most of coastal New Jersey. The flooding caused widespread power outages and fires, destroyed homes, and took lives. The reality of the devastation showed that planning and preparing for future extreme weather events must be prioritized. New Jersey has developed policies and passed regulations, statutes, and executive orders (EOs), taking specific actions to address sustainability and resilience at contaminated sites. This tech sheet summarizes these efforts.

Guidance

The New Jersey Department of Environmental Protection (NJDEP) first addressed the issue of resilience at contaminated sites in 2016 with the publication of the technical guidance Planning for and Response to Catastrophic Events at Contaminated Sites. This document was created to provide licensed site remediation professionals, the party responsible for conducting the remediation, and property owners guidance to help them prepare for, respond to, and recover from catastrophic events. The guidance addressed the following topics:

- planning for resilience when designing and implementing site remedies
- retrofitting vulnerable sites to decrease the disruption to existing systems
- establishing communication networks, chain-of-command structures, and procedures to be used during catastrophic events
- reviewing lessons learned
- reassessing systems to be better prepared for future catastrophic events

Regulations and Statutes

In 2018, the NJDEP addressed sustainability at contaminated sites in its Technical Requirements for Site Remediation, which states that the NJDEP "encourages the use of green and sustainable practices during the remediation of contaminated sites" (N.J. Admin. Code § 7:26E-1.9, NJDEP 2018). Although not a strong directive, it incorporated green and sustainable practices into the lexicon of site remediation in New Jersey and encouraged their consideration at contaminated sites during remediation.

A year later, the state incorporated green and sustainable remediation (GSR) into its statutes when the Site Remediation Reform Act was amended. The Brownfields statute (C.58:10B-12.1) amendment states:

The department [NJDEP] shall encourage the use of green and sustainable practices during the remediation of a contaminated site. The use of green and sustainable practices shall not alter the requirement that the remediation be protective of the public health and safety and of the environment.

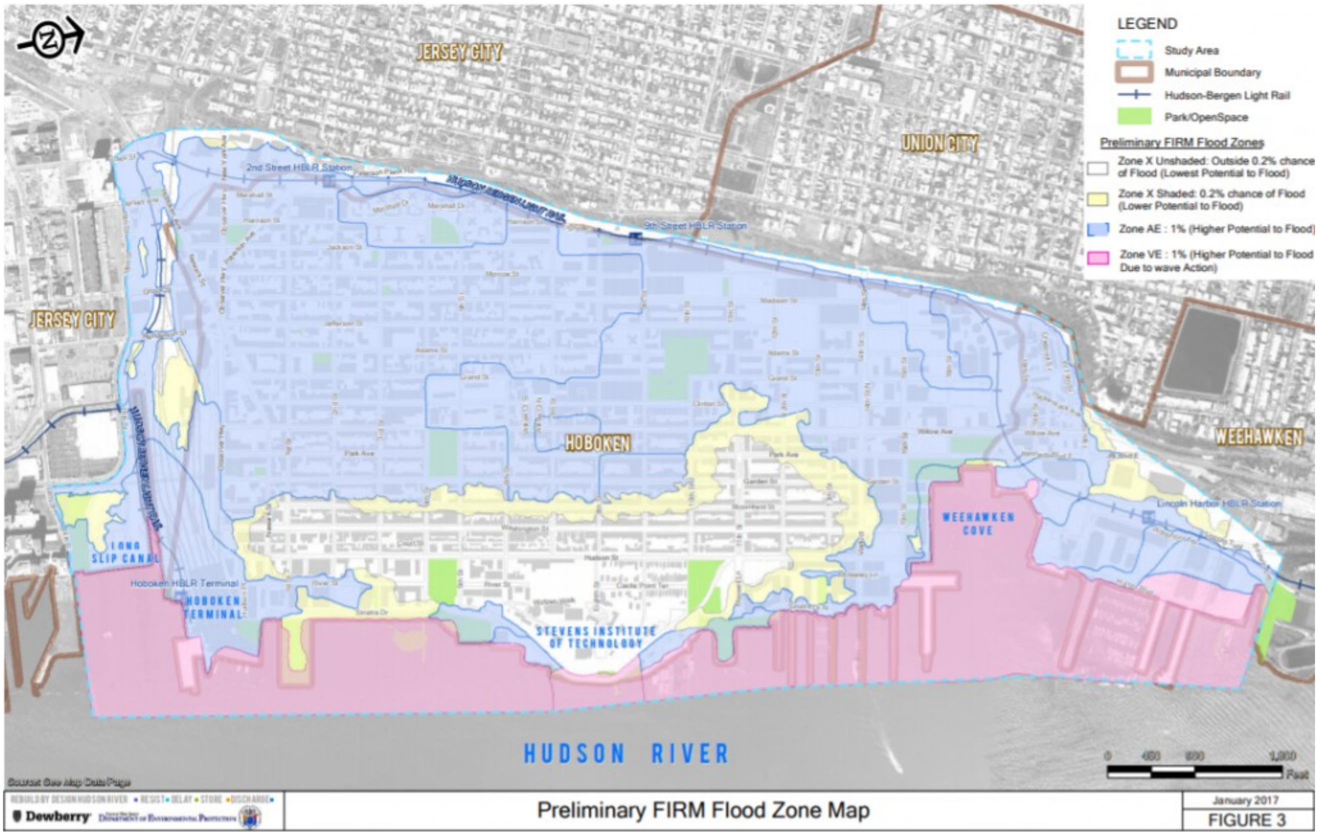
Once passed as law, the NJDEP determines what constitutes "encouragement" through the rule-making process.

