7 Monitoring and Maintenance Objectives and Approaches

The monitoring approach for capping sites should consider both the RAOs and the cap chemical isolation performance targets (see Section 3.1.2), with the understanding that it is important to distinguish between remedy effectiveness and cap performance. The objective of remedy effectiveness monitoring is to verify that risk-reduction goals are being achieved by the remedy and to measure progress toward achieving individual RAOs. The objective of cap performance monitoring is to verify that the cap is performing according to its design. In addition to these monitoring objectives, monitoring and maintenance programs should be informed by site-specific factors that include the CSM, the nature of COCs, site use and setting, the status of source control, and other factors. An effective monitoring and maintenance program requires appropriate performance objectives, as discussed in Section 3.

The 2014 Contaminated Sediments Remediation guidance document (ITRC 2014) remains applicable to monitoring capping remedies and includes a detailed discussion of monitoring approaches and objectives, along with links to additional resources. Because the 2014 Contaminated Sediments Remediation guidance document (ITRC 2014) discusses recommendations for remedy effectiveness monitoring, the discussion of monitoring and maintenance provided here generally focuses on cap performance monitoring approaches.

This guidance recognizes that in many cases capping is only one element of the remedial action, and that other technologies may also be implemented to meet risk-reduction goals. Other remedial elements that are important to consider when establishing a cap performance monitoring program are elimination or reduction of continuing sources of contamination and the natural recovery of surface sediment contamination in the areas surrounding the cap. These processes may occur over longer time scales, and sediments with elevated COC concentrations may deposit over the cap surface in the interim. This guidance recommends a multiple lines of evidence approach to better understand chemical isolation performance of the cap in the context of cap surface recontamination.

7.1 Monitoring Phases

ASTM (2018b) has published extensive guidance on sediment monitoring, which is needed to evaluate overall sitewide remedial effectiveness, including any capped areas. The ASTM Standard E3164-18 (ASTM 2018a) describes three phases of monitoring: pre-remediation baseline characterization, monitoring during remedy construction, and post-remediation monitoring.

- Baseline characterization monitoring is completed prior to remediation (typically as part of the site characterization or predesign investigation) to establish the baseline against which progress toward achieving RAOs will be measured.
- Monitoring during remedy construction is conducted to confirm that the cap and any other elements of the remedy were constructed as intended. Construction QA/QC monitoring information, as discussed in Section 6.6, may play an important role in understanding long-term monitoring results, and thus should be referenced in a post-remediation monitoring and maintenance plan.
- Ongoing, long-term post-remediation monitoring is typically needed to inform periodic remedy evaluations, such as 5-year reviews, and may include both cap performance monitoring and remedy effectiveness monitoring.

The phases of monitoring are depicted in Figure 7-1. This guidance focuses primarily on evaluating the cap performance with respect to the chemical isolation function during the post-remediation monitoring phase. Pre-remediation (baseline) information is necessary for the interpretation of certain types of monitoring data and to understand overall remedy effectiveness. Interpretation of post-remediation chemical isolation performance monitoring results also relies on post-remediation baseline monitoring of capped areas (which may not be sitewide).

