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.** As a project progresses through the various phases of the project life cycle, the components below them are considered and integrated.

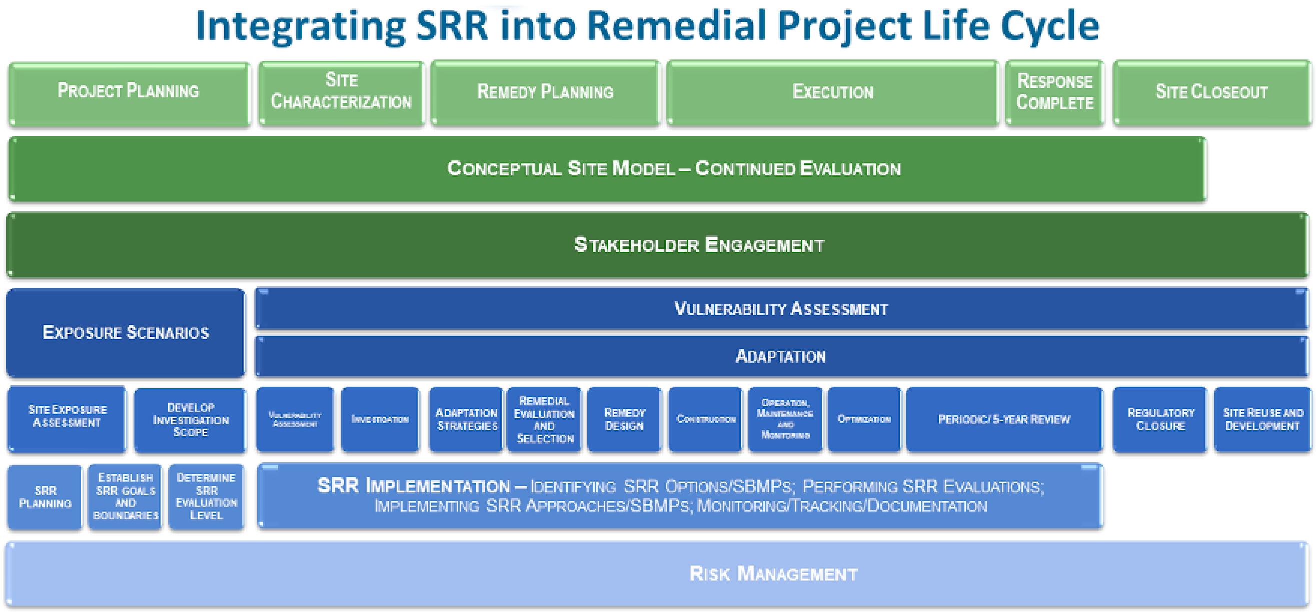


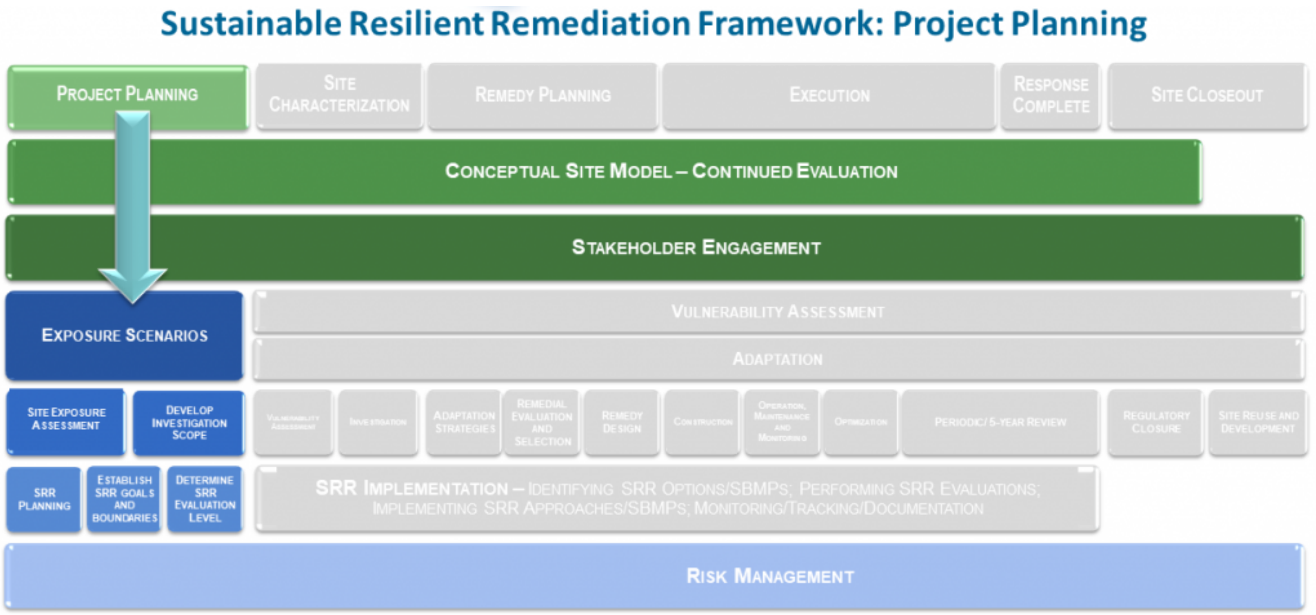
Figure 6-1. SRR framework.

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.



Return to Framework

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.

