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SuRF-UK bulletins provide additional guidance for implementing sustainable remediation.

Resilience and Adaptation for Sustainable Remediation

1. INTRODUCTION

Climate change is one of the biggest challenges facing society. In its latest report the Intergovernmental Panel on Climate Change (IPPC) noted that human-induced climate change, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability (IPCC, 2022). Society as a whole will be required to adapt and become more resilient to climate change (more detailed definitions for key terms are shown in Box 1). 'Business as usual' is not an option (Environment Agency, 2021).

Within the field of land contamination the concept of sustainable remediation already acknowledges the potential benefits and impacts associated with remediation and seeks to identify the optimal solution based on consideration of environmental, social and economic indicators (CL:AIRE, 2010). In the United States the Interstate Technology and Regulatory Council (ITRC) recently published a report entitled Sustainable Resilient Remediation (SRR) where SRR was defined "*as an optimized solution to cleaning up and reusing hazardous waste sites*[1] *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*" (ITRC, 2020). The release of the ITRC report and the definition of SRR prompted SuRF-UK to consider the current provision for incorporating climate change and broader considerations of resiliency in the context of current UK practice.

This bulletin summarises the main outcomes of this SuRF-UK work. It aims to:

1. Explain the context of resilience for remediation related to challenges such as climate change, but also resilience to economic and institutional change;
2. Explain how the SuRF-UK guidance on sustainability assessment explicitly considers resilience in several criteria;
3. Explain how proper consideration of resilience reduces project risks, especially for longer term projects and future land stewardship.

Interest in this topic area is not new, and resilience is directly considered in key remediation guidance documents in the UK. This bulletin explains how these considerations can be directly and transparently included in sustainability assessment. As early as 2007 work carried out as part of the Sustainable Urban Brownfield Regeneration: Integrated Management (SUBR:IM) research consortium (CL:AIRE, 2007) examined stakeholder perspectives and strategies, provided preliminary technical evidence of potential impacts of climate change on contaminated land and remediation systems and discussed potential technical adaptation strategies. The report concluded that certain climate change scenarios will have significant impacts on current and future contaminated land and remediation systems. Examples include severe physical damage to soil cover systems and stabilised/solidified soils, and extensive soil erosion and associated sediment/dissolved contaminant transport. In 2010 in its good practice guidance Guiding Principles for Land Contamination, the Environment Agency identified the requirement to consider climate change both in terms of mitigating greenhouse gas emissions during implementation, and in terms of the durability of the remediation options being considered (Environment Agency, 2010). Climate change and sea level rise were key drivers of CIRIA guidance on the Management of Landfill Sites and Land Contamination on Eroding or Low Lying Coastlines published in 2013 (Cooper *et al*., 2013) and updated in 2018 (Nicholls *et al*., 2018). Existing Environment Agency guidance on remediation technologies like Monitored Natural Attenuation (MNA) (2000) and Permeable Reactive Barriers (PRB) (2002) include the need to adapt to changing conditions anticipated over the long duration the risk management approach is implemented. Currently the Environment Agency Land Contamination Risk Management (LCRM) guidance (Environment Agency, 2021) includes recommendations to consider the potential implications of climate change at all three stages of the land contamination project lifecycle (risk assessment, remediation options appraisal, and remediation & verification). Detailed consideration is the subject of a number of on-going studies (being funded by the Environment Agency). Readers are advised to look for updates from the Environment Agency on gov.uk, or on the CL:AIRE (SuRF-UK) website.

Box 1: Defining Adaptation, Resilience and Vulnerability [to climate change] (United States Environmental Protection Agency (USEPA), 2022)

Adaptation Adjustment or preparation of natural or human systems to a new or changing environment which moderates harm or exploits beneficial opportunities.

Resilience is the capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment.

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

[1] The definition of 'hazardous waste sites' in the US is broadly equivalent to 'land contamination sites' in the UK.

2. ADAPTATION AND RESILIENCE IN CONTAMINATED SITE MANAGEMENT

2.1 Role of Resilience in Contaminated Soil and Groundwater Projects

To ensure that successful risk management of land contamination is maintained against the diversity of challenges presented by climate change but also financial and institutional changes (see Box 2), it is important that projects can adapt effectively when needed to make projects as resilient as possible. By doing this, the vulnerability of projects to these climate change related impacts is reduced.

