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# **Federal Contaminated Sites Action Plan (FCSAP)**

**FCSAP Long-Term Monitoring Planning  
Guidance**

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FCSAP Long-Term Monitoring Planning Guidance

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The current version of this document was completed in March 2013. Material relevant for aquatic contaminated sites was added and the initial document's structure and content were revised. A technical review of the document was also conducted. The draft version of the revised document was reviewed by members of DFO and Environment Canada (EC) FCSAP expert support. Comments received in this review were addressed in the final version of the guidance produced in March 2013.

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## LIST OF ACRONYMS

AANDC	Aboriginal Affairs and Northern Development Canada
AEC	Area of Environmental Concern
AFCEE	Air Force Center for Environmental Excellence
AMSRP	Abandoned Military Site Remediation Protocol
CCME	Canadian Council of Ministers of the Environment
CEAA	Canadian Environmental Assessment Agency
CoC	contaminant of concern
CSM	conceptual site model
CSMWG	Contaminated Sites Management Working Group
DCC	Defence Construction Canada
DEW	Distance Early Warning
DFO	Fisheries and Oceans Canada
DLCU	DEW Line Clean Up
DND	Department of National Defence
DQO	data quality objective
EC	Environment Canada
ESA	Environmental Site Assessment
ESD	expert support department
ESG	Environmental Sciences Group
FCSAP	Federal Contaminated Sites Action Plan
FACS	Federal Approach to Contaminated Sites
HC	Health Canada
HHERA	Human Health and Ecological Risk Assessment
INAC	Indian and Northern Affairs Canada
ISRAP	Interactive Sediment Remedy Assessment Portal
ITRC	Interstate Technology & Regulatory Council



## **LIST OF ACRONYMS, CONT'D**

LTM	long-term monitoring
MAC	Mining Association of Canada
MAROS	Monitoring and Remediation Optimization System
MEND	Mine Environment Neutral Drainage
MNA	monitored natural attenuation
NCS	National Classification System
NOAMI	National Orphaned/Abandoned Mines Initiative
NWT	Northwest Territories
O&M	Operation & Maintenance
PHC	petroleum hydrocarbon
PWGSC	Public Works and Government Services Canada
QA/QC	quality assurance/quality control
RA	risk assessment
RAP	Remedial Action Plan
RM	risk management
RMP	Risk Management Plan
R/RM	remediation and/or risk management
SCT	Site Closure Tool
SSTL	site-specific target level
TC	Transport Canada
TRAV	Tool for Risk Assessment Validation
TSM	Towards Sustainable Mining
US EPA	United States Environmental Protection Agency

## **I. INTRODUCTION**

### **A. Purpose of this Guide**

Existing guidance on federal contaminated site management tends to have been focused on the technical and managerial activities associated with assessment and remediation or risk management of contaminated sites (Steps 1 through 8 of the Contaminated Sites Management Working Group (CSMWG) *Federal Approach to Contaminated Sites* (FACS)). As Canada's Federal Contaminated Sites Action Plan (FCSAP) program matures, both assessment and remedial activities have been completed for an increasing number of federal contaminated sites across the country; the focus is now shifting to a longer view. Having addressed the immediate risk and liabilities to human health and the environment, federal project and program managers and expert support departments are now developing policies and technical guidance to ensure that follow-up actions and monitoring are successful in documenting the recovery of the site and the environment. A gap has been identified with respect to guidance for a consistent approach to long-term monitoring (LTM) on completion of Steps 8 and 9 of the FACS in the FCSAP program. This guidance document attempts to fill this gap by presenting a framework for developing and implementing technically defensible LTM plans for federal contaminated sites. This document was written for and in direct response to contaminated site custodians, expert support department advisors, and project and program managers who are responsible for the ongoing management of federal contaminated sites.

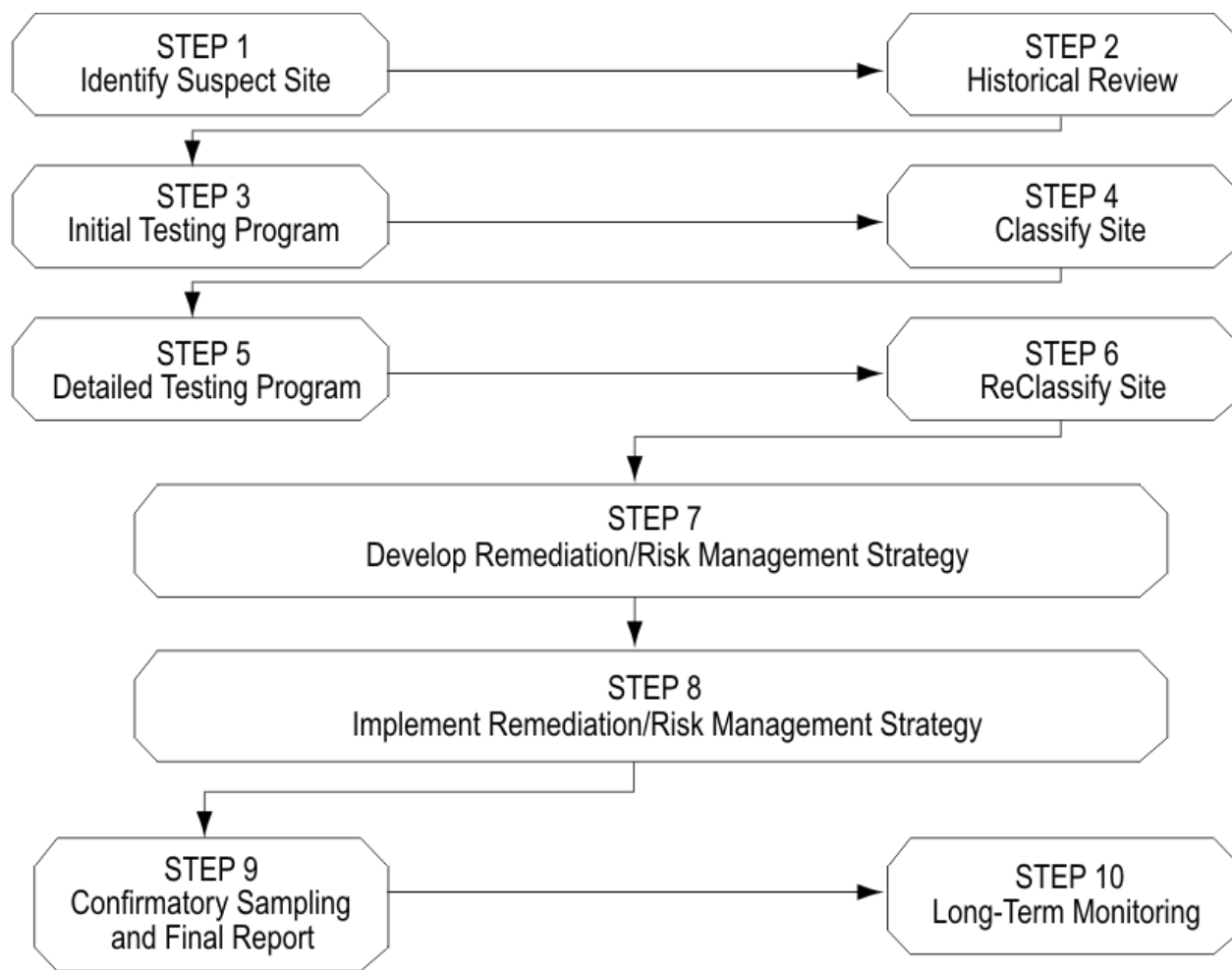
The overall goals of this guidance document are to:

- provide a framework for the development and implementation of scientifically defensible LTM plans;
- facilitate consistency, as is practicable, across federal departments, regions and regulatory jurisdictions for content and implementation of LTM plans; and
- establish procedures for identifying decision criteria prior to LTM data collection.

Specific objectives are to:

- focus custodians' (i.e., federal departments, agencies and consolidated Crown corporations responsible for contaminated sites) attention on the potential long-term monitoring requirements of a particular remedial option before it is selected and developed into a Remedial Action Plan (RAP) or Risk Management Plan (RMP)
- facilitate development of a baseline scope, schedule and cost for LTM; and
- provide a mechanism to ensure that the risk management/remediation performance and goals of a particular site continue to be achieved.

Contaminated site management encompasses activities that are designed to define the human health and environmental risks posed by the site, and then to take action to reduce or mitigate those risks. In the federal context, the FACS (CSMWG, 1999) describes a 10-step process that generally encompasses the activities that might be included in the management of a contaminated site. A flowchart illustrating the FACS process is shown in Figure 1.



**Figure 1: The 10 steps for addressing a contaminated site under the Federal Contaminated Sites Action Plan (FCSAP).**

## **B. Scope of this Guide**

This guidance document focuses on the contaminated site LTM process and its appropriate documentation in the Canadian federal context only for sites that will remain under federal control. It is not intended to provide regulatory or technical guidance on LTM of contaminated sites subject to provincial or territorial jurisdictions. Furthermore, this document is not intended to prescribe the scale, complexity, protocols, data quality objectives or investigation methods for meeting the needs of site-specific monitoring. Rather, it presents a framework that can be used to

develop and implement scientifically defensible and appropriate LTM plans that promote national consistency and transparency in the contaminated site management decision-making process.