Executive Orders (EOs)

New Jersey Governor Murphy signed EO 89 on October 29, 2019, on the seventh anniversary of Superstorm Sandy. The order directed the state, through the NJDEP, to develop a statewide climate change strategy to guide decisions and policies across state government. The EO also formed a Climate and Flood Resilience Program within the NJDEP and created the Interagency Council on Climate Resilience to promote the long-term mitigation, adaptation, and resilience of New Jersey's economy, communities, infrastructure, and natural resources.

The state's chief resiliency officer is the head of the newly formed Climate and Flood Resilience Program within NJDEP. The divisions and bureaus are responsible for addressing climate impacts that threaten the safety of the residents of New Jersey, including preventing or mitigating climate impacts at hazardous sites in flood zones.

As an example, the Bureau of Climate Resilience Planning provides planning and technical support to New Jersey's communities to help residents make informed decisions about climate resilience. The bureau is responsible for coordinating NJDEP policies, programs, and activities to plan for the impacts and the associated hazards of climate change and promote public awareness of climate change science. Coordinating with other programs such as the Site Remediation and Waste Management Program is part of the work.



A hazardous waste screening technical environmental study of Hoboken, NJ, and portions of two surrounding cities found 343 state historic and historic hazardous waste sites within the study area (NJDEP 2017).

Funding Sources

Incorporating SRR into state-funded response actions has many benefits, including contributing toward state-mandated climate and sustainability goals to reduce emissions and waste generation and planning for extreme weather events that may compromise a remedy at a contaminated site. New Jersey has several funding programs that can be used for SRR projects, including the following.

Office of Natural Resource Restoration

This office within NJDEP can provide funding for natural restoration projects that may also play a role in the sustainability and resiliency of a remediation project. A project example is the Harrison Avenue Landfill (that is, Cramer-Hill Waterfront Park), where funding was provided to institute a living shoreline, bolstering over 3,000 feet along the Delaware River in the City of Camden.

Hazardous Discharge Site Remediation Fund (HDSRF)

The HDSRF grants and loans are available to public entities, private entities, and nonprofit organizations that perform remediation pursuant to NJDEP's Site Remediation Program requirements. The HDSRF is funded through a constitutionally dedicated portion of the New Jersey Corporate Business Tax and is administered through a partnership between the NJDEP and the New Jersey Economic Development Authority (NJEDA). The NJDEP evaluates an applicant's preliminary eligibility requirements and the estimated remediation costs. Upon the NJDEP's recommendation for funding, the NJEDA evaluates an applicant's financial status, determines grant or loan eligibility, and awards funding.

Environmental Infrastructure Trust

New Jersey's Environmental Infrastructure Trust provides financial assistance through the Clean Water State Revolving Fund Program. Projects eligible for funding include nonpoint source pollution and stormwater management projects.

RGGI Strategic Funding

The NJDEP, Board of Public Utilities, and the NJEDA published a strategic funding plan for investing the state's auction proceeds from the Regional Greenhouse Gas Initiative (RGGI). New Jersey plans to invest an estimated $80 million each year (between 2020 and 2022) in programs that reduce greenhouse gas emissions, drive forward projects that boost clean energy and create jobs, protect the health of residents in environmental justice communities, and increase the resiliency of coastal communities. Information about specific funding opportunities will be released periodically through this website.