2.2 Climate Change Resilience

Climate change, resulting from the addition of greenhouse gases to the atmosphere, is having and will continue to have a profound effect on the environment, society and the economy. As the Earth warms and the total energy in the climate system increases, the climate and Earth systems react in different ways, such as changes in the hydrological cycle, rising sea levels and water temperatures, melting ice caps and glaciers, and increased likelihood of extreme weather events. The range of potential changes as well as potential impacts of climate change are shown in Figure 1 (Met Office, 2022). The international consensus is to limit warming to an average of 1.5^{o}C against pre-industrial levels based on the commitments written and ratified during the Conference Of the Parties (COP) conferences in Paris and Glasgow (UK Government, 2021). However, the rate of climate change and the relatively slow implementation of mitigation actions as well as the influence of positive feedback mechanisms (such as melting of polar ice caps reducing solar radiation reflectance and therefore accelerated warming over time, or permafrost melting resulting in increased greenhouse gas emissions) mean that climate change and the impacts of climate change will persist into the medium (i.e. 5-15 years) and long term (i.e. 15-30+ years) and therefore society must adapt to manage its effects (World Meteorological Organization, 2020).

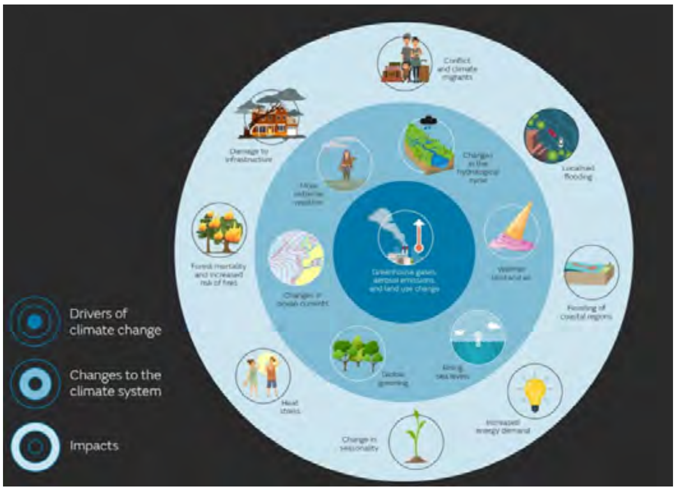

Figure 1. Effects of climate change (Met Office, 2022).

From a land contamination perspective, the impacts of climate change have the potential to undermine both long and short-term (i.e. <5 years) risk management activities. It has the potential to alter the dynamics between the source, pathway and receptor to make sites (especially those in coastal areas (Bardos *et al*., 2020)) more or less sensitive to risk from impacted soil and groundwater. A summary of the potential effects of climate change on soil and groundwater risk management is given in Table 1 and Table 2 (adapted from Maco *et al*., 2018). This list is not exhaustive but does illustrate the wide ranging impacts climate change can and will have on land contamination projects.

Box 2: Financial and Institutional Resilience

In addition to climate change, there are two resilience considerations for remediation options that need to remain functional over a long period (e.g., containment systems, pump and treat). These are resilience to changes in financial or economic circumstances, and resilience to changes in institutional and governance circumstances. That is to say, resilience to changes across all of the pillars of sustainability, environmental (principally focused on climate), economic or social.

The financial and economic provisions for long-running remediation actions such as pump and treat need to be in place to ensure risks can be managed effectively. Furthermore, some remediation actions may require monitoring over a long period, and if these costs cannot be met then the risk management performance is no longer verifiable. The circumstances by which such changes in the financial or economic mechanisms may occur could be through changes in wider macroeconomic conditions, changes to the funding mechanisms for activities at a site, or new site ownership and liability management. Financial arrangements for long term interventions therefore need to be resilient over time.

Institutional controls cover a wide range of non-engineered instruments, such as administrative and legal controls, that help to minimise the potential for exposure to contamination and/or protect the integrity of a response action (USEPA, 2012). They can include governmental or other legal controls (e.g. land deeds) that impose restriction on land or resource use in a particular area, proprietary controls that can prohibit activities on a site that may compromise the remediation or mitigation action. Over time, institutional controls could be subject to change based on wider governmental changes or priorities, policy changes or changes in stakeholder perspectives. Institutional controls often underpin long-term remediation projects, hence the role of good record keeping and knowledge transfer to ensure decisions and actions are recorded to inform future site management for both site managers and those regulating them.