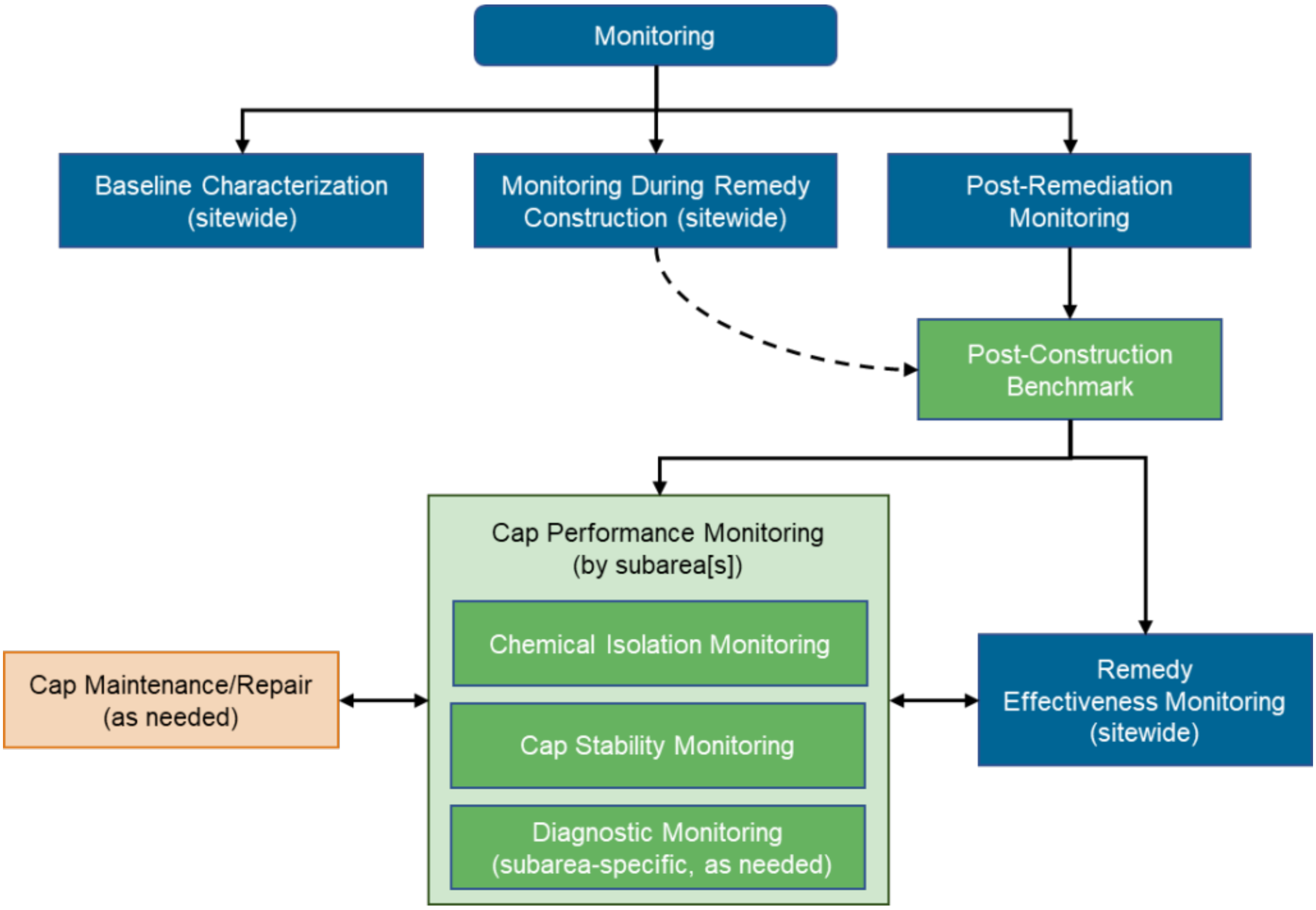

Figure 7-1. Chemical isolation cap monitoring programs.

Source: A. Lesser and K. Groff. Used with permission.

Figure 7-1 reflects the distinction between remedy effectiveness monitoring and cap performance monitoring (shown in green). As shown in Figure 7-1, cap performance monitoring includes diagnostic monitoring, which is intended to provide information to differentiate between chemical isolation performance and surficial cap recontamination due to deposition. As noted above, natural recovery processes may render caps irrelevant for achieving remedy effectiveness over the long term. In these cases, cap performance monitoring and maintenance may become less important or unnecessary.

The initial sampling after completion of remedy construction is a key benchmark that serves as a reference against which future monitoring results may be compared. Where data necessary to establish initial post-remediation conditions are not collected as part of the construction QA/QC program, these data should be collected shortly after construction is completed. A comprehensive post-construction sampling event, inclusive of any parameter and location anticipated for remedy effectiveness monitoring or cap performance monitoring, should be completed. This post-construction benchmark sampling event documents the progress toward achieving RAOs as a result of completing remedial construction. The post-construction benchmark data also serve as a point of comparison for maintaining RAOs or measuring ongoing progress toward achieving RAOs.

When interpreting post-construction data, including initial benchmark sampling results, it is important to note that contamination may be present within the cap material as a result of numerous factors, such as mixing with underlying materials during cap construction, contamination of cap material during placement (e.g., as a result of construction activities or natural causes such as wave-driven disturbances of adjacent impacted sediment), surface water quality, and inflow from impacted tributaries. Chemical analysis of cap material prior to placement is typically required to verify whether it meets construction QA/QC requirements and sediment RGs. Results of this analysis should also be considered during interpretation of long-term monitoring results, as the cap material may not have been totally free of contamination (e.g., dredge material used for cap construction). Monitoring data can be misinterpreted if baseline sampling is only conducted prior to construction (e.g., as part of a predesign investigation) and not shortly after construction.

Post-construction, most chemistry changes within the cap occur over the long term and would not be expected to be immediately apparent. Appropriate cap chemical monitoring intervals are determined on a site-specific basis and consider factors such as contaminant mobility, degree of monitoring difficulty, and cap design. The intervals may vary over time.

7.2 Cap Monitoring Objectives

The 2014 Contaminated Sediments Remediation guidance document (ITRC 2014: 155) states that "The primary long-term goal of capping is to provide sufficient containment of contaminants so that either of the following occur:

- The flux and near surface contaminant concentrations in a cap remain low enough that the cap is protective of the surficial sediments, the benthic community residing there, and overlying water.
- The contaminant is contained for a sufficient period to allow natural recovery processes to effectively make the cap irrelevant."