### **C. Intended Users**

This guidance is intended for use by federal contaminated site remediation/risk management project managers, managers of contaminated site programs (groupings of projects) and project sponsors (organizations that have management responsibility for contaminated properties). This guide has been developed primarily for use by custodian department project managers, expert support departments and other FCSAP practitioners.

### **D. Development of the Guide**

This guide was developed through a collaborative process, via group consultation and personal interviews with custodian department representatives knowledgeable in the implementation of LTM at federal contaminated sites and representatives from federal expert support departments. Input was sought from individuals identified with the help of Environment Canada (EC). Input was sought from experienced custodian departments such as Aboriginal Affairs and Northern Development Canada (AANDC), the Department of National Defence (DND) and Transport Canada (TC). A questionnaire was used with both individuals and the expert support group to guide discussions about the desired and required content of this document. A list of LTM challenges identified through group consultation is presented in Appendix A.

In addition to consultations with FCSAP practitioners, a review was conducted of policy guidance materials available from other jurisdictions, most notably the US Environmental Protection Agency (US EPA) and the US Department of Energy Office of Legacy Management. Much of the information presented herein has been adapted from these established and widely used approaches to LTM.

Consultation, initial review and preparation of the draft guidance document were completed by Franz Environmental Ltd. The Environmental Sciences Group (ESG), based at the Royal Military College of Canada, added material relevant for aquatic contaminated sites and produced the final version of the guidance document.

## E. Document Organization

This document is organized as follows:

1. **Section I:** *Introduction.*
2. **Section II:** *Understanding Long-term Monitoring in the Context of the Federal Approach to Contaminated Sites (FACS).* This section defines LTM, provides examples of LTM activities, discusses where LTM fits within the FACS 10-step process, and provides guidance on when LTM is required for a FCSAP project.
3. **Section III:** *Steps for Developing an LTM Plan – The US EPA Six-Step Process.* This section describes a scientific approach for developing a monitoring plan that is capable of achieving site closure where possible. Guidance is provided on the development of monitoring objectives and decision rules for interpretation of monitoring program results.
4. **Section IV:** *Project Management and Policy Considerations.* This section discusses issues related to project management, such as FCSAP cost eligibility, roles and responsibilities, stakeholder involvement, adaptive management, and LTM project scope considerations.
5. **Section V:** *References.*
6. **Appendix A:** *Main Findings of Custodian and Expert Support Consultation on FCSAP LTM.* This appendix provides further details on the consultation outcomes.
7. **Appendix B:** *Terrestrial Contaminated Sites: Guide to Additional References for LTM Program Design and Management.* This appendix includes examples of best practices for LTM at terrestrial contaminated sites and a guide to further resources for LTM project management.
8. **Appendix C:** *Aquatic Contaminated Sites: Scientific and Technical Guidance for Developing LTM Programs and a Case Study Review.* This appendix provides further technical guidance for LTM of aquatic contaminated sites, including a case study review.
9. **Appendix D:** *Long-Term Monitoring Plan Template.* This appendix provides a template for LTM plan content that may be used to develop a scope of work for LTM plans.
10. **Appendix E:** *Long-Term Monitoring Plan Review Checklist.* This appendix provides a checklist that may be used to review the content of LTM plans.

## **II. UNDERSTANDING LONG-TERM MONITORING IN THE CONTEXT OF THE FEDERAL APPROACH TO CONTAMINATED SITES (FACS)**

LTM takes place in Step 10 of the FACS process and begins after the remediation/risk management (R/RM) goals have been achieved. The FACS states that LTM may or may not be required at a particular site; however, LTM is “always required in cases where remediation used containment, *in situ* or isolation techniques” (i.e., at risk-managed sites). LTM is an integral part of many risk management strategies and allows the implementation of an alternative action/contingency plan in the event that LTM findings indicate that risk management measures are not being effective.

There is currently no federal guidance available for planning and implementing LTM. Some custodian departments have developed their own process for planning and implementing LTM; this guidance is not intended to replace these established processes, but such processes should be aligned with the intent contained herein.

The following section provides an overview of LTM in the context of the FACS ten-step process. Definitions and examples of LTM activities are provided, as well as guidance on when LTM is required for a site. The need to plan for site closure is also discussed.

### **A. Definitions: What Is LTM?**

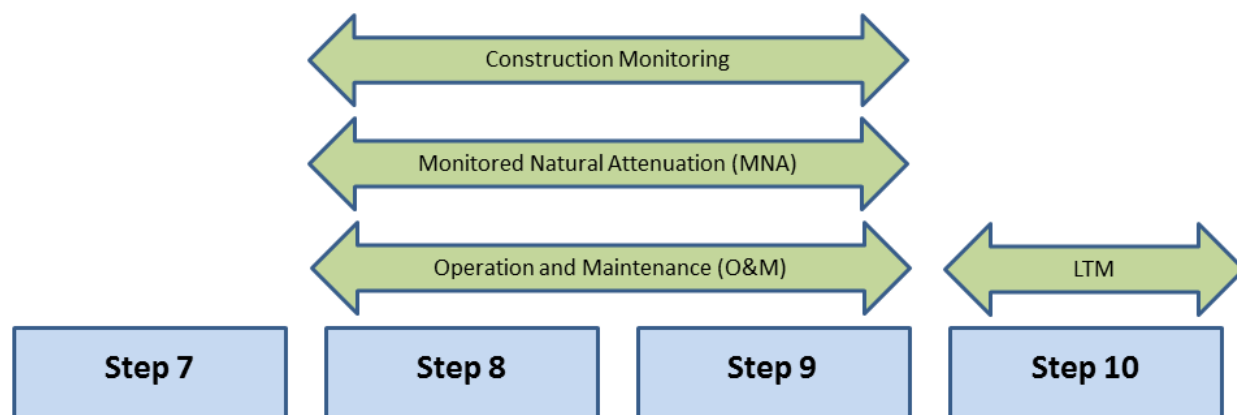
Elzinga et al. (1998) provide a definition of monitoring that is most applicable to the monitoring typically associated with the remediation of contaminated sites: “the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective.”

The US EPA’s *Guidance for Monitoring at Hazardous Waste Sites* (US EPA, 2004) similarly defines monitoring as “the collection and analysis of data, be it chemical, physical, and/or biological, over a sufficient period of time and frequency to determine the status and/or trend in one or more environmental parameters or characteristics.” The EPA guidance cautions that long-term monitoring should not produce a “snapshot in time” measurement, but rather should involve repeated sampling over time in order to define the trends in the parameters of interest relative to clearly defined management objectives.

According to the FACS ten-step process, the objective of LTM is to confirm that the nature and extent of the remediation activities have been carried out as per the site management goals, and that the objectives of the remediation or risk management strategy continue to be met over time to protect human health and the environment. Thus, LTM plans are typically designed to meet one or more of the following goals: (1) to audit the R/RM action and evaluate its overall effectiveness and efficiency over time; (2) to provide early warning that additional R/RM action may soon be necessary; and (3) to audit contaminant concentration levels at a compliance location. This assumes that the R/RM goals have already been met, as confirmed by the

confirmatory sampling conducted in Step 9, but that for one reason or another there is residual risk necessitating LTM, which occurs at Step 10. LTM is most applicable to cases where contaminant concentrations are not reduced but, rather, exposure pathways are mitigated — for example, through construction of landfill caps or containment walls.

There are a number of types of environmental monitoring related to contaminated site management. Many of these monitoring methods are associated with the implementation of the remedial/risk management plan (Step 8 of the FACS) and are therefore NOT considered to be part of LTM. A pipeline indicating where each of the monitoring activities fits within the FACS 10-step process is provided in Figure 2.



**Figure 2: Pipeline indicating where environmental monitoring activities fit within the FACS 10-step process.**

### ***1. Construction Monitoring***

Construction monitoring is monitoring that takes place during the construction of remedial infrastructure (Step 8 of the FACS). It includes monitoring activities that are stipulated within the construction specifications, such as monitoring of dust, suspended sediment or wastewater generated as a result of construction activities. This type of monitoring ensures that the design criteria for any remedial construction activity have been met.

### ***2. Operation & Maintenance (O&M)***

O&M typically involves the operation of soil, sediment, groundwater or surface water remediation measures that are meant to reduce contaminant concentrations to pre-established cleanup goals within a reasonable time frame (e.g., 10 years). Consequently, O&M should be considered part of Step 8 (Implement Remediation/Risk Management Strategy) of the FACS. It can include *in situ* soil remediation measures, such as soil vapour extraction and *in situ* bioremediation, and *ex situ* bioremediation, such as biopiles or land treatment facilities. Use of pump-and-treat systems to remediate contaminated groundwater is another example of O&M activities. Monitored natural attenuation (MNA) and monitored natural recovery (MNR) should be considered *in situ* remediation strategies requiring O&M, provided that MNA/MNR are

expected to result in reduction of contaminant concentrations to cleanup targets, as discussed in the following section. O&M assumes that the R/RM goals have not yet been met but are attainable through the remedial action.