Other resources exploring the impacts of climate change on land contamination

The topic of climate change and implication for land contamination risk management is quickly gaining traction. Other organisations such as CIRIA and the Environment Agency are developing materials to support our understanding of how climate change impacts land contamination projects with a focus on UK-specific regulatory setting.

Table 1. Example impacts of climate change on soil and groundwater risk management activities (adapted from Maco *et al.*, 2018).

Change to the climate system	Impacts of climate change	Consequent risk management- impacts
Altered precipitation pattern	Wetter and less predictable: Flooding, storms, more runoff, erosion	Mobilisation of contaminants (e.g., from vadose zone to groundwater) → Higher contaminant concentration/export, overpowering significant degradation rate in groundwater zone could remove natural protective barriers or cause infill subsidence in low-lying areas
	Drier: Drought	Oxidation of soils Increased volatility Less dilution → Higher contaminant concentration/export Reduced mobilisation → Higher contaminant persistence (higher contaminant concentration/ export) Insufficient water for remediation; Overuse of groundwater Possible enhanced natural attenuation, expedited contaminant removal
	Altered salinity	Altered degradation rates (physical, microbial), Increased leaching
Sea level rise	Erosion	Damage to site integrity
	Site inundation	Increased mobilisation of contaminants, possible dilution, or compromised site with mixing or loss of contaminated materials, increased bioavailability of contaminants
	Sediment mobilisation	Mobilisation of contaminants where clean sediments are transported on top of contaminated sediments
	Elevations increase	Changing footprint of flood plains, river boundaries, and coastal shoreline encroachment → Impact on regulations (e.g., dredging, cleanup levels, negotiation of water levels, monitoring)
	Altered salinity	Altered degradation rates (physical, microbial), Increased leaching
Extreme weather	Scour (wind/wave action; surface water flow velocity)	Damage to site integrity, capping systems
	Flooding	Possible dilution (lower contaminant concentration/export), or compromised site with mixing or loss of contaminated materials, damage to capping systems
	Extreme heat	Increased volatility → Mobilisation of contaminants from site through soil and air Changes in use of site by wildlife
	Freezing conditions	Damage to capping systems and *in situ* stabilisation systems
Increasing temperature	Altered transformation or degradation	Increased or decreased toxicity, degradation, volatilisation
	Decreased dissolved oxygen/ anoxic conditions	Altered transformation, decreased species resilience
	Increased species heat stress and associated conditions	Increased sensitivity to contaminants

Table 2. Example impacts of climate change on remediation technologies (adapted from Maco *et al.*,2018).

Remediation approach	Technique	Climate change impact for remediation activity
Soil treatment	Bioremediation	Degradation activity may change, unexpected intermediaries
	Landfarming	Inundation of site by sea level rise or flooding
Groundwater treatment	Pump and treat	Altered rate of recharge and extraction
Removal of contaminated materials		Extreme weather, flooding, or sea level rise will complicate containment Groundwater level decline may support expedited removal
Engineered *in situ* solutions	Soil washing	Insufficient water would limit feasibility
	Soil extraction	Warmer temperatures may help
	Natural attenuation	Models do not include climate change which may alter resident time of contaminants in soil Attenuation rates may vary
	Incineration	Emissions allowances may change due to temperature or greenhouse gases
	Capping systems	Climate change may degrade the cap (e.g., because of extreme precipitation

2.4 Overlapping and Exacerbated Impacts

Land contamination projects need to be resilient to risks in addition to those caused by climate change impacts. Resilience to financial and institutional impacts are especially relevant to projects that run over a long period of time (Box 2). The impacts associated with climate change and changes to financial and institutional controls, can each be detrimental to a project. But there are circumstances where these could combine to present a greater impact to continued risk management on a project. Examples could be the impact of climate change to drive changes in stakeholder perspectives on environmental issues; or climate change impacts driving changes to institutional controls such as land management priorities.

In terms of remedy selection, more intrinsically resilient solutions would be those that are effective over a shorter period, so with a lower demand on long term financial and institutional provision; otherwise institutional and financial resilience has to be built into the solution. However, resilience is only one component of project decision making and should be weighed against the project-specific advantages for pursuing a long-term risk management option.

3. IS RESILIENCE CONSIDERED IN THE LAND CONTAMINATION REGULATORY FRAMEWORK?

Although climate change resilience is a relatively recently used term, the land contamination legislation in the UK already includes requirements that effectively address resilience.