Appendix D. Sustainable Best Management Practice Checklists

Click **here** to download the Sustainable Best Management Practice Checklists.

Appendix E. Team Contacts

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Appendix F. Glossary

A

Active layer

The upper layer of the soil starting at the soil/air interphase to the depth of maximum annual thaw

Adaptation (to climate change)

An adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Adaptive capacity

The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Adaptive management

A process of iteratively planning, implementing, and modifying strategies for managing resources in the face of uncertainty and change; adjusting approaches in response to observations of their effect and changes in the system brought on by resulting feedback effects and other variables.

Aerobic bioremediation

In the presence of aerobic conditions and appropriate nutrients, microorganisms can convert many organic contaminants to carbon dioxide, water, and microbial cell mass. Aerobic bioremediation uses oxygen as the electron acceptor.

Agroforestry

Land management involving the growing of trees in association with food crops or pastures.

Anaerobic biodegradation

The degradation of compounds by microorganisms in the absence of oxygen. The process whereby microorganisms use a chemical other than oxygen as an electron acceptor.

Avoided costs

Costs that are not incurred because ecosystem services are protected or preserved—for example, offsetting the costs of water treatment by protecting the watershed.

B

Beneficial reuse

The process of taking would-be waste and recycling it into a valuable commodity. Materials being recycled for beneficial reuse must be at least as safe for humans and the environment as the material they are replacing.

Biodenitrification

A microbially facilitated process in which nitrate (NO_3^-) is reduced and ultimately produces molecular nitrogen (N_2) through a series of intermediate gaseous nitrogen oxide products.

Bioremediation

The use of either naturally occurring or deliberately introduced microorganisms or other forms of life to consume and break down environmental pollutants to clean up a polluted site.

Biosparging

An in situ remediation technology that uses indigenous microorganisms to biodegrade organic constituents in the saturated zone. In biosparging, air (or oxygen) and nutrients (if needed) are injected into the saturated zone to increase the biological activity of the indigenous microorganisms.

Bioswales

Stormwater runoff conveyance systems that provide an alternative to storm sewers. They can absorb low flows or carry runoff from heavy rains to storm sewer inlets or directly to surface waters. Bioswales improve water quality by infiltrating the first flush of stormwater runoff and filtering the large storm flows they convey.

Bioventing

An in situ remediation technology that uses indigenous microorganisms to biodegrade organic constituents adsorbed to soils in the unsaturated zone. In bioventing, the activity of the indigenous bacteria is enhanced by inducing air (or oxygen) flow into the unsaturated zone (using extraction or injection wells) and, if necessary, by adding nutrients.

Boreal forest

A forest that grows in the cold regions of the northern hemisphere and is made up mostly of cold-tolerant coniferous species such as spruce and fir.

Brownfield

A brownfield is a property where expansion, redevelopment, or reuse may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant.

Built (gray) infrastructure

See Gray infrastructure.

C

Carbon footprint

A measurement of the amount of greenhouse gases (carbon dioxide, methane, nitrous oxide, and some fluorinated gases) emitted by something during a given period. A carbon footprint can be applied to a specific event, time frame, or area or looked at on a broad scale and measured throughout the entire life of a system, product, or individual.

Cleanup process

The process of cleaning up a hazardous waste site. The process is often described in six stages: 1) preliminary, 2) baseline, 3) characterization, 4) remedial design, 5) remediation/mitigation, and 6) postremedy.

Cleanup standards (risk-based)

Cleanup standards that are authorized under applicable environmental law for remediation of a particular property, taking into consideration the use of the property being remediated and any relevant contractual or other requirements.

Community resilience

The ability of communities to withstand, recover, and learn from past disasters to strengthen future response and recovery efforts This includes, but is not limited to, physical and psychological health of the population; social and economic equity and well-being; effective risk communication; integration of organizations in planning, responding, and recovering; and social connectedness for resource exchange, cohesion, response, and recovery.

Comprehensive Environmental Response Compensation & Liability Act (CERCLA)

Congress established CERCLA, aka Superfund, in 1980. CERCLA allows USEPA to clean up contaminated sites. It also forces the parties responsible for the contamination to either perform cleanups or reimburse the government for USEPA-led cleanup work. When there is no viable responsible party, Superfund gives USEPA funds and authority to clean up contaminated sites.