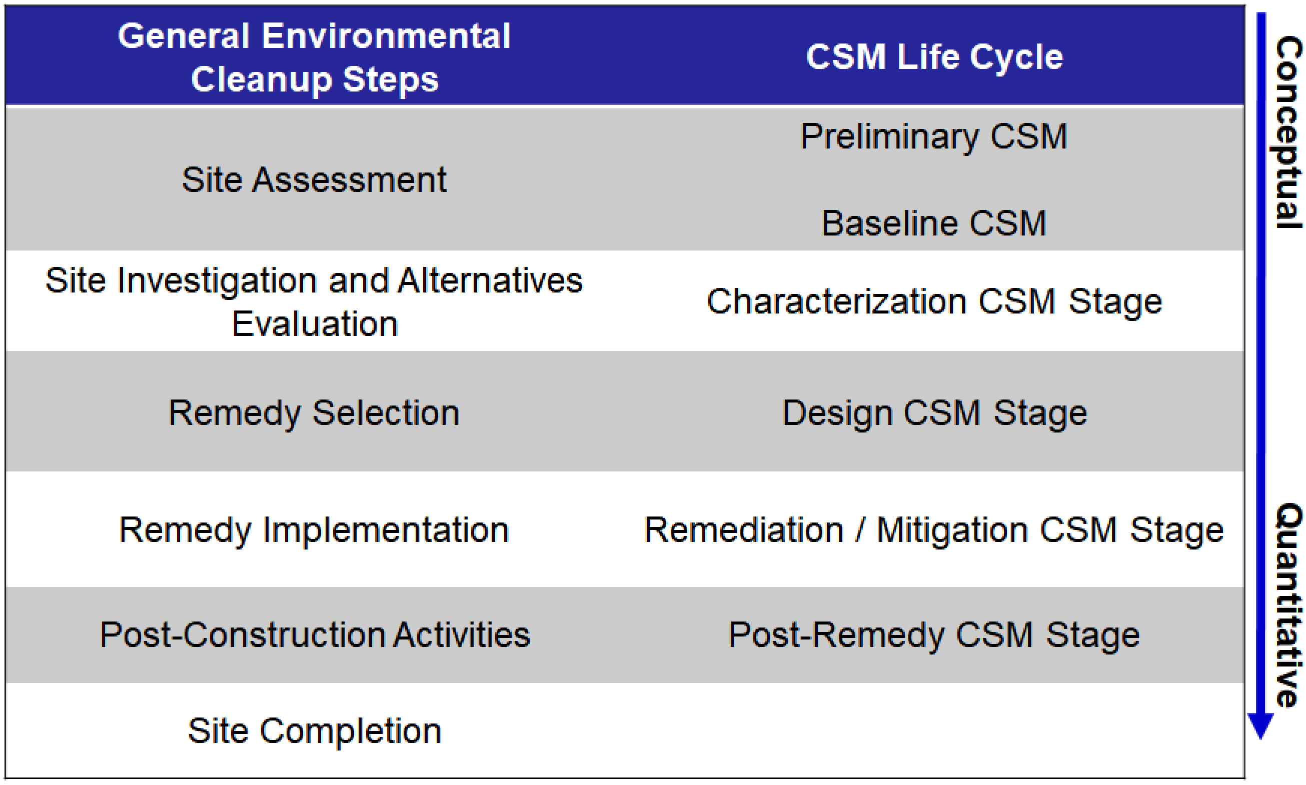


Figure 6-3. Environmental cleanup best practices: Effective use of the project life cycle CSM.

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.