Under the Environment Protection Act 1990, Part 2A, contaminated land remediation must be reasonable. In deciding what is reasonable, various factors must be considered including whether the remedial approach would be practicable, effective and durable. The requirement for both durability and effectiveness mean that any remediation option that is not resilient to changing circumstances, to the point that it fails to reduce risks to an acceptable level, is unlikely to meet the test of being 'reasonable'.

For land affected by contamination, remediation undertaken under the town & country planning system or voluntarily, the Environment Agency's supporting LCRM guidance states that options appraisal should seek to "*achieve sustainable remediation considering any reasonable climate change issues*".

4. HOW RESILIENCE IS ADDRESSED IN SuRF-UK FRAMEWORK

4.1 Project Lifecycle

In the SuRF-UK framework resiliency can be considered at several stages:

- at the outset of a project when the sustainability objectives are being developed;
- as part of the project definition phase (as defined in SR1 (CL:AIRE, 2020a)); and
- in the sustainability appraisal when identifying relevant social, environmental and economic indicators to include for the project.

SuRF-UK has developed a series of indicators to serve as a benchmark (the headline indicator categories are summarised in Table 3) that can be evaluated and applied on a site-specific basis.

Table 3. SuRF-UK Headline Sustainability Indicators (CL:AIRE, 2020b).

Environment	Social	Economic
Emissions to Air	Human health & safety	Direct economic costs & benefits
Soil and groundwater conditions	Ethics & equity	Indirect economic costs & benefits
Groundwater & surface water	Neighbourhoods & locality	Employment & employment capital
Ecology	Communities & community involvement	Induced economic costs & benefits
Natural resources & waste	Uncertainty & evidence	Project lifespan & flexibility

Consideration of resilience is directly addressed in the SuRF-UK indicator set (CL:AIRE, 2020b), under the economic indicator set and specifically as part of the "Project lifespan and flexibility" sustainability headline indicator category (underlined in Table 3). This headline indicator category includes seven sub-indicators, of which four are considered applicable to resilience (Figure 2). These sub-indicators are likely to be qualitative and best framed in discussion with the providers of the shortlisted remediation options, or in the case of institutional controls the policies and perspectives of regulators and/or the planning authority. Furthermore, their relevance to a specific project may vary between the different stages of the framework they are applied to. For example, when setting the remediation strategy, having knowledge of the likely local and regional implications of climate change will help define whether a long or short-term remediation approach is favourable, whereas consideration of this sub-indicator at Stage B of the framework and the options appraisal, may be limited, especially if the remediation is anticipated to be completed over a short timescale.

Figure 2. Individual indicators under the "Project Lifespan & Flexibility" headline indicator that may be directly relevant to the consideration of resiliency in a project (CL:AIRE, 2020b).

When resiliency to climate, financial or institutional change are identified as key considerations for a project, the relevant indicators can be carried forward and the SuRF-UK framework adapted to incorporate them through the project lifecycle (Figure 3).