Conceptual site model (CSM)

A representation of the site that summarizes and helps project planners visualize and understand available information. The CSM is the primary planning and decision-making tool used to identify the key issues and the data necessary to transition a project from characterization through postremedy. It documents current site conditions and serves to conceptualize the relationships among chemicals in environmental media, sources, and receptors through consideration of potential or actual migration and exposure pathways.

Concomitant

Existing or occurring with something else, often in a lesser way; accompanying; concurrent.

Co-use/Cobenefit

The added uses or benefits we get when we act to control climate change, above and beyond the direct uses or benefits of a more stable climate. They are sometimes referred to as “multiple uses or multiple benefits.”

Cryogenic expulsion

Displacement of petroleum by water in the soil pore space, and subsequent expulsion by the formation of ice crystal structure and resultant pressure of crystal formation.

Cultural services

The human benefits obtained through ecosystem services, such as cultural diversity, recreational opportunities, or aesthetic amenities.

D

Debris flow

A moving mass of soil, rock, and debris made fluid by rain or melting snow.

Debt financing

Debt financing occurs when a company raises money by selling debt instruments, most commonly in the form of bank loans or bonds. This type of financing is often referred to as financial leverage.

Deconstruction

Taking a building apart piece by piece. This can range from a soft strip, in which only the highest value and easy-to-extract materials are removed intact, to a full deconstruction, in which the entire structure is “un-built” to maximize reuse of materials.

E

Economic impact

Economic vitality, jobs, infrastructure, cost-effectiveness. The effect that an event or scenario has on the economy in the surrounding community, such as impacts on business revenue, employment, and salaries.

Ecosystem (Ecological system)

A community of living organisms in conjunction with the nonliving components of their environment, interacting as a system.

Ecosystem services

All the processes and outputs that nature provides us with. These include provisioning services (food, fuel, water), regulating services (air quality, fresh water), supporting services (soil formation, photosynthesis), and cultural services (recreation and tourism).

Engineered wetlands

Constructed wetland treatment systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality.

Engineering controls

The physical barriers used or constructed to prevent exposure or isolate materials from people, animals, and the environment.

Environmental assessment

The process of identifying, estimating, and evaluating the environmental impacts of existing and proposed projects by conducting environmental studies to evaluate the relevant negative effects prior to making decisions and commitments.

Environmental footprint

The effect that a person, company, activity, etc., has on the environment—for example, the amount of natural resources that they use and the amount of harmful gases that they produce.

Environmental justice

The fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.

Environmental justice communities

Communities most impacted by environmental harms and risks. Communities where there is a disproportionate exposure to environmental hazards and an increased vulnerability to those hazards. These typically include minority, low income, tribal, or indigenous populations or geographic locations in the United States that potentially experience disproportionate environmental harms and risks.

Environmental optimization

Cleanup efforts that generally result in improvements to remedy effectiveness, cost reduction, technical improvement, site closure, and energy and material efficiency.

Executive order

A president's or governor's declaration that has the force of law, usually based on existing statutory powers. It requires no action by Congress or the state legislature.

Extreme weather events

Weather phenomena (heat waves, droughts, tornadoes, and hurricanes) that occur at the extremes of the historical distribution and are rare for a particular place and/or time, especially severe or unseasonal weather.

F

Fate and transport

Describes how chemicals entering the subsurface from point or nonpoint sources relate to groundwater concentrations elsewhere.

Fire barriers

A network of buffer areas around the site made devoid of fuel to prevent fire spread.

Floodplain

A nearly flat plain along the course of a stream or river that is naturally subject to flooding.

G

Gabion

A basket or cage filled with earth or rocks and used in building a support or abutment.

Gray (built) infrastructure

The human-engineered infrastructure for water resources such as water and wastewater treatment plants, pipelines, and reservoirs. Gray infrastructure typically refers to components of a centralized approach to water management.

Gray water

All wastewater generated in residential dwellings or office buildings from streams not containing fecal material. These streams include sinks, showers, baths, dishwashers, and washing machines. Gray water may be reused for purposes such as toilet flushing, irrigation, or gardening.

Green and sustainable remediation (GSR)

The site-specific employment of products, processes, technologies, and procedures that mitigate contaminant risk to receptors while balancing community goals, economic impacts, and environmental effects.

Green infrastructure

The preservation or restoration of ecological systems or use of engineered systems with ecological processes to increase resilience to climate change, manage other environmental hazards, or both.

Green remediation

The practice of considering all environmental effects of remedy implementation and incorporating options to minimize the environmental footprints of cleanup.