Monitoring activities that may occur as part of O&M include confirmatory sampling to assess whether R/RM goals have been met. For example, multiple rounds of confirmatory sampling are often required during use of a pump-and-treat system to remediate contaminated groundwater. The goal of this sampling is to show that contamination has been removed or stabilized effectively and that the R/RM cleanup objectives have indeed been attained after the remedial action has been implemented. At some sites, LTM may be required after confirmatory sampling indicates that the R/RM goals have been achieved, to ensure the continued effectiveness of a particular remedial action. The site would pass from the O&M stage to LTM when confirmatory sampling indicated that the R/RM goals had been achieved.

### ***3. Monitored Natural Attenuation***

Natural attenuation describes a variety of physical, chemical or biological processes that, under favourable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume or concentration of contaminants in soil, sediments or groundwater. These processes include biodegradation, advection, dispersion, dilution, adsorption, volatilization, and chemical or biological stabilization, transformation or destruction of contaminants.

Monitored natural attenuation (MNA), also known as monitored natural recovery (MNR), is a remediation strategy that relies on these natural processes to achieve site-specific remedial objectives. Where it is identified to be a viable remedial approach, MNA should be used within the context of a carefully controlled and monitored site cleanup approach. To be considered an acceptable remedial strategy, MNA should be expected to achieve site remedial objectives within a reasonable time frame comparable to that offered by other more active methods. MNA may be used in combination with source control, i.e., removal of the source of the contamination to the degree practicable.

MNA is comparable to any other remedial strategy that requires detailed design, implementation and operation and maintenance, such as *in situ* or *ex situ* on-site remedial actions, to reduce contaminant concentrations to target levels. Thus, MNA should be considered an *in situ* remedial strategy (Step 8 of FACS) and would follow the closure process for that type of approach, which would include confirmatory sampling. MNA should not be considered a form of LTM unless remedial targets have already been met and monitoring is deemed to be required to ensure that contaminant concentrations are stabilized and continue to meet cleanup targets. When MNA is defined as a remedial action rather than a risk management measure, confirmatory sampling will be required to show that MNA has achieved the desired goals. Whether or not LTM will be required to demonstrate the MNA goals are continuing to be met will depend on the specifics of the site.



## **B. When is LTM required, and when is it not required?**

Generally, the main driver for developing LTM plans is the need to ensure that remediation/risk management controls remain protective of human health and the environment. It may not always be possible to clean up a site to a level that results in removal of all contaminants at concentrations in excess of either generic or site-specific target levels (SSTL). The feasibility of cleanup may be constrained as a result of limitations in technology, safety concerns related to implementing a remediation strategy, limitations in available funding, accepted operating practices of the industry, and/or the nature of the contamination.

Residual risk describes the risk remaining at a site after implementation of the RAP/RMP. Such risk might remain at a site for a variety of reasons. Examples of residual risks may be the possible loss of integrity of an engineered containment system such as a barrier wall, landfill cap or liner, which would pose a risk to the continued success of an RMP that depends on the elimination of a contaminant transport pathway between source and receptor; the potential for “rebound” of contaminants of concern (CoCs) in groundwater after decommissioning of a water treatment system; or assuring continued effectiveness of administrative or institutional controls such as fencing and signage to prevent injury from physical hazards remaining on the site. Such residual risks may result in short- and long-term restrictions on intended land and/or water use for the site, and as such are primary drivers for LTM requirement.

According to the available FCSAP guidance materials, long-term monitoring may or may not be required depending on the nature and extent of remedial activities at a particular site. LTM is NOT typically required at sites that:

- have undergone remediation wherein all contaminated materials and media have been removed from the site and confirmatory sampling has been completed and confirms this;
- have had contaminated material or media treated such that no contaminants of concern have been left in place at concentrations above the remediation criteria established for the site and confirmatory sampling has been completed and confirms this;
- do not constitute a risk to human health or the environment and require no further remedial action based on the findings of a risk assessment; or
- have been investigated and demonstrated to not exceed applicable guidelines, standards or criteria, whether generic or risk-based.

Each site must also be evaluated for potential risk for migration of contaminants off the site and for ongoing impacts to the surrounding environment.

R/RM at many federal contaminated sites, especially those that are remote, often involves leaving some contaminants on site. Risk management approaches that rely on containment, fixation or other sequestration methods to eliminate contaminant transport pathways to receptors generally require some level of ongoing monitoring. In the case of U.S. federal contaminated sites (Superfund sites) that rely on such methods, ongoing monitoring is required at five-year intervals in perpetuity. Detailed guidance on the US EPA Five-year Review process is discussed in Appendix B.

The following are examples of remedial actions, infrastructure and situations that typically require LTM (US EPA, 2001):

- on-site waste encapsulation, stabilization or fixation;
- landfill caps or covers and slurry walls;
- site access controls such as roads, signage and fencing;
- sediment capping;
- sites at which R/RM has been implemented but where residual contaminants in soil, sediment or groundwater (usually at depth) are still present at levels above generic or site-specific criteria and represent a continuing threat to the receptors and potential users of the site; or
- sites where contaminants were left in place based on the results of a risk assessment (RA), but site conditions are dynamic and require confirmation that the site model on which the RA is based remains valid over time (e.g., submerged tailings or contaminated sediment or seasonal variation of water table).

A flowchart outlining the main remedial actions and criteria determining when LTM is required is provided in Figure 3.

Consultation with custodian department representatives has indicated that other factors may be drivers for developing an LTM plan for a particular site. For instance, an LTM plan is a requirement for acquiring a water use licence from regulators in northern Canada such as the Nunavut Water Board. Such regulatory requirements are typical for many federal contaminated sites in northern Canada, especially mine and military sites. Legal/regulatory requirements for LTM are not usually very prescriptive and are generally performance-based — for example, to prevent impacts to wildlife or fish habitat (Pike, 2011). Whether or not LTM is necessary for a particular RM strategy is a decision that must be made by the professional or group of professionals responsible for the site management.

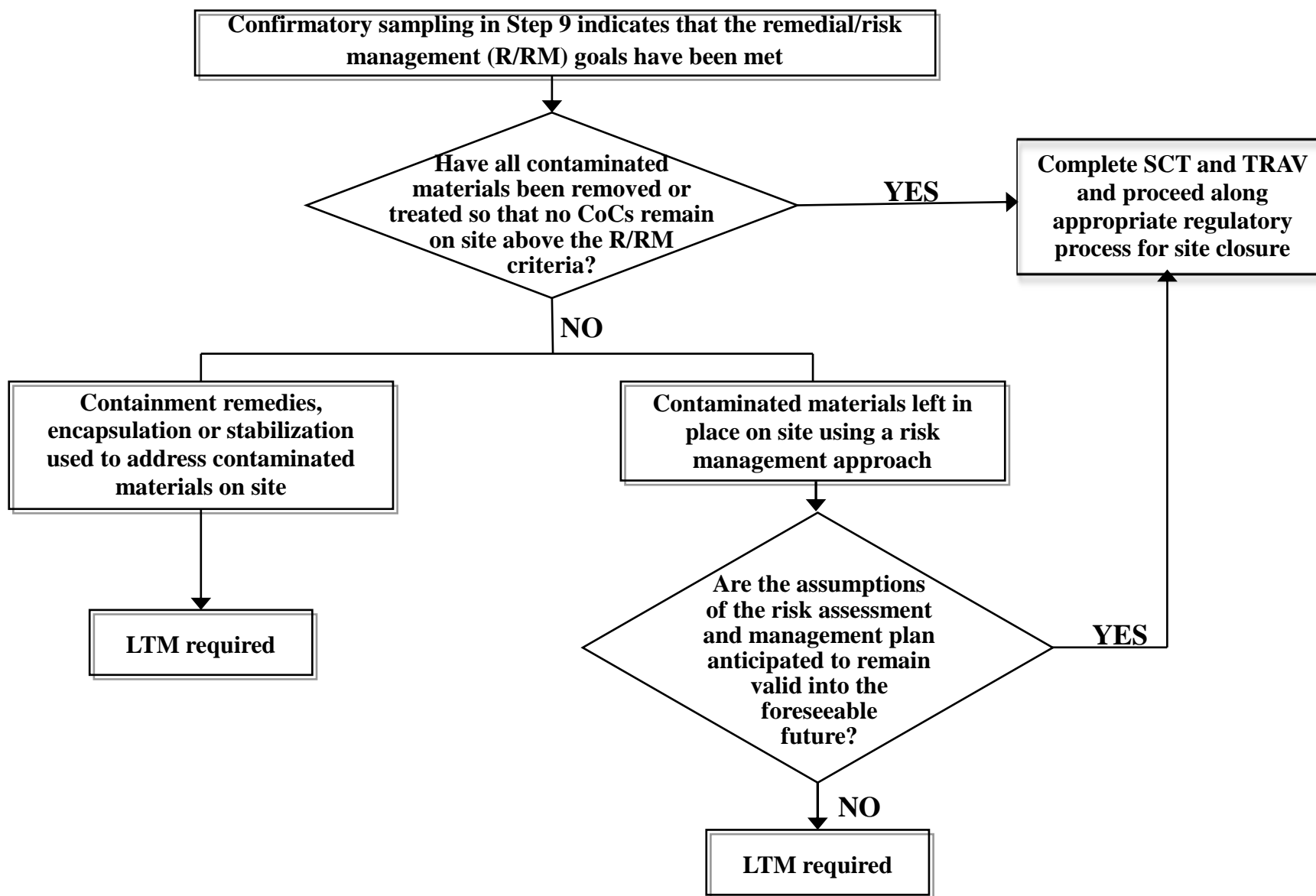


Figure 3: Flowchart indicating when LTM may be required for a FCSAP site. CoCs = Contaminants of Concern; SCT = Site Closure Tool; TRAV = Tool for Risk Assessment Validation.