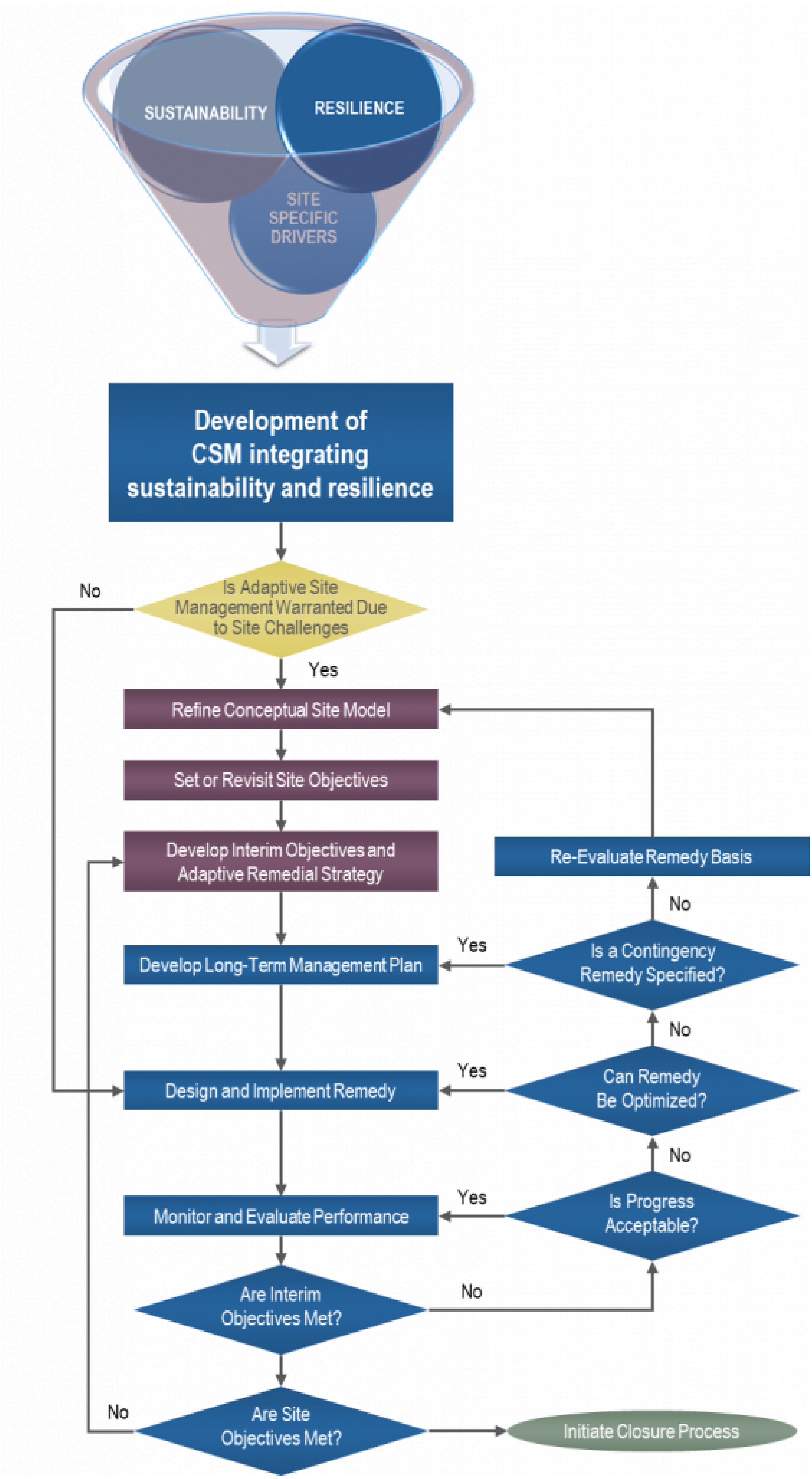

SUSTAINABILITY
RESILIENCE
SITE SPECIFIC DRIVERS
Development of CSM integrating sustainability and resilience
Is Adaptive Site Management Warranted Due to Site Challenges
No
Yes
Refine Conceptual Site Model
Set or Revisit Site Objectives
Develop Interim Objectives and Adaptive Remedial Strategy
Re-Evaluate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

Figure 6-4. SRR CSM.
Source: Adapted from ITRC (2017).

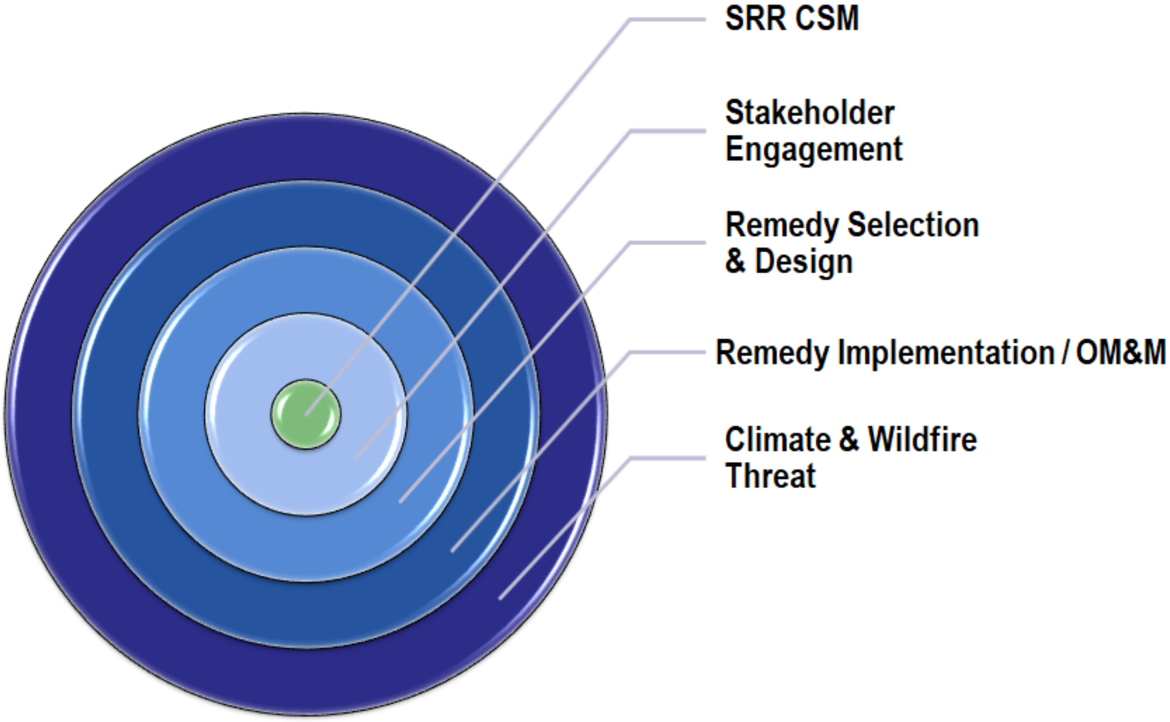


Figure 6-5. Expansion of CSM influences.
Source: Roy Thun. Used with Permission.

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).

Return to Framework

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 that are 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 of tools, 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 the International Association for Public Participation's Public Participation Spectrum

Return to Framework

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.

Return to Framework

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.

Return to Framework

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.