The 2014 Contaminated Sediments Remediation guidance document (ITRC 2014: 160-161) goes on to state that "the goal is to achieve adequate containment to delay or reduce the flux or contaminant levels in the biologically active, surficial sediments to negligible levels or to reduce the flux to the overlying water to levels that can be managed by natural attenuation processes. These processes can include contaminant transformation and degradation in the sediment or water column, but often are simply physical processes that lead to isolation (burial by natural deposition) or dilution of the contaminants."

Further, Table 5-2 of the 2014 Contaminated Sediments Remediation guidance document (ITRC 2014) identifies the following two objectives for post-remediation cap performance monitoring, along with potential chemical, physical, and biological monitoring approaches useful for evaluating these objectives (ITRC 2014: 159):

- "Determine whether the remedy has been successful in reducing mobility of COCs in sediment (and therefore near-surface COC concentrations) to acceptable levels (RAOs)."
- "Determine whether flux and near surface contaminant concentration remain sufficiently low to protect surficial sediments, benthic community, and overlying water. Fish tissue levels meet (or are expected to meet within some established time frame) the RAOs that are protective of human health as well as piscivorous birds and mammals."

This guidance affirms the monitoring objectives and long-term goals for capping remedies presented in the 2014 Contaminated Sediments Remediation guidance document (ITRC 2014) and builds on those objectives to further differentiate between remedy effectiveness monitoring objectives and cap performance monitoring objectives.

Remedy effectiveness monitoring approaches include those that evaluate attainment of RAOs, which can include a variety of media (surface sediment, biota, surface water, porewater). It should be noted that information collected to support remedy effectiveness evaluations can also provide insight on cap performance. For example, at sites where remedy effectiveness monitoring includes sampling surface sediment, surface sediment chemistry may provide an indirect line of evidence about chemical isolation performance. Using this example, if the surface sediment COC concentrations are below RGs or consistent with known background concentrations, then adequate chemical isolation performance can be inferred. If surface sediment exposure concentrations increase above those anticipated from external inputs, more direct evaluation of chemical isolation performance is likely appropriate or necessary.

Cap performance monitoring approaches include those that confirm the long-term physical integrity and stability of the cap and confirm the long-term chemical isolation performance of the cap (which includes diagnostic monitoring). Development of a cap monitoring plan should include specific data-use objectives that outline how various information gathered will be used to support these performance monitoring objectives. Data quality objectives (DQOs) should be developed for each of these monitoring objectives and should inform the sampling frequency, duration, and methodology. DQOs should also consider the appropriate spatial scales for evaluating remedy effectiveness and cap performance. As indicated in Section 3.7.2, several design decisions will also affect cap monitoring approaches, including cap thickness, presence of amendments, presence of geotextile, presence of armor that may require the installation of sampling ports, and analytical reporting limits on chemistry samples collected from the cap (e.g., porewater). Where distinct design approaches have been employed for different subareas of the cap, monitoring requirements should be adjusted accordingly.

Long-term cap physical integrity and stability is a critical indicator of cap performance. Impairment of the physical integrity and stability of the cap might result in exposure to or releases of underlying sediment contamination and compromise RAO attainment. Alternatively, cap erosion or instability may result in the loss of cap material thickness (potentially including all or a portion of the CIL) and reduce the cap's ability to isolate underlying contamination over the desired timescale. This guidance recommends that monitoring plans developed for any capping site include physical stability monitoring. Physical monitoring is discussed in Section 7.4.2.

The objective of chemical isolation performance monitoring is to evaluate the migration of COCs from underlying contaminated sediments into overlying cap layers (or deposited sediment) and surface water and evaluate whether the concentrations pose potential risks to receptors. Chemical isolation performance monitoring has the following goals:

- compare actual long-term performance to performance anticipated in the design
- update the anticipated chemical isolation lifespan
- diagnose and distinguish between chemical migration through the cap and contamination associated with depositing materials over the cap surface
- evaluate the ability for natural recovery processes to maintain a protective condition at the cap surface (independent of COC migration through the cap)
- inform the scope of cap maintenance activities

7.3 Data Quality Considerations

A critical element of any monitoring plan is the selection of analytical methods for chemical monitoring. Specific analytical methods should be established in the monitoring plan and/or the QA project plan prior to conducting sampling. For solid matrices, the preparation, extraction, and digestion methods should also be predetermined and specified in these documents. To the extent practicable, it is recommended that the preparation, extraction, digestion, and analytical methods remain consistent for the duration of the monitoring program and be selected to ensure the results will achieve their desired data use objectives. In addition, using the same laboratory for the duration of the monitoring program, when possible, will avoid potential issues with interlaboratory variability. A framework for the selection of analytical methods for sediment analysis is described in ASTM Standard E3163-18 (ASTM 2018b).

For a given analyte, multiple methods can often be performed by commercial analytical laboratories. Beyond the target analyte list, the selection of methods may include many important considerations, such as the following:

- consistency or comparability with pre-remediation sampling methodology
- matrix or analyte interferences
- reporting and detection limits
- availability of laboratories to perform method
- sample hold time
- cost

Readers are encouraged to consult previous guidance documents for recommendations for developing effective long-term monitoring plans that may be relevant for capping sites (USEPA 2005; ITRC 2014; ASTM 2018b).