## **C. Examples of LTM Activities**

There are many LTM activities that apply to federal contaminated sites. Some examples of these are listed below.

### ***1. Inspection of on-site containment and treatment facilities***

On-site containment of contaminated material is a common approach to managing the risk to human health and the environment that these materials may represent. Containment is considered a risk management approach because the CoCs are not removed from the site; rather, the potential transport pathways are removed through the use of engineered controls. Sediment caps, on-site engineered containment facilities for contaminated sediments, landfills and caps, and surface water drainage controls are examples of typical containment strategies. Appendix B provides additional detail and recommended best practices for monitoring constructed facilities.

### ***2. Evaluation of risk assessment and/or risk management assumptions***

Risk management plans are often based on the results of a human health and ecological risk assessment (HHERA), which may include various lines of evidence to determine risk levels and to set site-specific criteria and/or protection goals. This category of monitoring consists of collecting data to ensure that exposure pathways, CoCs and receptors have not changed and that the site continues to meet the project RA criteria. Depending on the lines of evidence used for the RA, public concern about the site and the current or future land use, additional environmental media and potential exposure pathways may need to be evaluated in an LTM plan. Key risk management assumptions should also be identified and monitored to ensure that they remain valid over time.

This type of monitoring is commonly used at aquatic sites and may involve the collection of sediments and biological samples (e.g., fish) to ensure that contaminant concentrations in the aquatic food web are decreasing. Another example would be the collection of hydrological data and groundwater monitoring data to validate the results of the confirmatory sampling conducted after remedial activities and to substantiate the continuing effectiveness of the remedial strategy. At sites where R/RM strategies are designed for a particular set of climatic conditions, particularly in the North, climate change monitoring is important. The sampling and analysis should be completed over a predefined initial period and then reduced or terminated based on predetermined exit criteria.

### ***3. Inspection of stabilized structures***

Stabilized structures are engineered measures that are used to control migration of contaminants from a site, limit erosion or mitigate potential physical hazards. They are predominant features of mine sites and include tailings ponds, the dikes and dams that contain them, waste rock and tailings piles, pit walls, access roads, berms and a multitude of other earthen infrastructure. Other examples of common stabilized structures include barrier systems to prevent contaminant

migration or moisture penetration; shoreline stabilization through the addition of rock material; or grading and revegetation for slope stabilization. Long-term monitoring activities include visual inspection of stabilized structures to ensure continued stability, measurements of permafrost degradation and/or aggradation in northern regions, chemical analysis of groundwater, surface water and soil quality, and evaluation of revegetation success. Best practices and guidance for LTM of such stabilized structures are available from a variety of sources; several resources are summarized in Appendix B.

#### ***4. Institutional and administrative controls***

At some risk-managed contaminated sites, restricting site access is one form of institutional or administrative control with the goal of preventing exposure to residual contamination to ensure continued protection of human and environmental health. If restriction of site access is a component of a risk management plan for a site, confirmation of the continued integrity of these measures should be included in the LTM plan for the site. Some typical site access measures that would require monitoring and maintenance over time include fencing, blockage of underground mine surface openings, site access road barriers, and warning signage.

In addition to these physical site access restriction measures, other institutional and administrative controls may be established to restrict the use of and/or access to a site. Such controls may include security programs, establishment of discretionary land and water uses such as fish consumption advisories, and building placement restrictions. While “inspection” of these administrative controls may not be applicable, a review of their continued implementation is equivalent to inspection in this context.

It is important to consider whether implementation and monitoring of institutional and administrative controls is practicable before including them as a major component of a risk management plan.

### **D. Planning for Site Closure**

The current Treasury Board definition of a “closed” site is one for which no future action is required and no further liability exists. Site closure is not listed as a discrete step in the FACS framework, but it corresponds to the final decision point on the achievement of remedial goals — that is, the point at which the contaminated site no longer poses human and ecological risks and these conditions are anticipated to continue for the foreseeable future so no further management action is required. Achieving site closure for sites under FCSAP is important as this makes it possible to demonstrate program and site-level achievements as well as to document the successful completion of the remedial and/or risk management objectives.

It is essential to evaluate the monitoring requirements of a particular remediation or risk management approach and incorporate them into the scope of the remedial options analysis (Step 7 in the FACS ten-step process: Develop remediation/risk management strategy). Clear

definition of remedial objectives is necessary to determine and measure the success of a selected remediation approach; similarly, the ongoing success of a remediation project requires clear definition of the LTM objectives. Selection of the remedial option and development of the RAP or the RMP should be done in conjunction with the evaluation of the LTM requirements (if any) associated with the proposed remedial option. This facilitates the achievement of site closure by defining the final project acceptance criteria early in the planning process, and also allows for potential monitoring costs to be taken into account during the remedial options analysis (Pike, 2011).

EC and Public Works and Government Services Canada (PWGSC) have developed tools to assist FCSAP project and program managers in the evaluation and documentation of site closure activities for federal projects. The Tool for Risk Assessment Validation (TRAV) was developed to confirm the quality and documentation of risk assessments that are undertaken to support a risk management approach to contaminated site remediation. The TRAV was subsequently integrated into a more comprehensive Site Closure Tool (SCT). The SCT includes recommended minimum requirements for risk management and LTM, and provides a template so that RM and LTM measures for the project are clearly documented. The process of closing federal contaminated sites has many inter-related steps. Upon completion of Step 5 of the FACS (Detailed Testing Program), project and program managers may begin to use the FSCAP SCT to document the process and to guide future site planning to ultimately achieve site closure.

Site closure is intimately tied to the design of the monitoring program: the monitoring objectives, measurement endpoints and associated monitoring exit criteria decided at the start of the program are used to determine when the LTM goals have been achieved. To document progress toward site closure, quantifiable measurement endpoints and action levels that indicate when the monitoring objective has been achieved must be defined as part of the monitoring program design. A time frame within which site closure is expected to be reached must also be identified to facilitate LTM statistical design and program management. A scientific approach for developing LTM plans capable of achieving site closure, intended to guide custodians in planning for monitoring endpoints and site closure when designing LTM programs, is outlined in Section III of this document.

In practice, since federal projects often incorporate risk management (where contaminants are left in place or are treated in some way and left on site), many sites require some level of ongoing LTM. However, the scope of monitoring can be reduced greatly over time as knowledge of the R/RM strategy performance increases and as monitoring indicates that R/RM remedial goals continue to be met. An objective of this guidance document for the FCSAP Secretariat and the federal departments involved with delivery of this program is to standardize and clarify the LTM requirements so that custodian departments will continue to meet the monitoring requirements associated with any residual liabilities and risks at remediated contaminated sites in a consistent manner.