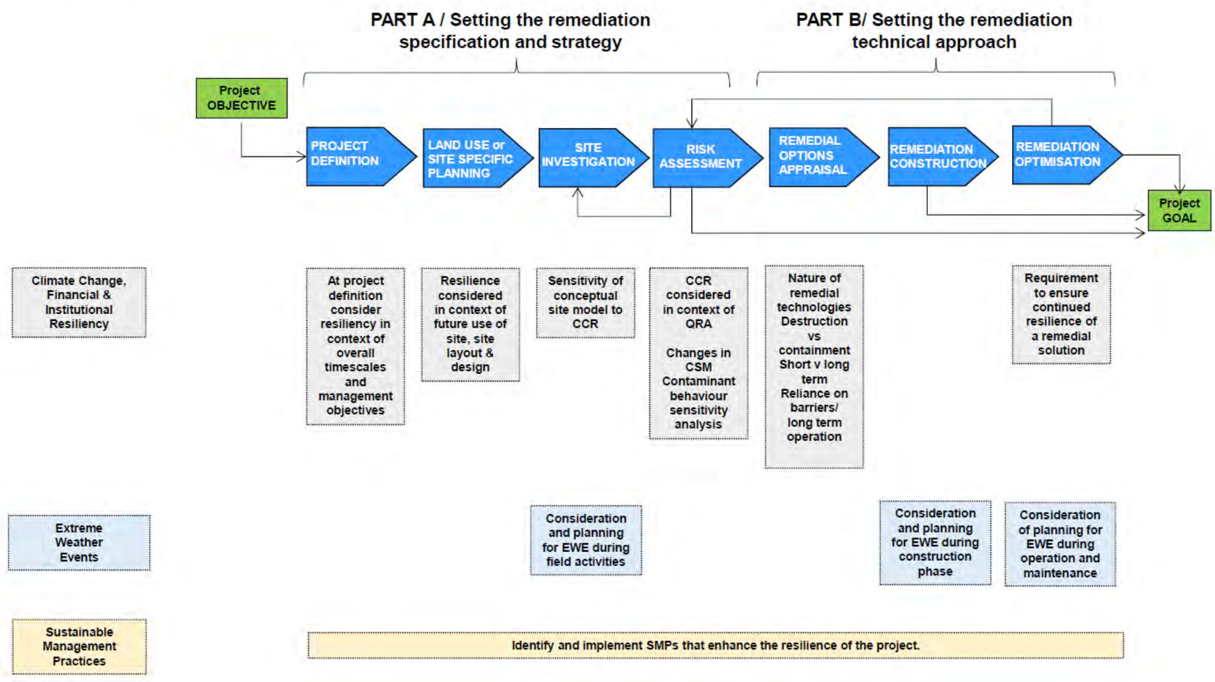

Figure 3. Opportunities to incorporate resiliency to climate change impacts across the project lifecycle. Abbreviations: CCR - Climate Change Resilience; EWE - Extreme Weather Event; QRA - Quantitative/ Qualitative Risk Assessment.

Part A/ Setting the remediation specification and strategy (according to Fig. 3)

At the beginning of a project, considering resilience at both project definition stage and the land use and site planning stage will provide valuable insights into the extent resilience needs to be incorporated into the project. Understanding of the project's location and duration may be sufficient to justify a more in-depth evaluation of the potential climate change impacts on the project.

The ITRC SRR document (Box 3) provides detail on developing climate change vulnerability assessments that help develop an understanding of the potential future risks. There are a range of global and UK specific tools that may be helpful when evaluating project risks from climate change:

- UK flood risk maps
- UK Climate Projections
- UK Climate Change Risk Assessment
- UK Future Flow and Groundwater information (eFLaG datasets)
- UK Coastal erosion management
- Projections of future coastline

At the site investigation stage, climate change impacts may have implications for the development of the Conceptual Site Model (CSM). Recent research by CIRIA (in prep) helps to develop an understanding of the UK-specific considerations that climate change may introduce to a CSM. In addition, the increased likelihood of extreme weather events may disrupt field activities, hence robust contingency planning to mitigate the impacts to the project schedule will be necessary.

Risk assessments may be especially subject to the influence of climate change impacts because of the range of potential impacts over time and the subsequent influence on contaminant fate and transport. Guidance on incorporating climate change impacts into risk assessment has recently been published by SoBRA (2022).

Box 3: Sustainable and Resilient Remediation

If remediation is required to be or is anticipated to run over a long time period (such as capping) or is in an area especially vulnerable to extreme weather events or other aspects of climate change, it may be worth evaluating the impacts in more detail. This could be through incorporating exposure scenario evaluations and site exposure assessments to understand the likely climate or extreme weather hazards that the site could be exposed to over the duration of the project.

ITRC (2020) presents a tiered approach for these evaluations with more complicated projects requiring a more in-depth assessment commensurate with a higher tier of evaluation. If there is a viable scenario based on site history and forecasts, then a vulnerability assessment is used to identify the various climate and extreme weather scenarios that could impact the site. The results help prioritise potential options to increase the site's resilience to identified potential climate and extreme weather events. The findings of these assessments are included into the CSM.

Part B/ Setting the remediation technical approach

When selecting a remediation technique, it is important to consider how vulnerable it is to climate change impacts. Typically, those technologies that are short term in implementation and operation are likely to be less vulnerable to climate change impacts and therefore more resilient compared to remediation options that run over longer time periods. Although, as indicated in Figure 2, the remediation construction stage of a project may be sensitive to extreme weather events – even in the short term. Technologies that fit into the former category (such as, excavation and onsite treatment, soil vapour extraction or thermally enhanced vapour extraction) are typically those designed to destroy contaminants (depending on the long-term behaviour of any residual contamination) and target the source zone. Technologies that may require more consideration for the influence of climate change and financial and institutional impacts are typically those that rely on longer term operation and maintenance and are typically based on isolating or containing contamination (like hydraulic containment, capping or MNA). In most of the examples, as noted above, the construction and installation of the remediation works has the potential to be subject to extreme weather events and the associated logistical and remediation performance issues that need to be managed.