7.4 Cap Performance Monitoring Framework

This section discusses a recommended approach for monitoring and evaluating long-term chemical isolation performance. This section also provides a summary of the use of physical integrity and stability monitoring and remedy effectiveness monitoring as lines of evidence to support better understanding of chemical isolation performance.

This guidance acknowledges that specific sampling methodologies, frequencies, and timeframes selected for cap performance monitoring and remedy effectiveness monitoring are site specific and may depend on factors such as size of the site, size of the capped area, accessibility, water depth, hydrodynamic environment, nature and extent of contamination, sensitive receptors, public involvement and interest, and many other factors. Monitoring chemical isolation and monitoring remedy effectiveness should be considered separately and in combination and will likely result in multiple approaches to monitoring (physical and chemical) and sampling of multiple media.

7.4.1 Chemical Isolation Performance Monitoring

7.4.4.1 Overview

As described in Section 2, long-term contaminant migration through caps generally occurs via advection, diffusion, or dispersion of porewater; bioturbation; or ebullition. Since long-term chemical isolation focuses on retarding contaminant advection, diffusion, and dispersion via porewater, Section 3.1 of this guidance recommends developing porewater-based chemical isolation performance targets as the primary indicator of chemical isolation performance. In unamended granular caps, bulk sediment chemistry data can also be used to evaluate chemical isolation performance. Sampling of sorbing cap material such as activated carbon should be avoided or interpreted carefully, as these materials are, by design, intended to accumulate high concentrations of COCs (potentially higher than the underlying sediment as they sorb contamination from porewater flux into the CIL). To assess the performance of the cap relative to design expectations, measuring COC concentrations in porewater or cap material at different depths within the cap and comparing these results to performance targets developed during the design stage provides the best basis for evaluating long-term chemical isolation performance. Measuring porewater concentrations, as opposed to bulk chemical concentrations in cap material, is more representative of the bioavailable fraction of the COC. In addition to sampling for COC concentrations, measurement of other key design parameters (such as seepage rates, TOC and DOC, and deposition rates) is recommended.

At a minimum, monitoring should occur at the point of compliance established during the design stage (see Section 3.2.1). Conducting monitoring at this point and comparing monitoring results against performance targets established during the design stage (see Section 3.1.2) allows for direct comparison of actual chemical isolation performance against performance anticipated in the design. When other key design parameters are also measured from sampling locations, the design model can be calibrated to represent post-remediation conditions and estimate the remaining chemical isolation lifespan. Section 5.7 discusses the benefits of a post-construction model audit with respect to validating long-term monitoring results and informing the scope and frequency of long-term performance monitoring and informing cap maintenance plans.

In addition to monitoring at the point of compliance, a monitoring approach that evaluates COC concentrations at multiple depths throughout the cap in sediment, porewater, or both should be established. Using these data, vertical profiles can be developed to support diagnostic evaluations of cap performance when remedy effectiveness concerns arise. This recommendation is made because sediment transport (i.e., deposition, resuspension, and movement) can create a complex scenario when interpreting data in a cap monitoring program. Sediment deposition is beneficial when newly deposited sediment contributes to natural recovery (i.e., overlying sediment concentrations are below RGs or within known background concentration thresholds). But in cases where newly deposited sediment results in recontamination of the cap surface, it may be difficult to definitively assess cap performance from surficial samples. Measurement of chemical concentrations in vertical profiles through the cap and into the underlying sediment provides a means to empirically evaluate the migration of COCs through the cap and assess what influence this COC migration is potentially having on overlying sediment. These measured profiles can also be used to further validate a post-construction audit model used to represent post-remediation conditions. Sampling the underlying sediment or porewater as part of the profile provides a direct measurement of the local source concentration for evaluating COC transport through the cap. Finally, developing profiles and maintaining a post-remediation model can be used to estimate the long-term rate of COC migration through the cap to compare against ongoing natural recovery rates in surface sediments. In cases where natural recovery rates are sufficiently higher than COC migration rates through a cap, it may be possible to demonstrate that natural recovery processes are expected to maintain a protective condition independent of chemical isolation performance.

This guidance recognizes some limitations to the porewater monitoring approaches described above. In some cases, the CIL (or cap) may be too thin to sample porewater at multiple depths in order to create COC profiles. In these cases, porewater monitoring at the point of compliance may become an important line of evidence for assessing long-term chemical isolation performance.

Another potentially limiting factor may result from placing large or impenetrable armor over the CIL for erosion protection. In this case, it may not be possible to deploy certain sampling methods. As noted in Section 3.7.2, one approach to overcoming this limitation is to install monitoring ports at preselected locations during cap construction. These monitoring ports not only allow easier sample collection but ensure consistency in the monitoring location.