Greenfield development

The creation of planned communities on previously undeveloped land. This land may be rural, agricultural, or unused areas on the outskirts of urban areas.

Greenhouse gases

Atmospheric gases (for example, carbon dioxide, water vapor, methane, nitrous oxide, ozone, and fluorinated gases) that allow sunlight to pass through the atmosphere but prevent the heat from leaving the atmosphere.

Greenwashing

Situations where there is a claim that GSR approaches have been implemented, but where GSR options have not been evaluated and backup documentation is lacking.

H

Hazard mitigation

Any sustained action taken to reduce or eliminate the long-term risk to life and property from hazard events. It is an on-going process that occurs before, during, and after disasters and serves to break the cycle of damage and repair in hazardous areas.

Hazardous material

Any item or agent (biological, chemical, radiological, and/or physical) that has the potential to cause harm to humans, animals, or the environment, either by itself or through interaction with other factors.

Hazardous waste site

A property with hazardous chemicals and waste that make it dangerous or capable of having a harmful effect on human health or the environment.

Hidden benefit

An advantage or profit gained from something that is not initially apparent or originally intended.

Holistic planning

A decision-making framework that integrates all aspects of planning from social, economic, and environmental concerns.

Hydrogeology

The area of geology that deals with the distribution and movement of groundwater in the soil and rocks of the earth’s crust (commonly in aquifers).

I

In situ treatment

Treatment technologies involving the application of chemical, biological, or physical processes to the subsurface to degrade, remove, or immobilize contaminants without removing the bulk soil or groundwater.

Institutional controls

Institutional controls (ICs) are legal or administrative restrictions on the use of or access to a site or facility to eliminate or minimize potential exposure to chemicals of concern (such as proprietary controls or governmental controls). Institutional controls are used when contamination is first discovered, when cleanups are ongoing, and when residual contamination remains on site at a level that does not allow for unlimited use and unrestricted exposure after cleanup.

Integrated project planning

The collection of processes that ensure various elements of projects are properly coordinated. It establishes and manages the involvement of all relevant stakeholders and resources, according to defined processes devised from the organization’s set of standard processes.

Intentionality

Being deliberate or with purpose in actions.

Intergenerational equity

The principle of intergenerational equity states that every generation holds the earth in common with members of the present generation and with other generations, past and future. The principle articulates a concept of fairness among generations in the use and conservation of the environment and its natural resources

Invasive vegetation

A plant(s) that is both nonnative and able to establish on many sites, grow quickly, and spread to the point of disrupting plant communities or ecosystems.

J

K

L

Land use restrictions (controls)

Land use controls may consist of non-engineered instruments, such as administrative and legal controls, or engineered and physical barriers, such as fences and security guards. Land use controls help to minimize the potential for exposure to contamination and/or protect the integrity of a response action and are typically designed to work by limiting land and/or resource use or by providing information that helps modify or guide human behavior at a site.

Life cycle assessment

A compilation and evaluation of the inputs, outputs, and potential environmental impacts of a product or system throughout its life cycle.

Living shoreline

Are a green infrastructure technique using native vegetation alone or in combination with low sills to stabilize the shoreline. Living shorelines provide a natural alternative to “hard” shoreline stabilization methods like riprap or bulkheads, and provide numerous benefits, including nutrient pollution remediation, essential fish habitat structure, and buffering of shorelines from waves and storms. Research indicates that living shorelines are more resilient than bulkheads in protecting against the effects of hurricanes.”

M

Metrics

Measurable outcomes that can be used as a basis for evaluating actions (environmental, social, or economic) being considered throughout the site cleanup and redevelopment process.

Minimally invasive drilling techniques

Drilling techniques that minimize ground disturbances.

Mitigation (of disaster risk and disaster)

The lessening of the potential adverse impacts of biological, chemical, physical, and radiological hazards (including those that are human induced) through actions that reduce hazard, exposure, and vulnerability.

Monitored natural attenuation (MNA)

An important, groundwater remediation technology used for treating some dissolved groundwater contaminants. MNA relies on natural attenuation processes, coupled with a monitoring program, to achieve site-specific remediation objectives within a reasonable time frame compared to more active approaches.

N

Natural attenuation

Natural attenuation relies on natural processes to decrease or "attenuate" concentrations of contaminants in soil and groundwater.

Natural resources capital

The world's stock of natural resources, which includes geology, soils, air, water, and all living organisms. Some natural capital assets provide people with free goods and services, often called ecosystem services. Two of these (clean water and fertile soil) underpin our economy and society, and thus make human life possible.