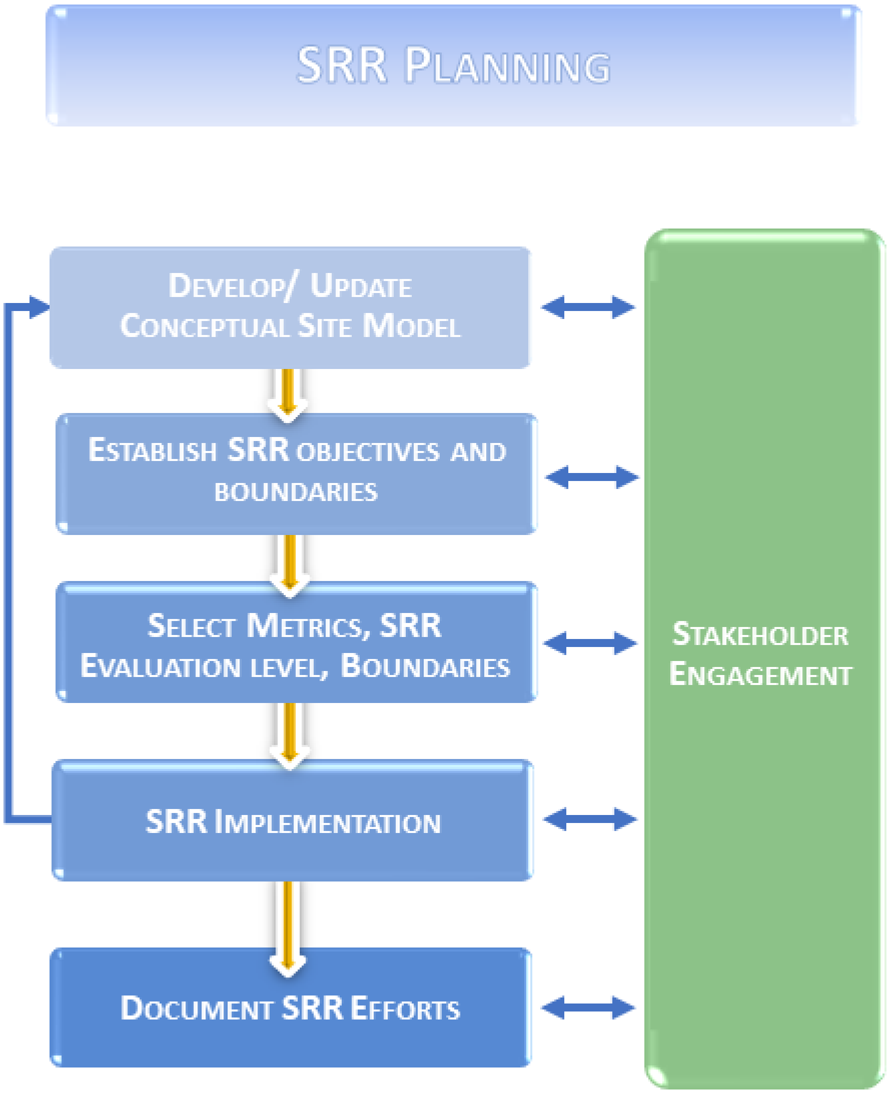


Figure 6-6 SRR planning.
Source: ITRC SRR Team.

- *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.

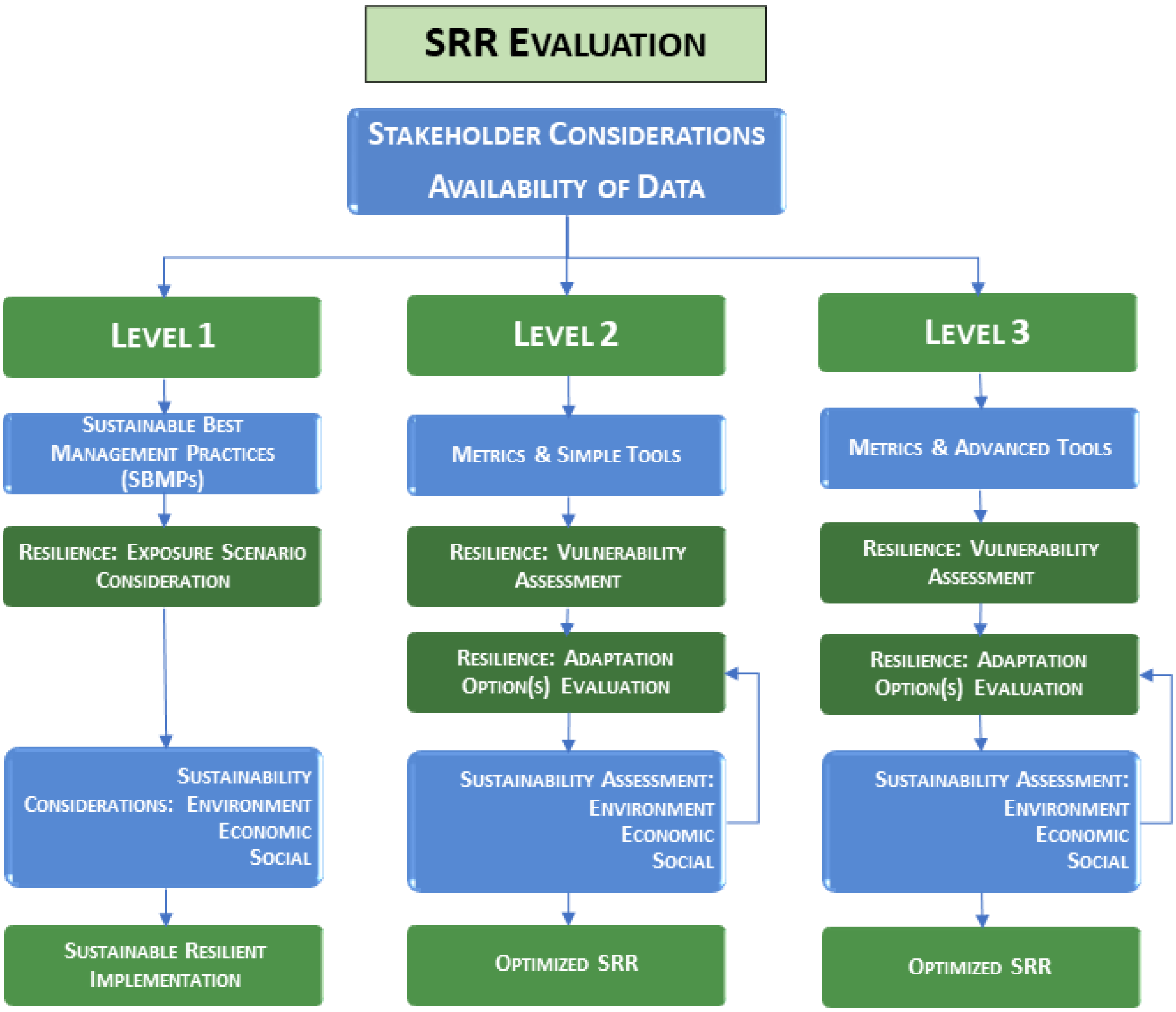


Figure 6-7. SRR evaluations.

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.

Return to Framework

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).