7.4.1.2 Interpretation of Results

This guidance recommends post-construction benchmark sampling within the cap for comparison to future monitoring events. To support future diagnostic monitoring, benchmark sampling locations should be selected to represent areas that are expected to experience the fastest COC migration (i.e., areas with the highest COC concentrations, highest seepage rates, or most sensitive combination of COC concentration and seepage rate). To the extent practicable, post-construction benchmark sampling and long-term monitoring should be completed using the same methods for accurate comparison of results. Porewater concentrations immediately following construction may be indicative of concentrations in overlying surface water (i.e., water that was entrained in the cap materials during construction) rather than concentrations migrating from underlying sediment through the cap.

Over time, caps may become recontaminated because of factors unrelated to physical integrity, stability and chemical isolation. A common cause of cap surface recontamination is deposition of sediments with concentrations above RGs. In other cases, declining cap performance may be a result of physical damage or instability or expected or unexpected migration of COCs from underlying sediments through the cap. Potential COC flux mechanisms through the cap that would have been considered in the design include porewater advection, diffusion, dispersion, and ebullition and bioturbation (Go et al. 2009; Thoma et al. 1993). In these cases, cap performance monitoring data (particularly diagnostic monitoring results) can be used to ascertain whether loss of cap integrity or other causes of declining performance are limiting remedy effectiveness. Diagnostic monitoring programs should incorporate DQOs related to evaluating whether recontamination of surface sediments is due to COC migration through the cap (bottom-up processes) or due to deposition of contaminated sediments over the cap surface (top-down processes).

Indicators of COC migration through the cap (bottom-up processes) include increasing porewater concentrations at a depth below the BAZ and deposited sediments. Where vertical profiles are established, porewater or cap material concentrations that are highest at the base of the cap and approach or exceed performance targets established in the design at the top of the profile are a strong indicator of declining chemical isolation performance. This guidance recommends using a cap model calibrated to represent post-remediation conditions as a secondary line of evidence to support interpretation of diagnostic monitoring results and to help estimate remaining chemical isolation capacity, where performance is declining.

Indicators of COC deposition over the surface of the cap (top-down processes) include increasing COC concentrations in surface sediment (discussed in Section 7.4.3.1) or porewater but lower COC concentrations observed in porewater or cap material at depths below both the BAZ and the thickness of deposited sediment (Figure 7-2). Where vertical profiles are established, observations of recontamination dominated by top-down processes could include high COC concentrations in sediment and porewater at the cap surface that decrease with depth through the cap profile. Concentrations that are highest at the base of the cap and increase in concentration closer to the surface of the cap may indicate transport from below the cap. Concentrations that are below anticipated performance targets may indicate that the cap is performing as intended. These two processes can also occur at the same time, resulting in a COC concentration profile that is high at the surface, decreases with depth through the cap profile, then increases again near the base of the cap. Modeling may be a useful secondary line of evidence to demonstrate that empirical cap profile data reflect expected cap performance.

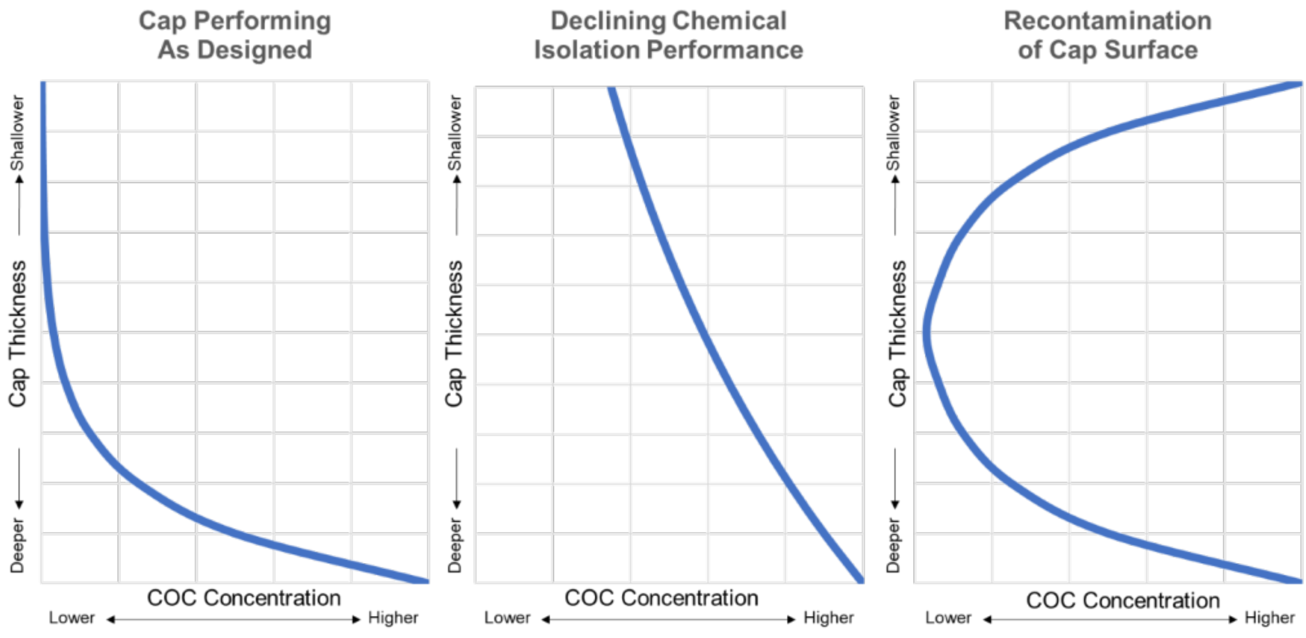

Figure 7-2. Conceptual illustration of vertical concentration profiles (not to scale).