### **III. STEPS FOR DEVELOPING AN LTM PLAN: THE US EPA SIX-STEP PROCESS**

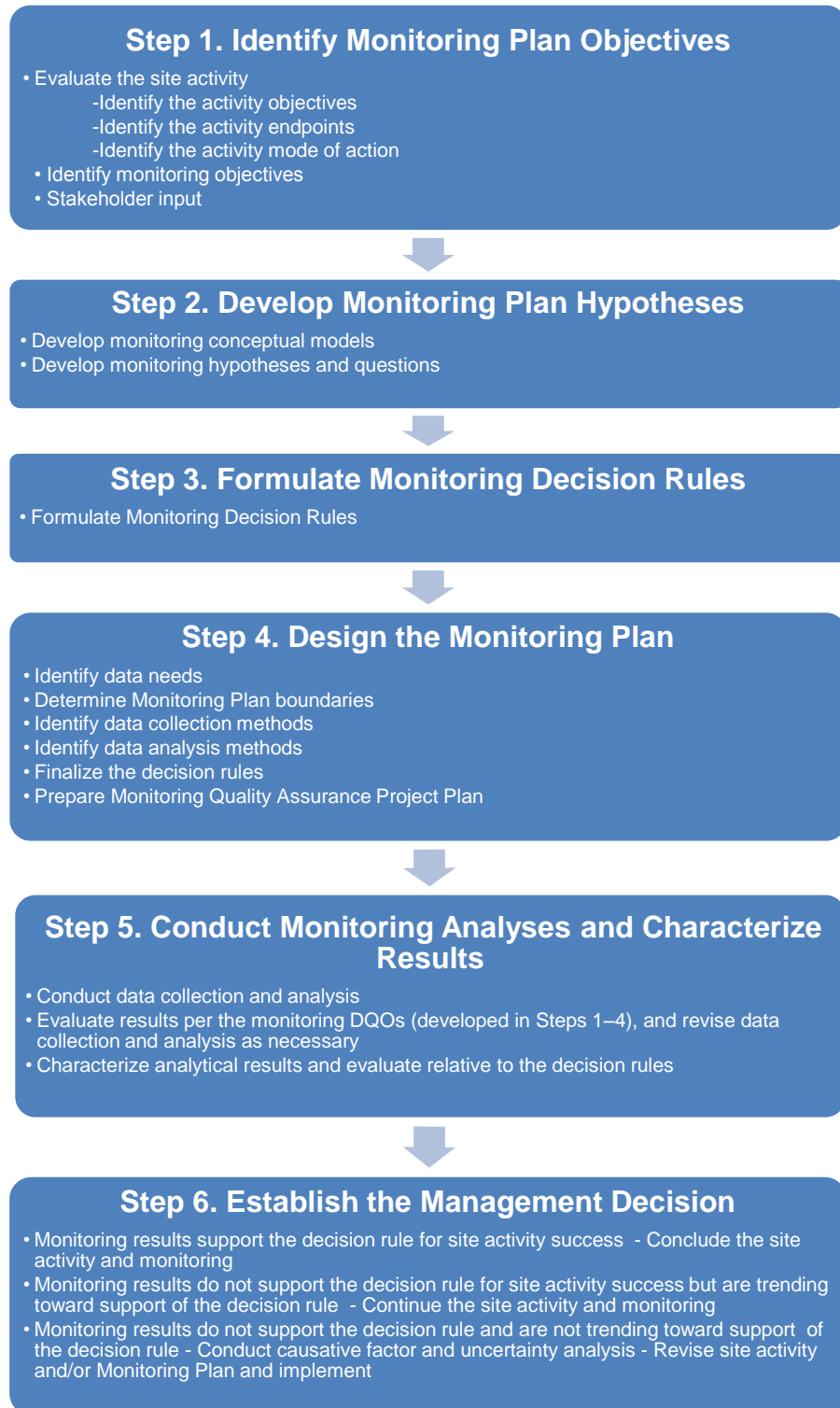
#### **A. Overview**

In 2004, the US EPA published a framework for developing and implementing technically defensible monitoring plans for hazardous waste sites. This US EPA document was written at the request of, and for, site managers who are legally responsible for managing remedial site activities at hazardous waste sites in the US. This framework has been adapted in the sections that follow for use in the Canadian context of the management of contaminated sites associated with the FCSAP program and the Federal Approach to Contaminated Sites. It is intended for use at contaminated sites for which Steps 1–6 of the FACS have been completed and for which a remedial action plan and/or risk management plan is in the process of being developed and implemented.

The US EPA guidance document presents a six-step framework for developing and documenting a LTM plan that will support management decisions and site closure (Figure 4). The framework includes identification of monitoring objectives and development of monitoring hypotheses to focus the monitoring program, and development of decision rules (exit criteria) that include action levels triggering termination, alteration, or continuation of the R/RM activities and/or the monitoring program.

Within this framework, Steps 1 through 3 document the logic and rationale of the monitoring program by developing monitoring objectives that are related directly to the objectives of the site remediation or risk management activity and by developing decision rules that will support site management decisions. Steps 4 through 6 ensure that this logic is maintained by focusing data needs and data collection and analysis methods to provide direct support to the monitoring objectives, decision rules, and subsequent management decisions. The framework is iterative and allows for evaluation of the monitoring data as they are generated, thus supporting adaptive management of the site activity and the monitoring program.

The following sections provide more detail on the US EPA LTM planning process.



**Figure 4. US EPA six-step process to develop scientifically defensible long-term monitoring plans (after US EPA, 2004).**



## **B. Step 1: Identify Monitoring Plan Objectives**

### ***1. Definitions, categories, and importance of clearly defined objectives***

*Monitoring goals* represent the overall aims for management of the ecosystem (e.g., the reduction of human health and ecological risks to acceptable levels). *Monitoring objectives* are specific statements that clarify the scope and intent of the monitoring goals (e.g., to assess the chemical and physical integrity of a sediment cap) (MacDonald et al., 2009).

Identifying a clear set of monitoring objectives is of critical importance in developing a monitoring plan capable of achieving site closure. These objectives can be used at the beginning of the LTM program to confirm the scope and focus of the monitoring program with regulators and other stakeholders. It is important that the monitoring objectives be quantifiable so that endpoints representing successful completion of the monitoring objective can be determined and discussed with stakeholders. This ensures that the project is planning for site closure from the beginning of the monitoring program.

In general, LTM plan objectives may be grouped into one of four categories (US EPA, 2004):

- identification of changes in ambient conditions;
- detection of movement of environmental constituents of interest (e.g., CoCs, sediment) from one location to another;
- demonstration of compliance with regulatory requirements; or
- demonstration of the effectiveness of a particular activity or remedial action.

Key monitoring questions are identified by reviewing the remedial strategy and its intended outcomes, the CoCs and associated remedial objectives outlined in the remedial/risk management plan, and the human health and ecological endpoints determined to be at risk for the site (US EPA, 2004). Activities that are not a direct consequence of the remedial strategy but are associated with its use, such as the re-vegetation of excavated areas or restoration of benthic habitat quality at dredged or capped sites, should also be addressed at this point. Stakeholder involvement in the definition of monitoring objectives allows stakeholder issues and concerns to be incorporated into the subsequent monitoring plan design (US EPA, 2004; Gerrits and Edelenbos, 2004). The process for identifying monitoring objectives is outlined in more detail below.

### ***2. Process for identifying objectives***

Experience from the management of mine sites in the Northwest Territories (NWT) suggests that the most effective way to develop an LTM plan for a site is to identify monitoring objectives for each component or area of environmental concern (AEC) individually to ensure that the remedial objectives for that component or area continue to be met (Pike, 2011). The sum of these

individual components or area monitoring needs can then be evaluated as a whole to identify overall efficiencies and broader monitoring requirements for the site. Pike (2011) argues that this bottom-up approach, with subsequent top-down review, can ensure that the residual risks that need to be managed at a site are being monitored appropriately. An example of this approach is the natural environment component of AANDC's Abandoned Military Site Remediation Protocol (AANDC, 2009).

Identification of the LTM plan objectives is generally based on an examination of the site activities (e.g., construction of a landfill, construction of a fence). This examination helps with identification of the physical, chemical and ecological parameters that could be used in developing the monitoring plan design. Examination of the site activities should address:

- The outcome of the site activity: What is to be accomplished through this activity and what are the specific entities expected to be affected by this activity (e.g., biological community structure or contaminant concentration)?
- The ways in which this activity is expected to meet the intended objective: What is the mode of action? For example, the mode of action of a sediment cap is the physical and chemical isolation of CoCs from contact with the water column and aquatic receptors.
- The human health and ecological receptors determined to be at risk for the site.
- The CoCs and associated cleanup criteria: What are the contaminants driving the risk, and what are the remediation/risk management criteria for reducing risks to acceptable levels?

Early involvement of stakeholders in LTM planning is important to ensure that stakeholder issues and concerns are identified before the monitoring plan is finalized and implemented. Informing stakeholders about the residual liabilities that may be associated with a particular remediation option is a key to achieving site closure. Stakeholder expectations should be identified early in the planning process, addressed within the process of developing objectives in the remediation planning stage, and managed throughout the duration of the project to ensure final acceptance of the completed remediation and LTM activities.

References with more detailed guidance concerning LTM objectives for various remedies at terrestrial sites are listed in Appendix B. Further guidance for developing LTM objectives for aquatic contaminated sites may be found in Appendix C, as well as ASTSWMO (2009) and SPAWAR and Environ (2010).

### ***3. Examples of site activities and monitoring objectives***

Table 1 provides several examples of site activities and related LTM objectives. The examples are meant for illustrative purposes and are not necessarily comprehensive of all site activities requiring LTM, nor are all of the LTM objectives necessarily relevant to all sites.