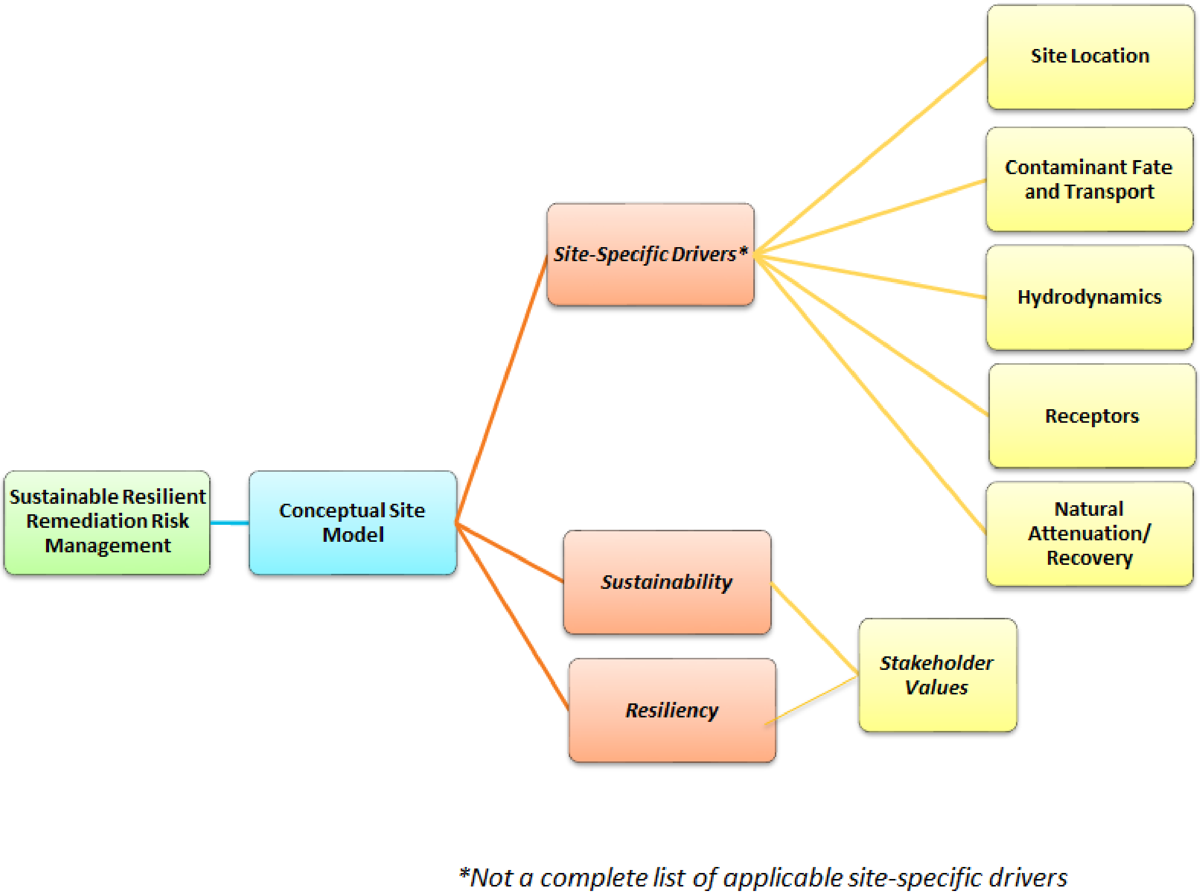


Figure 6-8. Example of SRR risk management approach.
Source: ITRC SRR Team.

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.

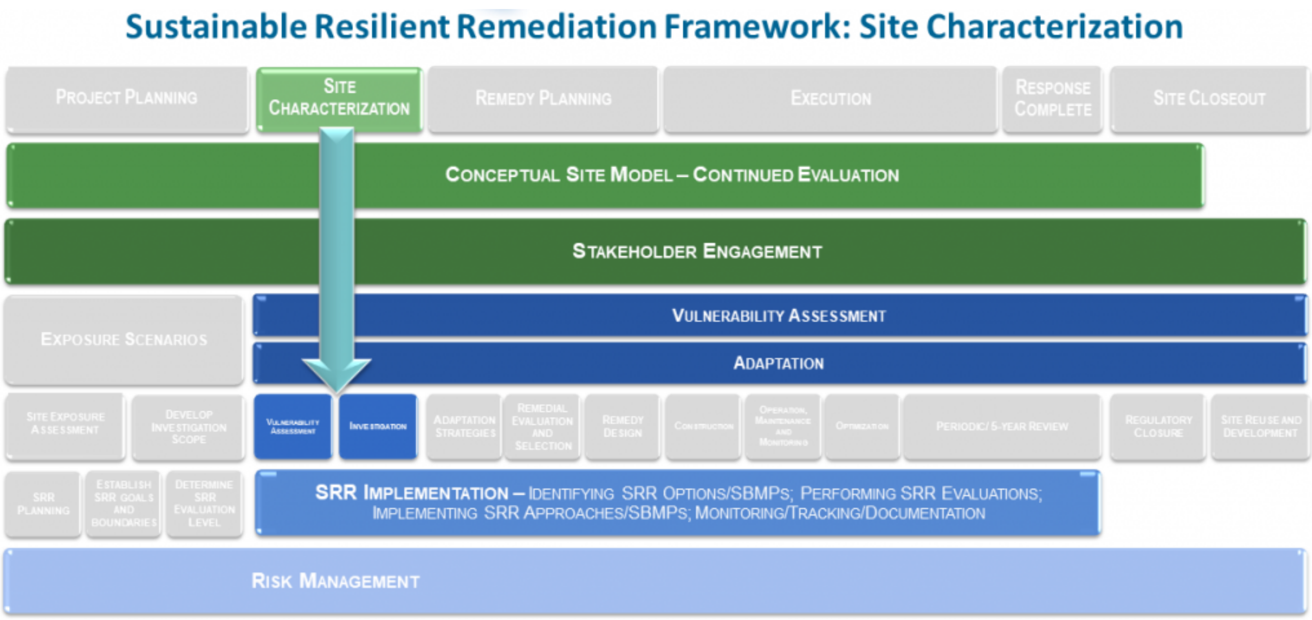
Sustainable risk management is the process of identifying, evaluating, selecting, and implementing actions that mitigate unintended environmental, social, and economic impacts from cleanup and restoration activities. The severity of risk or unintended impact is defined by stakeholder concerns and values 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.