Source: Wesley Thomas. Used with permission.

When interpreting results and evaluating cap performance monitoring results against maintenance trigger criteria, as discussed in Section 7.5, it is important to consider how declining chemical isolation performance will likely appear and progress over the capped area. It is important to note that the recommended chemical isolation monitoring approach described above will tend to bias monitoring in locations where COC migration through the capped area is likely to occur the fastest. Declining chemical isolation performance at a single location (and one where it is expected to occur fastest), or within a relatively small portion of the capped area, may not be representative of the cap as a whole. Therefore, maintenance triggers assigned to declining chemical isolation performance should consider the area over which declining chemical isolation performance might begin to affect remedy effectiveness. These considerations should include the magnitude of COC concentrations at the cap surface and the area over which exceedances of RGs or background concentrations exist. At sites where natural recovery processes are able to maintain a protective condition, declining chemical isolation performance may not require maintenance.

7.4.2 Physical Integrity and Stability Monitoring

Cap physical integrity and stability are integral to maintaining the cap's ability to chemically isolate underlying contaminated sediments. Physical monitoring is often the first and most repeated approach used to evaluate cap physical integrity and stability, since monitoring methods are relatively easy to implement, and many monitoring methods are nonintrusive. Furthermore, some causes of potential physical integrity and stability issues, such as settlement of underlying sediments, cap material settlement, cap material placement on steeper slopes, and erosion, are more likely to be observable earlier in the cap design life, particularly since most cap designs are intended to achieve chemical isolation over many decades or centuries.

It is not unusual for caps to experience a break-in period in the months and years after construction, in which underlying sediment consolidation, cap material settlement, minor erosion (particularly around the cap edges, where cap materials abut natural sediments) occur. To the extent practicable, cap designs should anticipate this break-in period and incorporate plans for more frequent physical monitoring and the potential for near-term maintenance, where necessary or appropriate. Many of these near-term minor physical changes may not require immediate maintenance for the cap to remain protective.

A wide range of methods and techniques may be used to evaluate long-term cap integrity. Specific physical monitoring methodology should be developed on a site-specific basis and be tailored to the needs and constraints of individual sites. Common physical monitoring approaches include bathymetric surveys, visual observations, and sediment and cap material thickness measurements via probing, coring, video probing, and SPI. Bathymetric surveys are the most commonly and widely used technique for physical monitoring. In general, bathymetry surveys are used to evaluate whether cap surface elevations are consistent with as-built elevations documented following cap installation and can also document sediment deposition rates over the cap surface over time. Direct inspection of the cap surface using sonar imagery, divers, or other techniques are used to assess whether armor layers are intact or whether there is visible evidence of deformation, physical disturbance, or erosion. Sediment and cap material thickness measurements provide additional empirical evidence that is useful for assessing whether the cap is maintained consistent with its design. In some cases, these data can provide lines of evidence to distinguish among sediment consolidation, cap material settlement, and erosion of cap material.

Construction QA/QC monitoring may appropriately document post-remediation baseline information. Typical elements of construction QA/QC monitoring are described in Section 6.6. Physical monitoring methods should be incorporated into routine post-remediation monitoring programs and be repeated at regular intervals.

Appropriate monitoring intervals are determined on a site-specific basis and may vary over time. For example, physical monitoring might be conducted during the first two years after construction but then reduced or eventually eliminated after establishing confidence that the cap will remain stable under a range of hydrodynamic conditions. Physical monitoring may also be triggered by specific events that could impact the cap condition, such as a major seismic event, a significant storm event, or an extreme high- or low-flow event. Triggers may be recommended for additional monitoring events to evaluate acute impacts of climate change–related incidents, such as sediment dynamic shifts due to storm intensity. Other criteria for additional monitoring, such as those related to sea-level rise, may need to be built into monitoring plans to assess longer-term effects on the cap's structure.