**Table 1: Examples of site activities requiring LTM and related monitoring objectives.**

Site Activity	Monitoring Objectives
Landfill	<ul style="list-style-type: none"> <li>• Conduct visual inspection of landfill stability.</li> <li>• Evaluate permafrost degradation or aggradation in landfills where permafrost is used in the design.</li> <li>• Evaluate the chemical integrity of the landfill (leachate, groundwater, surface water and/or soils).</li> </ul> <p>(UMA, 1999)</p>
Sediment capping	<ul style="list-style-type: none"> <li>• Evaluate the isolation of chemicals in impacted sediments below the cap.</li> <li>• Evaluate the physical stability of the cap.</li> <li>• Evaluate the potential for surface sediment recontamination.</li> <li>• Assess contaminant risk reductions to humans and wildlife.</li> <li>• Evaluate bioaccumulation of the CoCs.</li> <li>• Monitor the ecological recovery of the site.</li> </ul> <p>(SPAWAR and ENVIRON, 2010)</p>
Stabilization of mine tailings	<ul style="list-style-type: none"> <li>• Conduct periodic dam safety and stability reviews of structures that remain after closure.</li> <li>• Inspect seepage collection systems for water quality flows.</li> <li>• Inspect and maintain dam structures and/or spillways associated with flooded tailings over the long term.</li> <li>• In the case of water covers, ensure that there is sufficient water supplied to maintain an appropriate water depth.</li> <li>• Check for degradation or aggradation of permafrost for tailings containment structures where permafrost was used in the design.</li> <li>• Monitor pond water level and quality to confirm closure targets.</li> <li>• Evaluate/confirm success of revegetation activities: meets technical needs (maintains physical stability) or aesthetic needs (blends with surroundings) and meets end land-use targets.</li> <li>• Assess dust dispersion and vegetation uptake with wind dispersion of tailings.</li> </ul> <p>(INAC, 2007)</p>
Risk management at a dynamic site (e.g., contaminated sediments at depth left in place)	<ul style="list-style-type: none"> <li>• Evaluate the physical stability and burial of contaminated sediments.</li> <li>• Evaluate the chemical isolation of buried contaminated sediments.</li> <li>• Evaluate bioaccumulation of the CoCs.</li> </ul>
Risk management using institutional/administrative controls (e.g., restricted site access)	<ul style="list-style-type: none"> <li>• Conduct visual inspection of fencing and signage.</li> <li>• Evaluate potential wildlife entanglement.</li> </ul>

Appendix B lists references with examples of monitoring objectives for terrestrial remedies. Case studies with examples of monitoring objectives for aquatic sites may be found in Appendix C.

## **C. Step 2: Develop Monitoring Plan Hypotheses**

Monitoring hypotheses are statements and questions about the relationship between an R/RM activity and one or more expected outcomes for that activity. The development of monitoring objectives, monitoring hypotheses, and a monitoring conceptual model serves to focus the monitoring program on achieving a desired outcome (i.e., site closure) rather than facilitating the continuous collection of data for an undefined purpose. Identification of monitoring hypotheses is assisted by the development of a comprehensive conceptual site model, as outlined below.

### ***1. Develop post-remediation/risk management conceptual site model***

A conceptual site model (CSM) is a summary of all available site-specific information related to contaminant sources and release mechanisms, affected media, contaminant transport and environmental fate, and receptor exposure. A CSM must be updated as data and knowledge are acquired. This is crucial for assessing and optimizing remediation performance and monitoring programs. References with guidance for developing a CSM include Chapman (2010), Azimuth (2012), and Health Canada (HC) (2009).

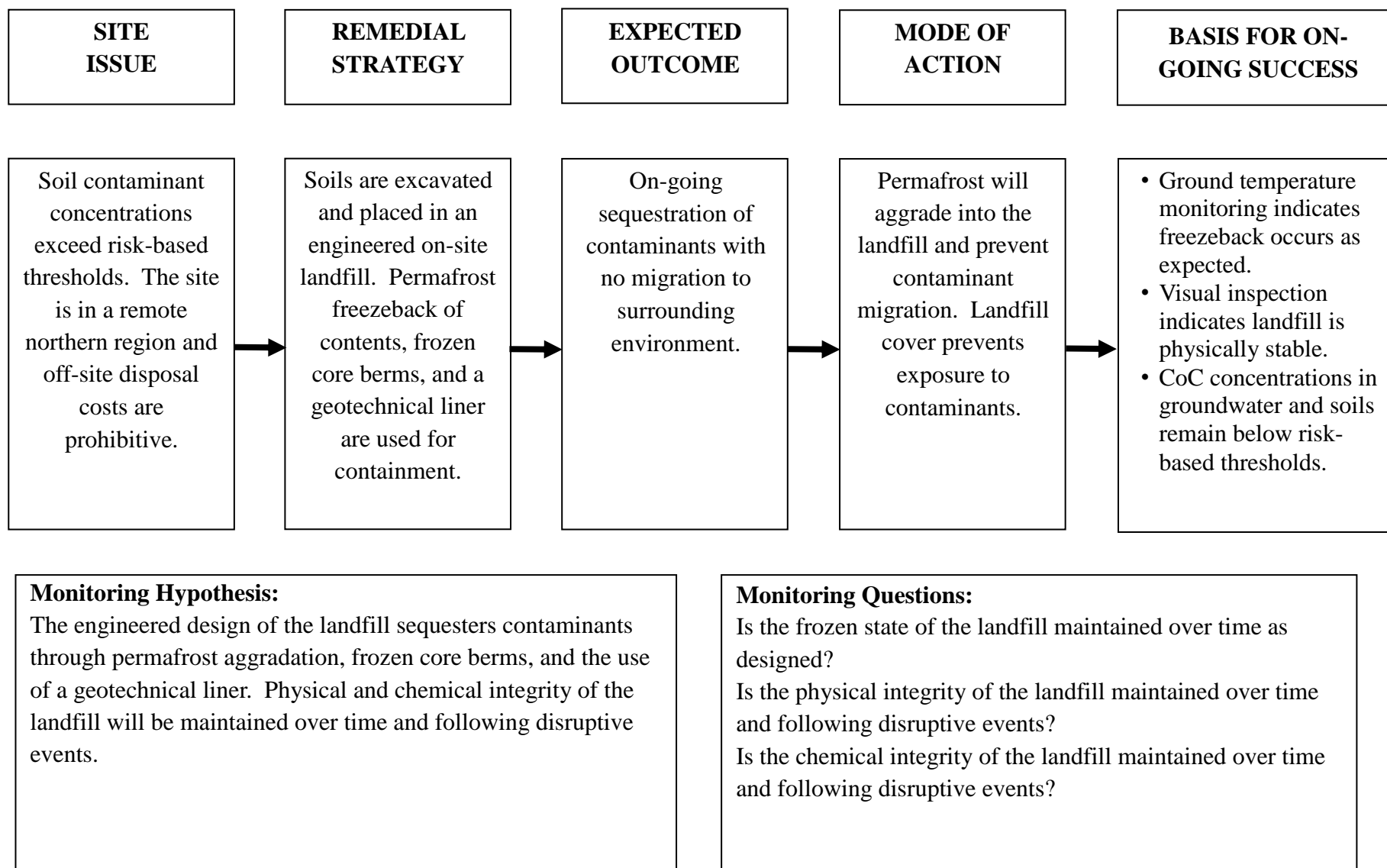
Although many federal contaminated sites share commonalities, each site is different. Just as a pre-remediation conceptual model that defines and lists the concentrations, distributions, fate, transport pathways and potential receptors of CoCs is necessary to develop a RAP/RMP, so too is development of a post-remediation CSM (or updating of an existing CSM) in order to plan a strategic, efficient and sustainable LTM approach for a given site. For sites undergoing RM, information from an HHERA or another RA would provide valuable input for a CSM to be used in LTM. A good CSM will help identify required data and data quality, the action levels for management decisions and, ultimately, an endpoint to monitoring requirements if possible.

In practice, the information provided in the Remedial Action/Risk Management Report, typically completed by the departmental representative (usually consulting engineers) responsible for site supervision as part of Step 9, Confirmatory Sampling and Final Report, should provide adequate information to form the basis of a post-remediation CSM. Project managers should seek input from expert support departments and stakeholders as well as their consultants when developing the site CSM.