Return to Framework

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.



Return to Framework

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.

Return to Framework

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.

Return to Framework

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 knowledge and 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).

Return to Framework

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).

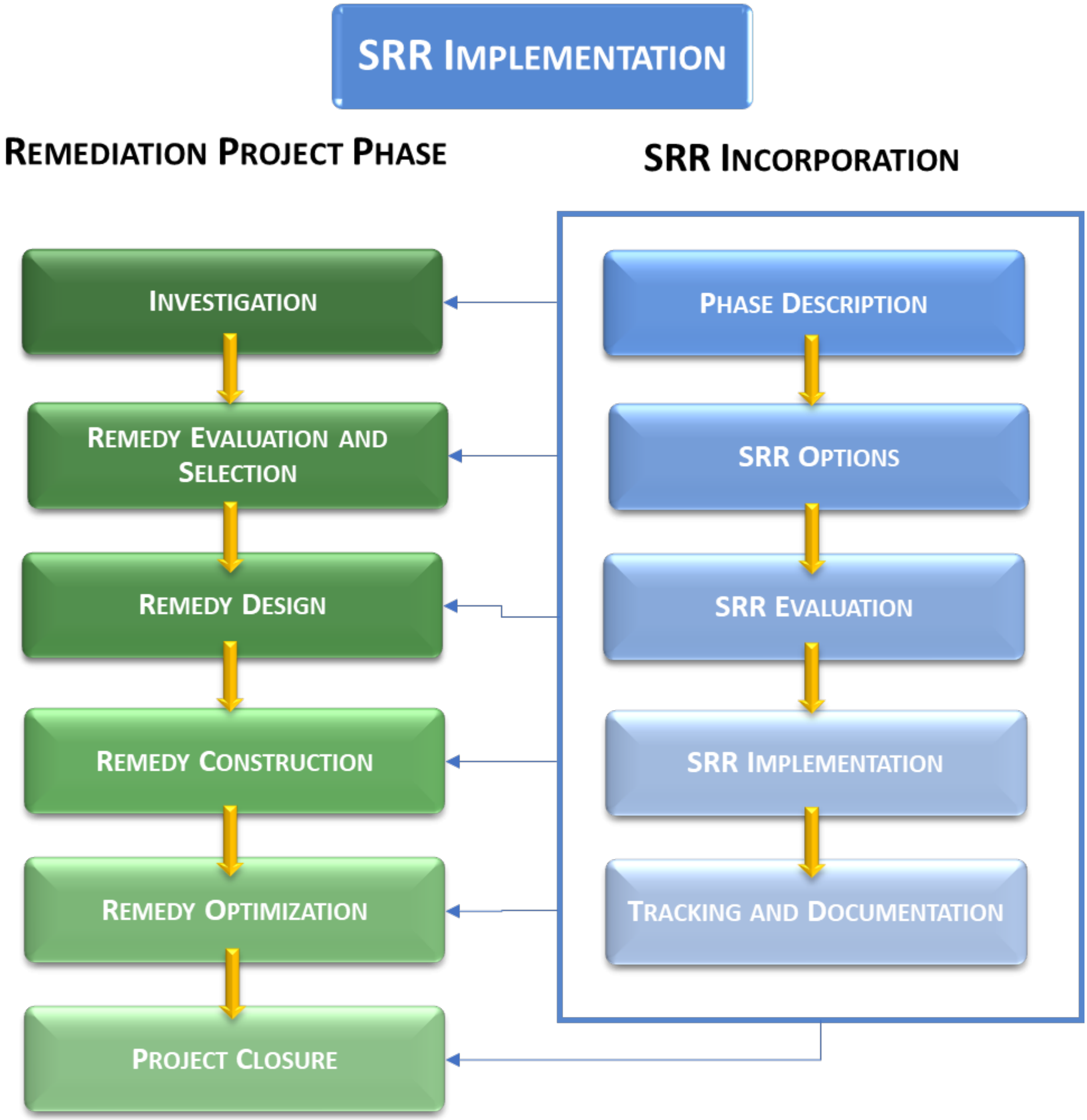


Figure 6-10. SRR implementation.

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.