Natural source zone depletion

Naturally occurring processes of biodegradation, volatilization, and dissolution of dense or light nonaqueous phase liquid petroleum hydrocarbon products in the subsurface.

Numeracy

The ability to understand and work with numbers.

O

Optimization

See Remedial optimization/remedy optimization.

P

Passive survivability

Refers to a building's ability to maintain critical life-support conditions in the event of extended loss of power, heating fuel, or water.

Perceived risk

The subjective judgment that people make about the characteristics and severity of a risk.

Permafrost

A thick subsurface layer of soil that remains frozen throughout the year.

Permeable reactive barrier wall

A wall created belowground to clean up contaminated groundwater. The wall is “permeable,” which means that groundwater can flow through it. Water must flow through the wall to be treated. The “reactive” materials that make up the wall either trap harmful contaminants or make them less harmful.

Phytotechnologies

Plant-based technologies that use plants and trees to remediate contaminated soil, groundwater, surface water, and sediments.

Pingo

Ice cored hills that exist withing the permafrost.

Project life cycle

See Remedial project life cycle.

Project management

The process of leading the work of a team to achieve goals and meet success criteria within a specified time frame.

Project planning

A procedural step in project management, in which required documentation is created to ensure successful project completion. Documentation includes all actions required to define, prepare, integrate, and coordinate additional plans. The project plan clearly defines how the project is executed, monitored, controlled, and closed.

Provisioning services

The production by ecosystems of products that are used by or directly impact human populations, including food, fuel, and fresh water.

Q

R

Rainscreen

An exterior wall detail in which the siding (wall cladding) stands off from the moisture-resistant surface of an air/water barrier applied to the sheathing to create a capillary break and to allow drainage and evaporation.

Regulating services

Ecosystem processes which temper natural phenomena. Regulating services include processes such as decomposition, erosion and flood control, water purification, climate, and pollination.

Regulations

Rules and administrative codes issued by governmental agencies at all levels (municipal, county, state, and federal) that are not statutes but have the force of law because they are adopted under the authority granted by statutes and often include penalties for violations.

Remedial alternatives

Solutions used in place of original remediation strategies to ensure that site cleanup objectives are met.

Remedial optimization/remedy optimization

A systematic process of evaluating the performance and effectiveness of existing site remediation systems and identifying recommendations that will move the site toward closeout more quickly and/or cost-effectively. Incorporating GSR into remedy selection maximizes environmental, economic, and social benefits and minimizes environmental impacts throughout the remedy life cycle.

Remedial project life cycle

The progression of environmental cleanup process often described in six stages: 1. preliminary, 2. baseline, 3. characterization, 4. design, 5. remediation/mitigation, 6. postremedy.

Remediation

The act or process of abating, cleaning up, containing, or removing a substance (usually hazardous or infectious) from an environment.

Remediation risk management

An approach that identifies and assesses site investigation and remediation activity risks.

Replacement cost

The cost of engineered systems to replace ecosystem services.

Resilience

The capacity of a community, business, or natural environment to prevent, withstand, respond to, and recover from a disruption.

Resilience measures

Potential measures to achieve a climate- and weather-resilient site remedy. Resilience measures may involve, but would not be limited to, actions such as physically securing one or more remediation systems, providing additional barriers to protect the systems, safeguarding access to the site and individual systems, and alerting project personnel of system compromises.

Resilient design

The intentional design of buildings, landscapes, communities, and regions in response to vulnerabilities to disaster and disruption of normal life.

Resilient development

The intentional design and construction of buildings, landscapes, communities, and regions in response to vulnerabilities to disaster and disruption of normal life.

Resilient risk management

Taking actions to minimize the effects of climate impacts and other future vulnerabilities. These actions fall generally into four categories: 1) mitigation, 2) adaptation, 3) geoengineering or climate engineering, and 4) knowledge-base expansion.

Resource Conservation and Recovery Act (RCRA)

The federal public law that creates the framework for the proper management of hazardous and nonhazardous solid waste.

Return on investment (sustainable)/Sustainable return on investment (S-ROI)

A methodology for identifying and quantifying environmental, societal, and economic impacts of investment in site remediation or contaminated site redevelopment (for example, factories, new product development, civil infrastructure, efficiency, and recycling programs, etc.).

Risk management

The process that evaluates how to protect public health by deciding whether and how to manage risks. This process requires consideration of legal, economic, and behavioral factors, and the human health and welfare effects of each management action and alternatives.