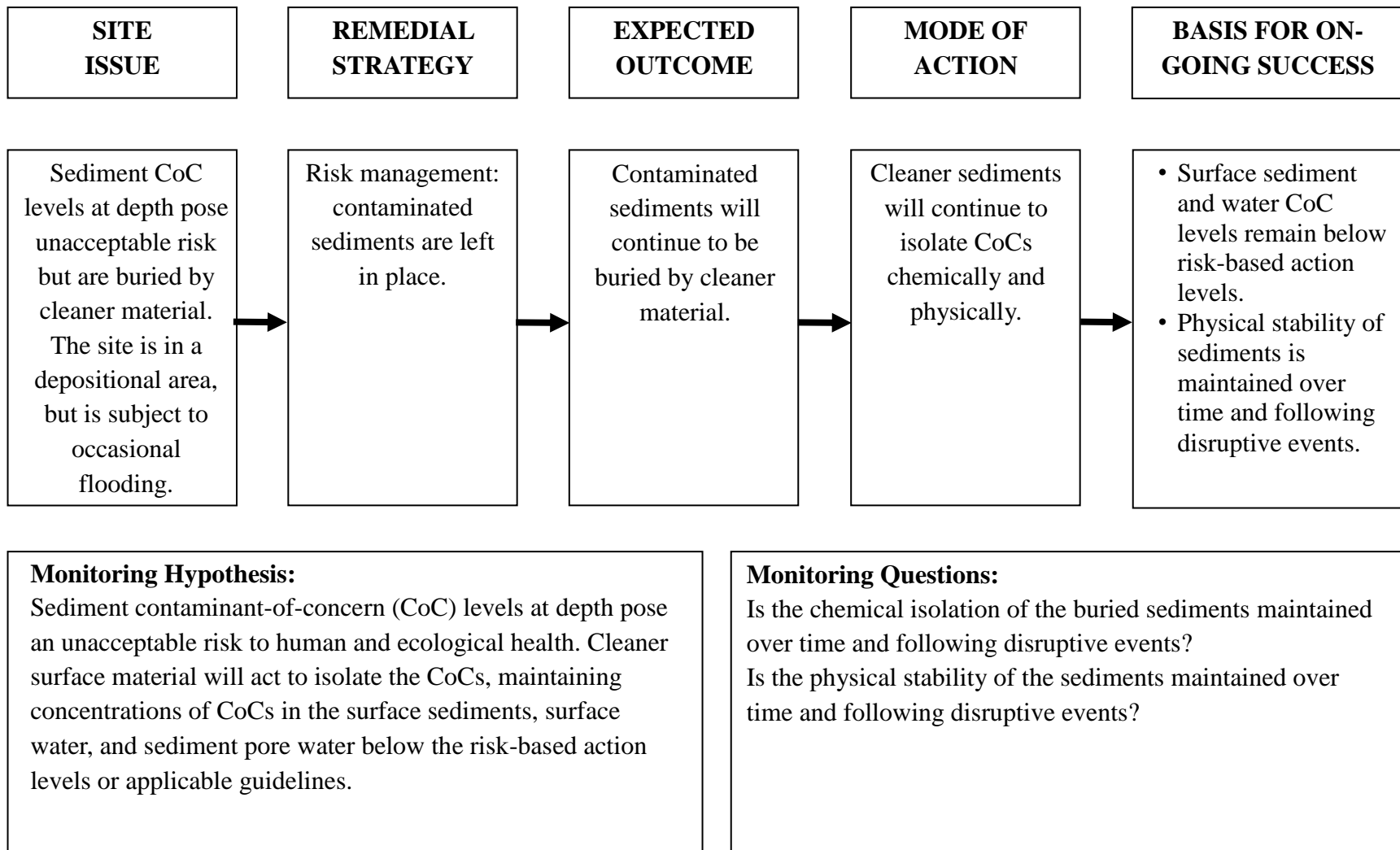
Some questions to consider when developing monitoring hypotheses based on the CSM are:

- Where was contamination left on site?
- Where are the residual vulnerabilities/risks to human health or the environment?
- Are there areas with incomplete understanding?
- Are there sentinel species, specific environmental media or measurement points on which LTM should focus?
- Have the locations and frequency of monitoring activities been guided by awareness of vulnerability points and current scientific and traditional knowledge?

Simple examples of monitoring plan conceptual models, hypotheses and questions are illustrated in Figures 5 and 6.



**Figure 5: Example of a conceptual model for monitoring a northern disposal facility for contaminated soils.**



**Figure 6: Example of a conceptual model for monitoring risk management of contaminated sediment at a dynamic site.**

## **D. Step 3: Formulate Monitoring Decision Rules**

### ***1. Definition and role of monitoring decision rules***

Once the monitoring hypotheses have been determined, decision rules for interpreting the monitoring data can be developed. Decision rules are quantitative pass/fail statements that generally take the form of “if... then” statements (NAVFAC, 2007). The roles of decision rules are to provide a basis for concluding that a desired condition has been or is being met; to facilitate adaptive management for the monitoring program and site activities; and to reduce the potential for unclear or incorrect decision-making. Each decision rule is composed of five main elements (US EPA, 2004; NAVFAC, 2007):

- the monitoring parameter being measured (e.g., groundwater contaminant concentrations);
- the metric used to measure the parameter (e.g.,  $\mu\text{g}$  of a contaminant/L of water);
- an action level (e.g., remedial objective) against which the monitoring results are compared and which results in an action when met or exceeded;
- the temporal considerations for the decision criterion (e.g., monitoring frequency) and timeframe within which the action level is expected to be reached; and
- the alternative actions to be considered for implementation when an action level has or has not been met or exceeded (e.g., assess causality and revise remedial strategy if necessary)

Some broad outcomes of the decision rules may be to:

- validate remedial success supporting site closure;
- continue, reduce or augment scope/frequency of monitoring of one or more parameters at a specific location; or
- require an additional remedial activity, in the form of a contingency plan, to address a failure or deficiency in meeting the R/RM goals.

### ***2. Process for developing monitoring decision rules***

Establishing the monitoring decision rules may be one of the most intellectually challenging aspects of developing an LTM plan. The decision rules must be as specific and detailed as is practicable but must also permit adaptation based on the most current knowledge of site conditions, available technologies and scientific understanding of the CoCs and site ecosystem dynamics. A bottom-up approach can be applied to establishing decision rules, with monitoring requirements for each component of the site being addressed individually. It may be useful to consider the following questions:

- Why are we going to monitor this specific component?
- What is the vulnerability or risk that LTM is mitigating?
- How would we know that there was a problem?
- What would constitute a trigger for action?

US EPA (2004, 2006) provides guidance on the process that may be used to develop decision rules for each monitoring objective and associated measurement endpoints. First, the spatial and temporal boundaries of the monitoring study should be defined (i.e., what is the smallest area in which a decision rule will apply, and what timeframe is anticipated for completion of the monitoring objective). Once the boundaries of the study are set, action levels can be determined for each decision rule. Quantitative action levels are specific to each metric and are used to evaluate monitoring results and make a choice among site management options. The development of scientifically defensible decision criteria, including exit criteria that indicate when the monitoring objective has been met, is essential for effective project management and decision-making. Examples of decision rules are outlined in Box 1.

References with guidance for determining decision rules for specific terrestrial remedies are listed in Appendix B; guidance for aquatic contaminated sites may be found in Appendix C and SPAWAR and ENVIRON (2010). NAVFAC (2007) provides guidance on decision rules for biomonitoring programs.



**Box 1: Examples of decision rules, action levels, and alternative actions for monitoring the chemical integrity of a sediment cap.**

Decision rules:

1. If CoC concentrations in surface water, inter-armouring water and/or sub-armouring water indicate that the chemical integrity of the cap is not maintained, then review and modify the remedial design accordingly.
  - Action levels: CoC concentrations in water samples will be considered good if they are below the CCME Water Quality Guidelines for the Protection of Aquatic Life.
  - Alternative Actions: (1) Continue monitoring program as planned if the action levels are met; (2) Determine causality if the action levels are exceeded. If the exceedances are due to chemical flux through the sediment cap (and not other upstream sources), then review and modify the remedial design accordingly.
2. If CoC concentrations in the cap sediments indicate that the chemical integrity of the cap is not maintained, then review and modify the remedial design accordingly.
  - Action levels: CoC concentrations in sediment core samples of the cap material will be considered good if they are below the risk-based Sediment Quality Objectives developed for the site.
  - Alternative Actions: (1) Continue monitoring program as planned if the action levels are met; (2) Determine causality if the action levels are exceeded. If the exceedances are due to chemical flux through the sediment cap (and not other upstream sources), then review and modify the remedial design accordingly.

***3. Developing exit criteria for site closure***

To assess progress toward site closure, it is critical to determine scientifically defensible action levels that represent the attainment of the desired condition associated with a particular monitoring objective. These site closure action levels can then be used to establish exit criteria for each monitoring objective: when the exit criteria are met, monitoring for that objective may be concluded. Overall closure for a site is achieved when the exit criteria have been met for all of the monitoring objectives.

Site closure action levels for a monitoring objective are specific to each monitoring parameter and the associated metric. The action levels should be linked closely with the remedial objectives defined in the development of the remedial action plan, as well as with previous risk assessment outcomes. For example, a human health risk assessment may have identified that fish tissue

contaminant concentrations at a site represent a potential risk to sport anglers. Back-calculation of the risk assessment equations can identify a target fish concentration that is protective of sport anglers; this target fish concentration then becomes the site closure action level for monitoring achievement of reduced risks to human health through fish consumption.

Exit criteria may also combine a temporal component with the specified action level as a basis for evaluating attainment of the desired condition (NAVFAC, 2007). For example, measurement of groundwater contaminant concentrations below the specified action level may be required for multiple and consecutive sampling periods (e.g., the action level must be attained for three consecutive sampling periods) before a management decision and response are prompted. This aids in ensuring reproducibility of the monitoring results and reducing uncertainty in decision-making. Trend analysis, where monitoring data are plotted over time, may also be included in decision-making criteria to evaluate the likelihood of attaining the exit criteria in the desired timeframe and to allow for adaptive management of the monitoring plan. Trend analysis can be very useful for monitoring objectives that are anticipated to take relatively long periods of time for completion. Examples of exit criteria for LTM programs are listed in Box 2.