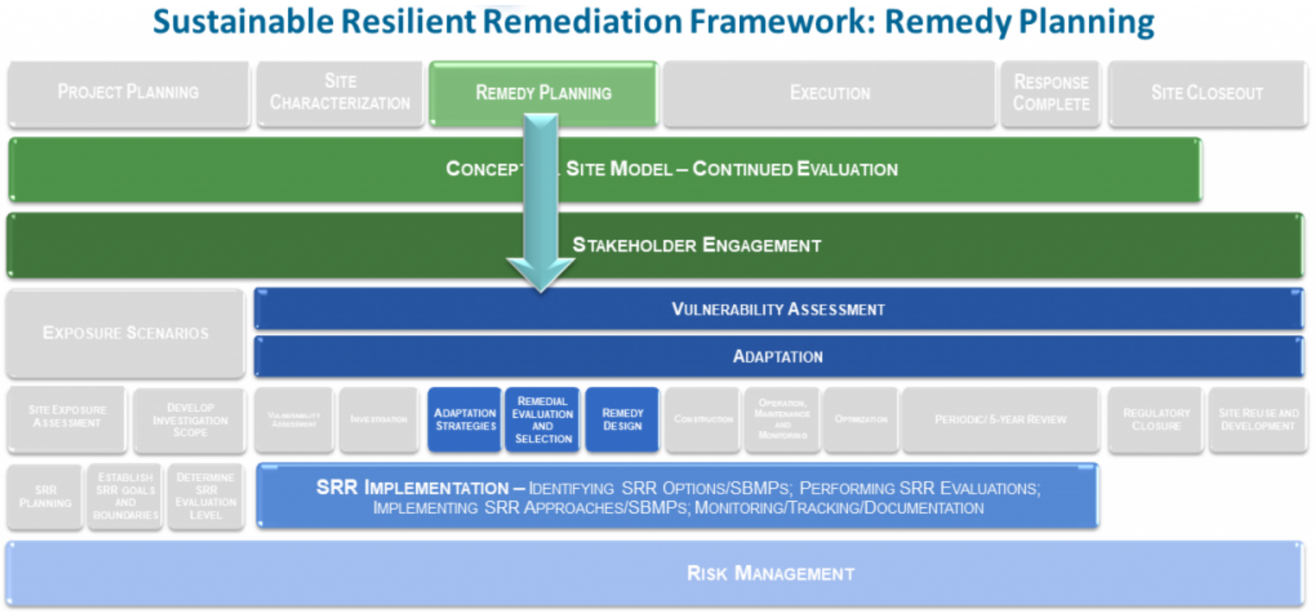
Return to Framework

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.



Return to Framework

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 to climate-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.

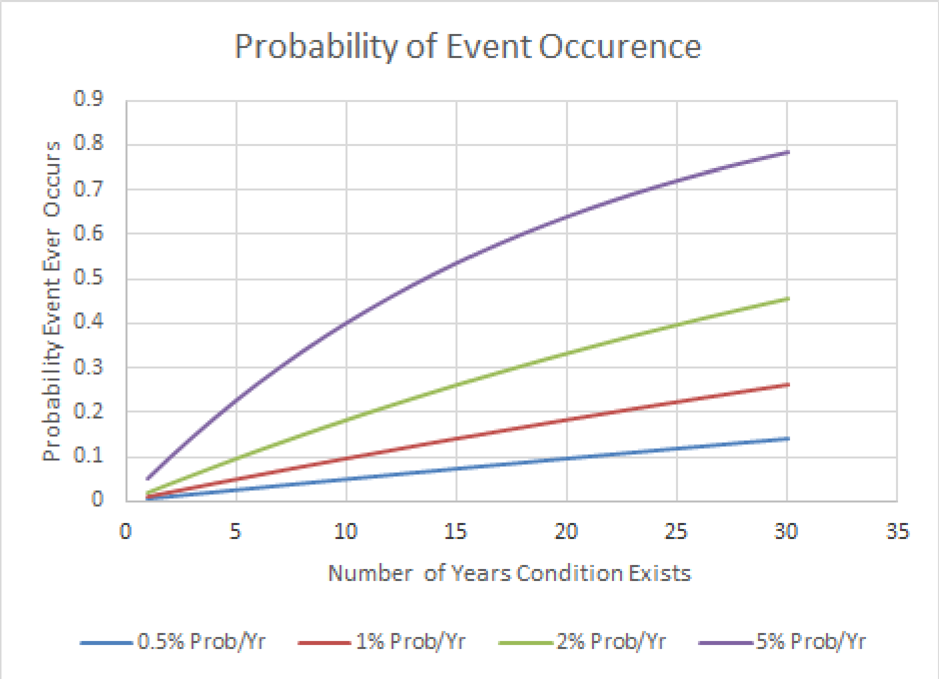


Figure 6-12. Probability of extreme weather event or wildfire occurring vs. length of time.
Source: ITRC SRR team

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.

Return to Framework

6.3.6 SRR Implementation

See Section 6.2.6

6.3.7 SRR Risk Management

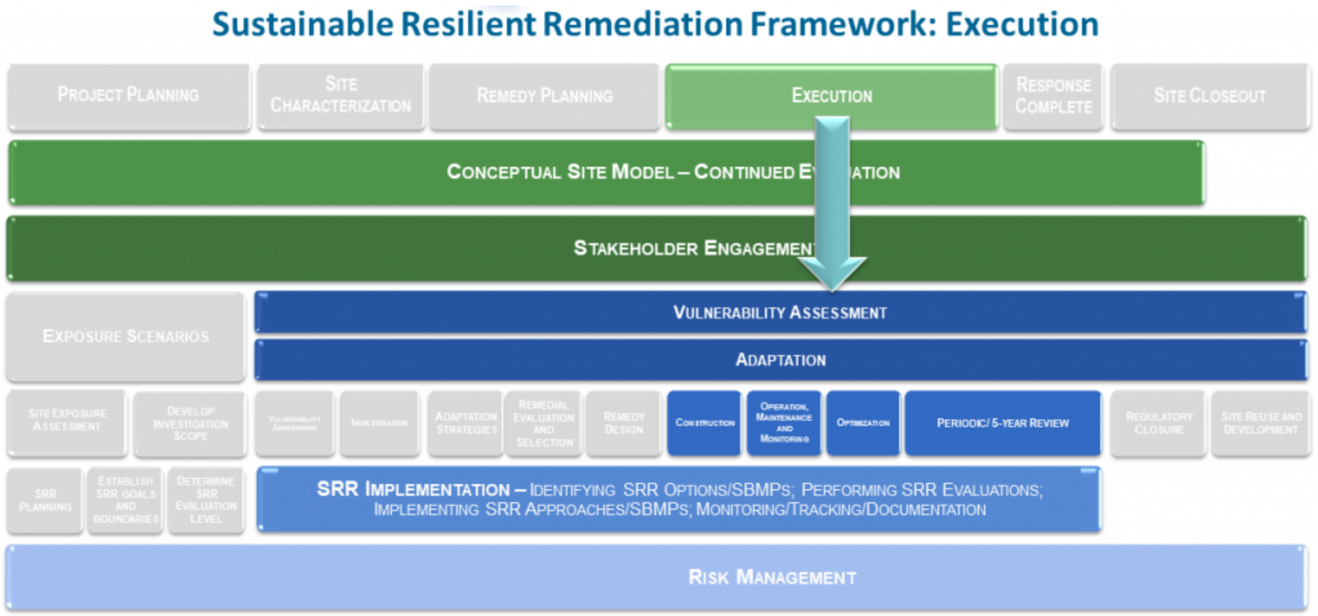
See Section 6.2.7

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).