S

Salt-water intrusion

The displacement of fresh or groundwater by the advance of salt water, usually in coastal and estuarine areas.

Scarify

Breaking up, loosening, or roughening a surface.

Sea-level rise

An increase in the level of the world’s oceans due to the effects of global warming.

Site closeout

A remediation life-cycle milestone signifying that all active management and monitoring at a site has been completed, the remedy is protective of human health and the environment, contaminant levels at the site allow for unlimited use and unrestricted exposure, and there is no expectation of expending additional funds at the site to maintain protectiveness.

Social justice

Fair treatment of all people in a society, including respect for the rights of minorities and equitable distribution of resources among members of a society.

Social license

Exists when a project has ongoing approval or acceptance within the local community and among other stakeholders.”.

Sociocultural

Of, relating to, or signifying the combination or interaction of social and cultural elements.

Socioeconomic

Refers to society-related economic factors. The socioeconomic factors that determine health include employment, education, and income.

Soft strip deconstruction

Intact removal of the most valuable and easy-to-extract building materials.

Source containment

A range of actions (for example, removal, treatment in place, containment) designed to protect human health and the environment by eliminating or minimizing migration of or exposure to significant contamination.

Stakeholder

A person, group, or organization that is affected, potentially affected, or has any interest in a project or a project’s outcome, either directly or indirectly.

Stormwater controls

Practices designed to both control stormwater volume and settle out particulates for pollutant removal. Stormwater controls may include gathering runoff in wet ponds, dry basins, or multichamber catch basins and slowly releasing it to receiving waters or drainage systems.

Straw wattles

Human-made cylinders of compressed, weed-free straw (wheat or rice). Also known as straw worms, bio-logs, straw noodles, or straw tubes.

Supporting services

Those ecosystem services not used directly by people, but that are necessary for all other ecosystem services, such as soil formation, photosynthesis, and nutrient and water cycling.

Supra-permafrost groundwater

Water in the active layer of thawed permafrost soil.

Sustainability

The holistic consideration of environmental, social, and economic impacts of an activity and evaluation of these impacts on future generations.

Sustainability assessment

An evaluation that considers environmental, economic, and social impacts throughout the life cycle of an environmental remediation project.

Sustainable best management practices (SBMPs)

Best management practices for green remediation that holistically address a cleanup project's energy requirements; air emissions; impacts on water; impacts on land and ecosystems; material consumption and waste generation; and long-term stewardship actions. SBMPs can be used for sustainable removal or cleanup activities at contaminated sites under Superfund, corrective action, underground storage tank, and brownfield cleanup programs. In other guidance these may be referred to simply as BMPs.

Sustainable demolition

Minimizing waste to landfill by deliberately and carefully removing all salvageable material before razing a structure.

Sustainable materials management

A systemic approach to using and reusing materials more productively over their entire life cycle. This approach considers local waste streams and socially conscious sourcing.

Sustainable resilient remediation

An optimized solution to cleaning up and reusing hazardous waste sites that limits negative environmental impacts, maximizes social and economic benefits, and creates resilience against the increasing threat of extreme weather events, sea-level rise, and wildfires.

Sustainable risk management

The process of identifying, evaluating, selecting, and implementing actions that mitigate unintended environmental, social, and economic impacts from cleanup and restoration activities.

Sustainability

Refers to efforts to align economic development with environmental protection and human well-being.

Systemic bias

The inherent tendency of a process to support particular outcomes. Also called institutional bias and is related to structural bias.

T

Talik

A layer or body of unfrozen ground occurring in a permafrost area due to a local anomaly in thermal, hydrological, hydrogeological, or hydrochemical conditions.

Thermal erosion

Permafrost degradation resulting from flowing water.

Thermokarst

The process of massive ice degradation that creates large voids leading to subsidence.

Thermosiphon

A gravity-assisted heat pipe.

Three pillars of sustainability

The three pillars of sustainability are economic (for example, profit/economic health), environmental (for example, green cities/pollution/energy) and social (for example, safety/mobility/quality of life). If any one of the pillars is weak then the system as a whole can become unsustainable.

Traditional ecological knowledge (TEK)

The knowledge held by indigenous cultures about their immediate environment and the cultural practices that build on that knowledge. TEK includes an intimate and detailed knowledge of plants, animals, and natural phenomena, the development and use of appropriate technologies for hunting, fishing, trapping, agriculture, and forestry, and a holistic knowledge, or worldview, that parallels the scientific discipline of ecology.