Ongoing operation and optimisation of some remediation systems has the potential to run over medium to long timescales, especially for options relying on pathway interception (e.g. pump and treat) or receptor protection (e.g. institutional controls). It is crucial that resilience to changes in climate, financial and institutional controls are incorporated into these projects. These types of resilience considerations are a key part of the land stewardship approach (Box 4) and the process of evaluating and adapting to changes to maintain risk management are an integral part of the approach (NICOLE, 2020).

Box 4: Land Stewardship

The land stewardship approach to managing sites whereby there is a collective recognition of the natural, social and economic capital that land possesses or may possess, and our responsibility and potential to unlock and conserve that value for the future (NICOLE, 2020). These projects by definition, operate over longer time periods and therefore require a level of resilience that ensures that not only are risks managed but the intrinsic value of the land is maintained and shared. The NICOLE Land Stewardship guide (2020) captures the need for continually assessing the status of the land (Step A) and adapting to changes in the planning and execution of the land management approach (Step F). Land stewardship demonstrates the need to continually appraise the risks associated with changes to climate, financial or institutional circumstances for projects active over long time periods.

4.2 Recommendations for Practical Measures at all Stages of Site Management in SMPs

Sustainable management practices (SMPs) are relatively simple, common-sense actions that can be implemented at any stage of a land contamination project or portfolio of works. SuRF-UK has recently updated and published its guidance on SMPs (CL:AIRE, 2021). The guidance includes a common set of SMPs listed in a spreadsheet that can be tailored to the needs of the practitioner or client; the list can be refined based on project stage or the particular aspect of sustainability they are trying to target. Those SMPs, taken from the spreadsheet, that could be selected to enhance a projects resilience are included in Table 5.

Table 5. SMPs relevant to "Project Lifespan & Flexibility" headline indicator and benefits associated with mitigating effects of changes in climate, financial or institutional controls.

SMP	SMP Benefit
Communicate remediation options to relevant stakeholders in a consultative process	Good communication with stakeholders to get buy-in for a particular approach is important to minimise impacts of financial changes or changes to institutional controls
Implement a plan to evaluate sustainability criteria/indicators sets for the project	Evaluates the appropriateness and effectiveness of the selected sustainability criteria and incorporate resilience if needed
Implement a plan to provide structured training in sustainable procurement practice	Improves the awareness of issues around resilience to the Procurement team
Implement a sustainable procurement plan for the project/site	Ensures that a commitment to sustainability and resilience are considered across the supply chain.
Obtain input on remediation options from relevant stakeholders and manage community needs and concerns	Good communication with stakeholders to get buy-in for a particular approach is important to minimise impacts of financial changes or changes to institutional controls
Plan site layout with regard to minimising the physical remediation required	The potential impacts from climate change could also be incorporated into the site plan to ensure remediation is more robust
Request that the functional performance specifications of products are supplied	Ensuring that the operational limits of materials and equipment can operate in the event of extreme weather events or other climate change impacts
Set sustainability criteria in the specification to motivate suppliers to provide more sustainable products and services	Drives a culture of sustainability across the supply chain
Consider that institutional controls are in place to secure future land use and funds to maintain the controls	Fundamental to managing changes in institutional controls and finance. This is facilitated by ensuring robust records management across the project lifespan to ensure decisions are recorded and their justification maintained for reference
Where appropriate, incorporate natural attenuation into a remediation strategy	Building in natural attenuation into a project plan can help ensure that, should the primary risk management approach fail, there is consideration of the fate and transport of substances in the wider environment
Ensure the remediation remains protective through adaptive management before and post-closure	The type and duration of the project may require alternative management approaches such as the Agile approach that focuses on collaboration, iterative design and feedback and continuous improvement (Henderson and Mu, 2021).

5. CONCLUSIONS

Land contamination project managers must navigate a range of operational risks in order to maintain controls and mitigate land contamination risks. Climate change and financial and institutional changes can introduce risks to projects and thereby undermine the effectiveness of certain risk management options. The SuRF-UK framework allows evaluation of resilience to be built into projects through incorporation of indicators at an early stage of the project and at the point of remedial option selection. Furthermore, the framework allows for the adoption of SMPs that can be implemented throughout the project lifecycle to maintain durable and effective risk management in a dynamic environmental, economic and social context.

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