Return to Framework

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.

▼Read more

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

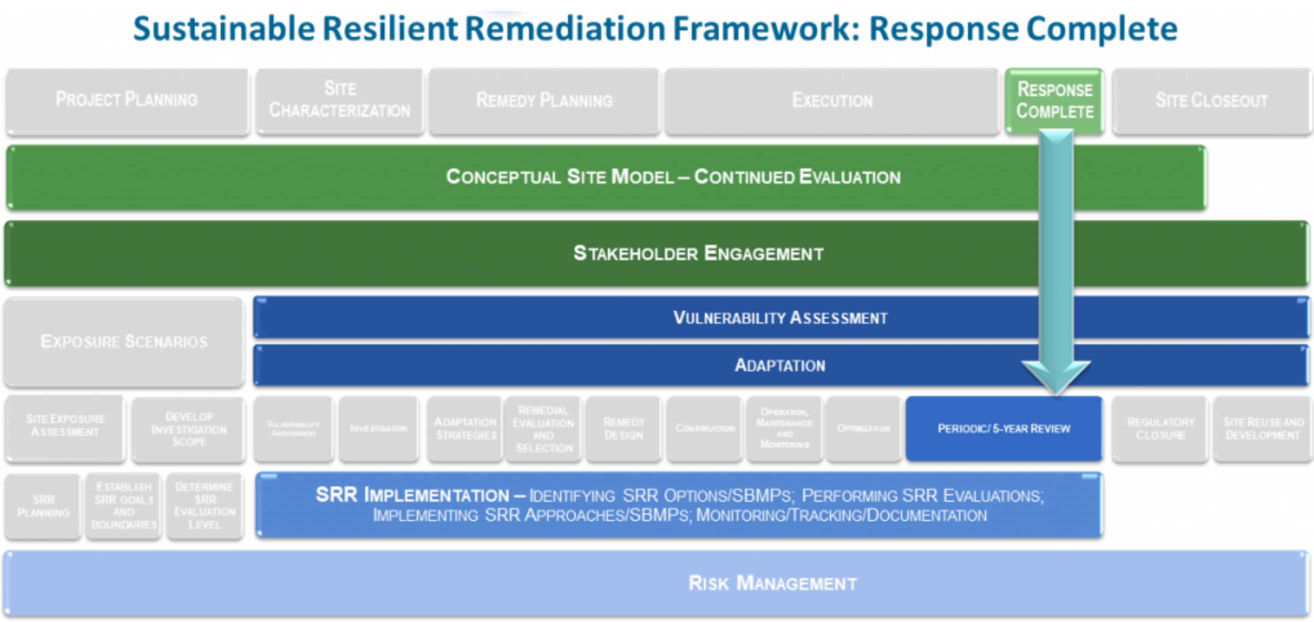
See Section 6.2.6.

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.



Return to Framework

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

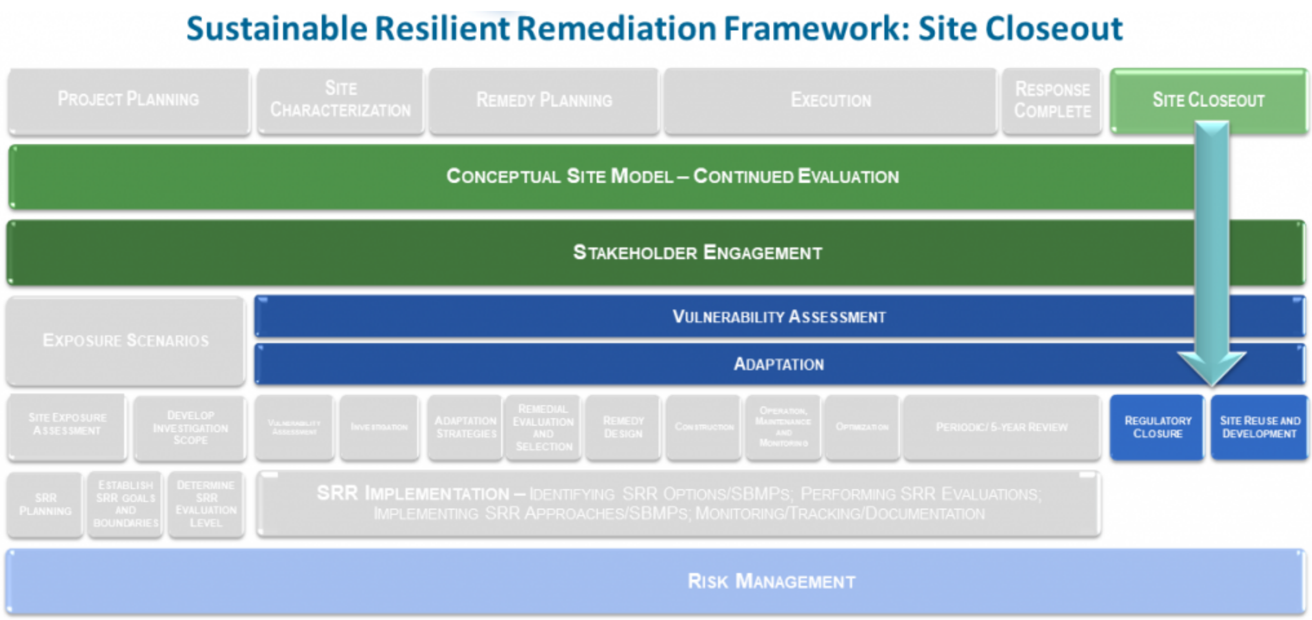
See Section 6.2.6.

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.



Return to Framework

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).

Return to Framework