7.4.3 Remedy Effectiveness Monitoring

Chemical monitoring of porewater, sediment, surface water, and biota is often required to demonstrate achievement of RGs or compliance with regulatory criteria. Other regulatory targets, such as biological or habitat monitoring, may also be needed to monitor overall remedy performance, of which the long-term effectiveness of the cap is an important piece (ITRC 2014). Chemical monitoring typically has the following goals:

- document reduction in unacceptable risks to human health or wildlife (e.g., from bioaccumulative organic compounds such as PCBs, dioxins and furans, organic pesticides) to achieve RAOs developed during the remedial investigation and feasibility study process
- collect long-term data for an interim review process required at the site (e.g., five-year reviews under the Comprehensive Environmental Response, Compensation, and Liability Act)

The parameters measured and the media sampled should be selected based on site-specific monitoring objectives. Because site-specific monitoring objectives and RAOs vary so widely, this guidance does not attempt to provide a comprehensive description of appropriate media, sampling density and frequency, sampling spatial scales, methodology, or data interpretation framework. Instead, this section summarizes common remedy effectiveness monitoring approaches, by media, and how these data might be used in concert with cap performance monitoring.

7.4.3.1 Surface Sediment and Porewater

Surface sediment (or cap surface) and porewater sampling for chemical analysis are commonly used to evaluate long-term remedy effectiveness. Surface sediment and porewater chemical monitoring may include COC concentrations and other parameters (e.g., general chemistry, geochemistry, or isotope measurements).

Remedy effectiveness monitoring programs should consider how to best sample sediment that deposits over the cap surface. As noted above, sampling of deposited sediments may be required to demonstrate RAO attainment or compliance with regulatory criteria. If deposited sediments contain COC concentrations that exceed RGs or established background concentrations, a sampling program that includes suspended solids in the water column (e.g., sediment traps) or sediment in nearby uncapped areas may provide useful lines of evidence for evaluating sources of cap surface recontamination.

Surface sediment samples are typically collected via coring, though grab samples may also be appropriate at some sites. Standard methods of sediment coring and logging for analytical sample collection are described in ASTM Standards D4823-95 (ASTM 2019), D2487-17 (ASTM 2020), and D2488-17e1 (ASTM 2018c). Cap disturbance resulting from sampling of cap materials is generally considered negligible.

Porewater can be collected using active or passive sampling methods and at multiple intervals below and within the cap. Some methods involve collecting grab samples, and others involve leaving a sampler in place to evaluate conditions over a longer period of time. The appropriate sampling method may depend on numerous factors, including the monitoring objective, target analyte(s), volume requirements, thickness and type of sediment or cap material where the porewater sample will be collected, and the accessibility of the sample location. A summary of available porewater sampling methods is available in Appendix C of the 2011 Incorporating Bioavailability Considerations into the Evaluation of Contaminated Sediment Sites Guidance (ITRC 2011).

7.4.3.2 Surface Water

Surface water sampling may be required to demonstrate attainment of RAOs or compliance with regulatory benchmarks, or it may be a useful line of evidence when interpreting the results of other matrices. But surface water sampling alone is not a straightforward indicator of cap chemical isolation performance, as the appropriate sampling approach will depend on site-specific conditions such as the size and location of the cap (e.g., water depth, hydraulic regime, climate, and proximity to sensitive receptors), physical and chemical characteristics of the COCs (e.g., are they likely to be detected in surface water), and pre-remedy concentrations of COCs in surface water as well as representative background concentrations upstream of the cap. Regardless of the specific environment, distinguishing the impact of porewater discharged through the cap from other sources, including background and aerial deposition, is often difficult or impracticable.

If surface water sampling is included in the monitoring program, sampling done as part of the remedial investigation may serve as an adequate baseline for documenting improvements post-remediation. Certain surface water criteria may be very low and below what is achievable based on background influences such as atmospheric deposition and regional background. This should be considered when developing the sampling plan and interpreting the sampling results. For example, in a river setting, data should be collected from an upstream area, the site area, and a downstream area.

7.4.3.3 Biota Sampling

Sampling of biota, particularly fish is a common remedy effectiveness element, particularly for sites with bioaccumulative COCs. Sampling of fish tissue is sometimes incorporated in monitoring plans because of potential sport fishing, fish ingestion advisories, and associated ecological and human health risks, and sampling of invertebrates may be used to confirm that tissue concentrations have declined or have achieved RAOs. While fish tissue chemical monitoring may be included to monitor ecological and human health risks, fish tissue concentrations integrate exposures over the lifetime and home range of the fish and are not sensitive indicators of cap chemical isolation performance. When sampling of biota tissue is included in a monitoring plan, the design of tissue monitoring programs must consider the species collected to understand their exposure patterns (e.g., size and location of the home range relative to that of the cap), role in the food web, connection to receptors found to be at risk in the risk assessment, and background concentrations. Guidance documents available to support the development of a robust biota monitoring program include Choudhury et al. (2000), 2005 USEPA Guidance (2005), and (Henry et al. 2008).