Triple bottom line

Balancing the three pillars of sustainability—economic, environmental, and social—to optimize environmental cleanup projects.

Tundra

The vast, flat region in the northern hemisphere where the subsoil is permanently frozen and vegetative growth is hindered by low temperatures and a short growing season.

U

United Nations sustainable development goals

The sustainable development goals or global goals are a collection of 17 interlinked goals designed to be a “blueprint to achieve a better and more sustainable future for all.” The United Nations General Assembly set the goals in 2015; they are intended to be achieved by the year 2030.

V

Value of benefit

Values of social, economic, or environmental benefits that may be considered in remedial options for a cleanup site.

Vulnerability

The degree to which a system or site is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes.

Vulnerability assessment

Assessing the degree to which a system or site is susceptible to or unable to cope with, adverse effects of climate change, including climate variability and extremes. This includes:

- evaluating the remedy’s exposure to climate or weather hazards of concern (such as high floodwater or soil subsidence).
- evaluating the remedy’s sensitivity to the hazards of concern (likelihood for the hazards to reduce remedy effectiveness).

W

Watershed

The land area that channels rainfall and snowmelt to creeks, streams, and rivers, and eventually to outflow points such as reservoirs, bays, and the ocean.

Wildfire

A sweeping and destructive conflagration especially in a wilderness or a rural area.

X

Y

Z

Appendix G. Acronyms

ABC	asphalt, brick, and concrete
ADEC	Alaska Department of Environmental Conservation
ADNR	Alaska Department of Natural Resources
AFB	Air Force Base
AOC	Administrative Order on Consent
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
BMP	best management practice
CBA	cost-benefit analysis
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CRSI	Climate Resilience Screening Index
CSM	conceptual site model
CSVI	Community Social Vulnerability Indicators
DNAPL	dense nonaqueous phase liquid
DNR	Department of Natural Resources
DOD	Department of Defense (U.S.)
DOE	Department of Energy
DON	Department of Navy
DTSC	Department of Toxic Substances Control

EA	enhanced attenuation
EJ	environmental justice
EO	Executive Order
ERT	electrical resistivity tomography
ESA	environmental site assessment
ESI	Evaporative Stress Index
ET	evapotranspiration
FAQ	frequently asked questions
FEMA	Federal Emergency Management Agency
GAO	Government Accountability Office
GHG	greenhouse gases
GIS	geographic information system
GSR	green and sustainable remediation
GWSA	Global Warming Solutions Act
HDPE	high-density polyethylene
HDSRF	Hazardous Discharge Site Remediation Fund
HSPF	Hydrologic Simulation Program – Fortran
HVAC	heating, ventilation, and air conditioning
ISB	in situ bioremediation
ITRC	Interstate Technology and Regulatory Council
LCA	life-cycle assessment
LCS	life-cycle sustainability

LCSM	LNAPL conceptual site model
LFG	landfill gas
LNAPL	light nonaqueous phase liquid
MassDEP	Massachusetts Department of Environmental Protection
MCDA	multicriteria decision analysis
MCP	Massachusetts Contingency Plan
MUA	Municipal Utility Authority (Camden, NJ)
NCP	National Contingency Plan
NJDEP	New Jersey Department of Environmental Protection
NJEDA	New Jersey Economic Development Authority
NOAA	National Oceanic and Atmospheric Agency
NPL	National Priorities List
NRC	National Research Council
OM&M	operation, maintenance, and monitoring
OPR	Office of Planning and Research (California)
P & T	pump and treat
PCBs	polychlorinated biphenyls
PV	photovoltaic
RCRA	Resource Conservation and Recovery Act
RDI	Resilient Design Institute
RGGI	Regional Greenhouse Gas Initiative
RI/FS	remedial investigation/feasibility study

ROI	return on investment
RRM	residual risk management
SBMP	sustainable best management practices
SEFA	Spreadsheets for Environmental Footprint Analysis
SMART	specific, measurable, attainable, relevant, and timely
SRR	sustainable resilient remediation
SSEM	Social Sustainability Evaluation Matrix
SURF	Sustainable Remediation Forum
SuRF-UK	Sustainable Remediation Forum-United Kingdom
SVE	soil vapor extraction
SVOC	semi-volatile organic compound
TEK	traditional ecological knowledge
TTZ	XXXX
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USDA-ARS	U.S. Department of Agriculture – Agricultural Research Service
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geologic Survey
UUUE	unlimited use unrestricted exposure

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