Biota monitoring to assess remedy effectiveness often focuses on resident fish tissue but, depending on the specificities of the site, could also include microinvertebrates and macroinvertebrate crabs, mussels, or other location-specific species. These data can provide a higher-resolution indicator of CIL effectiveness because microinvertebrate and macroinvertebrate species have smaller home ranges than most fish species. Chemical monitoring of benthic tissue may be included in a monitoring plan if baseline data are available and the RAOs include reductions in these tissue concentrations, typically to protect higher-trophic-level organisms. Benthic invertebrates collected from the cap surface or biota deployed in cages over the cap surface may provide a more targeted estimate of cap performance than fish tissue because organism exposure is more controlled; however, the influence of COCs in surface water also needs to be considered. Baseline sampling for biota is especially important if the biota monitoring is included as part of long-term monitoring. Understanding the time period over which COC concentrations in biota would reasonably be expected to change is also an important consideration for interpreting biota data for monitoring remedy effectiveness. For example, the fish tissue sampling time frames for smaller fish should consider the lifespan of the target fish species such that sampling would begin when a new generation of fish is present, such as after the first year. For larger sites, or for fish species with longer life spans, fish tissue sampling before year five is unlikely to provide any useful information. In any fish program, baseline data are critical to determine whether the remedy has had any effect.

7.4.3.4 Benthic Community Health and Abundance Monitoring

Monitoring of benthic populations can be a reliable reflection of the overall health of the base of the food chain. Some types of biological monitoring, such as monitoring of biota in the vicinity of the cap or habitat assessment (e.g., benthic recolonization, vegetation), are a reflection of overall remedy effectiveness rather than an indicator of only the chemical isolation function of cap.

Benthic community monitoring may be required to confirm that the benthic community is being reestablished following cap construction, but these surveys are not a direct measurement of chemical isolation performance. Benthic community monitoring can be accomplished via visual observation of the cap surface to document the presence and abundance of benthic invertebrates, SPI to document the presence of epibenthic and infaunal invertebrates, or collection of grab samples from the sediment surface for taxonomic identification of the organisms that colonize the cap surface. The design of a long-term effectiveness monitoring program should consider the numerous factors that contribute to the structure of benthic invertebrate communities and complicate the establishment of monitoring goals for benthic communities.

7.5 Cap Maintenance

As indicated in Section 3.2.2, a typical widely accepted cap design life is 100 years (or more). Although caps are generally designed to achieve long lifespans, it is important to recognize that caps may require maintenance over their lifespan to continue to perform as the design intended. Cap maintenance should be considered and incorporated into project planning in the same manner as maintenance planned or expected for any built asset. To protect the remedy over the long term, implementation of institutional controls may be used to manage activities and land uses in the vicinity of the cap and outline long-term monitoring and maintenance responsibilities. More information is available in ITRC’s Long-Term Contaminant Management Using Institutional Controls (IC-1) guidance (ITRC 2016).

When developing a maintenance plan for caps, the factors most likely to result in the need for cap maintenance should be identified. These factors are site specific and may include the following:

- geotechnical setting, which may contribute to excessive consolidation of underlying sediment, cap consolidation, and slope instability
- risk of high-energy events causing cap erosion or other damage
- current and potential future uses of the area, which may increase the likelihood of damage from prop wash scour, anchoring, or sunken vessels

Cap maintenance may also be initiated as a result of COC migration through the cap. Over the course of post-remediation monitoring, the need for cap maintenance is determined based on cap performance monitoring results. As described in Section 7.4, cap maintenance plans should include maintenance trigger criteria based on these factors. Maintenance plans may also use trigger criteria to initiate more frequent or focused monitoring to better assess the appropriate scope and time frame for cap maintenance. Maintenance triggers should include physical criteria (e.g., monitored cap thickness less than a minimum thickness threshold, in a single location or on average across a predetermined area) and chemical criteria (e.g., porewater or sediment COC concentrations indicative of excessive COC migration through the cap).

When establishing cap maintenance triggers, designers should consider the precision of the cap construction and monitoring techniques (refer to Section 6). For example, it would be unrealistic to install and expect to maintain a 12-inch cap at precisely 12 inches thick. Constructing a cap to be thicker than the minimum effective thickness determined during design is a conservative outcome. A design cap thickness greater than the minimum protective thickness would allow for minor deviations with cap construction and monitoring measurements, thus providing an acceptable range of cap thicknesses before maintenance is needed. It should be noted that small areas or small deviations from the cap requirements do not necessarily reduce overall or long-term effectiveness of the cap (ITRC 2014). Alternatively, exceedance of trigger criteria, even if minor, may warrant early maintenance to avoid an increased possibility of a more significant exceedance of trigger criteria. Ideally, a response trigger should allow for some flexibility in interpreting cap monitoring results and evaluating potential responses. Exceedances of trigger criteria warrant further evaluation to better define the most appropriate response and timing.

As described in Section 7.4.1.2, maintenance triggers assigned to declining chemical isolation performance should consider the area over which declining chemical isolation performance might begin to affect remedy effectiveness and the magnitude of COC concentrations at the cap surface. At sites where chemical isolation performance is critical to maintaining remedy effectiveness, maintenance trigger criteria should be structured so that maintenance planning and construction can be completed before overall remedy effectiveness is compromised.