Monitoring decision criteria should be re-examined periodically as part of an adaptive site management process to ensure that the exit criteria are appropriate and achievable (US EPA, 2004). New information that alters the risk assessment for a site may also impact risk-based target action levels for some monitoring objectives. Alternatively, monitoring results may indicate that the attainment of a target action level may not be feasible in the anticipated timeframe. For example, a target fish tissue concentration may have been selected as an action level to monitor reduced risk to human health. However, monitoring results indicate that fish tissue contaminant concentrations are not decreasing and are likely to reflect exposure to off-site contaminant sources associated with elevated background concentrations or general urban runoff. In this case, it may be decided that the exit criterion for this monitoring objective cannot be achieved and that continued administrative controls (e.g., fish consumption advisories) are necessary. The monitoring program may be scaled down in level of effort and monitoring frequency to accommodate this new information.

**Box 2: Examples of exit criteria for LTM programs.**

Monitoring objective: Evaluate bioaccumulation to aquatic organisms (sport fish)

- Exit criteria: The 95% UCL of fish tissue contaminant concentrations is below the risk-based threshold for upper trophic level consumers for three sampling periods.

Monitoring objective: Evaluate on-going success of slope stabilization through revegetation

- Exit criteria: The proportion of vegetation cover has met the design criteria for three consecutive sampling years.

Monitoring objective: Evaluate recovery of aquatic habitat productivity

- Exit criteria: No significant differences in measures of aquatic habitat productivity between test and reference sites.

**E. Step 4: Design the Monitoring Plan**

In Step 4 of the EPA six-step approach to designing a monitoring plan, the data needs, data collection and analysis methods, quality assurance/quality control (QA/QC) requirements and final decision rules are developed.

The method for developing monitoring plans presented in this guidance relies heavily on the use of the US EPA data quality objective (DQO) process (US EPA, 2000). This is an iterative process that is integrated with the development of a sampling and analysis plan, and it is revised as needed. It describes a general approach for determining sample size, sample collection equipment, and field analytical methods. The DQO process employs statistical parameters and specifies tolerable limits on decision errors. It provides an approach to problem resolution and defensibility of data collection and forces the user to identify all possible uses of data and assess whether all criteria will be satisfied. Further details on the DQO process may be found in Appendix C and in the US EPA guidance document *Guidance on Systematic Planning Using the Data Quality Objectives Process* (US EPA, 2000).

The following points need to be considered at this step in the LTM planning process:

***1. Identify the data needs***

A variety of data may be necessary to test the monitoring hypotheses, to answer the monitoring questions, and ultimately to support a management decision. These data may be chemical, physical and/or biological in nature, depending on the hypotheses and questions and on the decisions to be made. Data should also be collected to test the validity of key assumptions used to develop the conceptual site model. It is suggested that QA/QC expectations and protocols

(analytical or field) for LTM sampling activities be commensurate with those established for phased Environmental Site Assessments.

Guidance for selecting monitoring tools for long-term monitoring at aquatic contaminated sites is provided in Appendix C, as well as at the on-line Interactive Sediment Remedy Assessment Portal (ISRAP): <http://www.israp.org/Default.aspx>. Guidance for identifying data needs for terrestrial sites is provided in Appendix B.

## ***2. Determine the monitoring boundaries***

The monitoring boundaries represent the “what, where, and when” aspects of the monitoring plan. They identify the target population of interest and specify the spatial and temporal features pertinent for decision-making or estimation. If the target population consists of “natural” entities (e.g., people, plants, or fish), the definition of sampling unit is straightforward: it is the entity itself. When the target population consists of continuous media, such as air, water or soil, the sampling unit must be defined as some area, volume or mass that may be selected from the target population. Once the necessary data have been identified and the spatial boundaries selected, the temporal boundaries should be established. Identification of the temporal boundaries should include information on when samples should be collected (e.g., spring, summer, dawn, dusk); how often they should be collected (daily, weekly, annually, etc.); and how long sampling should continue (e.g., six months, two years, until a specified condition is reached).

Guidance for determining the spatial and temporal boundaries of the monitoring study is provided in Step 4 of the US EPA (2006) DQO process. Spatial boundaries delineate the entire geographical area of the site and divide the site into relatively homogeneous sub-units that can be used to define sampling locations. Data collected in previous site characterization, risk assessment and remedial plan studies, as well as the site conceptual model, should be reviewed to define the spatial boundaries of the site.

Inclusion of one or more reference sites in the monitoring study is often critical for interpretation of the monitoring results. Reference sites may be defined as areas that have physical, chemical and ecological characteristics similar to those of the site of interest, but with minimal human disturbance and contaminant concentrations typical of background levels (Stoddard et al., 2006). Reference condition generally implies a range of measured values for the parameter of interest that captures the natural variability associated with the measure (EC, 2010). Significant differences between monitoring data for a particular measurement endpoint (e.g., soil contaminant concentrations, aquatic habitat productivity) compared with reference condition therefore suggest that site conditions are outside the range of natural variability. Often, suitable reference areas will have been identified as part of site investigation activities and should continue to be sampled as part of the monitoring program. Reference conditions can also be informed by any pre-disturbance data that may have been collected before the site was developed, although this information is often not available.

Determining the temporal boundaries of the monitoring study involves identifying a consistent sampling period (the index period) as well as the overall anticipated timeframe for monitoring. Many metrics are influenced by time-related factors, such as seasonal changes or weather patterns; therefore, the selection of a consistent index period for monitoring minimizes the influence of natural temporal variability on the monitoring outcomes.

Baseline monitoring establishes initial post-R/RM reference values for CoCs at a particular site for the purposes of future comparison with LTM data. It is alternatively referred to as the Year 0 or  $t=0$  starting point conditions for LTM. To make scientifically defensible management decisions, it is very important to have these reference values to compare with results gathered during the monitoring program. Additional information to be considered when establishing  $t=0$  conditions are the background sampling data gathered during the site assessment phase or as part of a risk assessment. These data may be used to gain an understanding of naturally occurring elements and to help to set appropriate decision criteria for the LTM plan.

The timeframe required for the achievement of site closure will vary greatly from site to site, depending on site characteristics, the remedial strategy employed and the nature and scale of ecosystem impacts. The anticipated timeframe to achieve the decision rule exit criteria differs for each monitoring objective and the associated indicators. Generally, the attainment of remedial goals associated with ecosystem recovery will require the most time. For example, in some cases, several decades may be required for mitigation of risks to upper-trophic-level and human receptors through bioaccumulation of persistent organic chemicals, such as PCBs. Estimates of the timeframe required for monitoring may be developed through review of the site conceptual model, comparisons with similar sites, and statistical and modelling analyses. Trend analysis of monitoring data can provide insight into rates of ecosystem recovery and allow for estimates of the timeframe required for site closure on an adaptive management basis.

The final stage in determining the monitoring study boundaries is to identify a scale of inference for decision-making (US EPA, 2006), the means by which the planning team delineates the smallest unit of area, volume or time over which data will be collected, analyzed, compiled and interpreted for decision-making. The consequences of making incorrect decisions should be considered so that an appropriate scale for decision-making may be identified. Decision units may be established using considerations such as risk, technological factors, temporal variability, financial scale, or other factors such as the presence of “hotspots” of contamination. Further guidance in setting an appropriate decision-making scale of inference is provided in US EPA (2006).

### ***3. Identify the data collection methods***

There may be a variety of approaches to collecting the necessary data for a specific data need; some may be more costly or difficult to implement than others. It may not be possible to identify specific sampling designs at this stage of monitoring plan design. However, at this point, data

collection methods that may be appropriate for collecting the required data are identified, and a preliminary determination is made of the feasibility of using those approaches to collect the data with the required characteristics and within the required time and cost constraints. A list of screening criteria that may be used to facilitate selection of monitoring tools for a particular data need is provided in Box 3.

**Box 3: Screening criteria to aid in selection of monitoring tools for addressing a particular monitoring need.**

***Commonality of tool use:*** frequency of tool use in addressing the monitoring need (very rare to very common).

***Special considerations:*** significant restrictions and other important information about the tool that may limit or enhance its application.

***Spatial experimental design complexity:*** the complexity and level of expertise required to identify the location and number of monitoring points required for successful application of the monitoring tool.

***Temporal experimental design complexity:*** the complexity of making decisions about the timing and frequency of the monitoring tool use, including time constraints associated with the monitoring tool.

***Monitoring tool logistical complexity:*** the difficulty associated with using the monitoring tool.

***Difficulty in locating tool in marketplace:*** whether it is widely available or likely to be unavailable from commercial sources.

***Relative cost:*** relative cost ranking for various tools that fulfill the same monitoring need.

***Level of expertise required for data interpretation:*** level of analyst expertise required to interpret and use data to address the monitoring need within a decision-making framework.

***Uncertainty in addressing monitoring need:*** the level of uncertainty associated with using data collected with a specific monitoring tool to satisfy the monitoring need. This ranges from high to low confidence in the ability of the monitoring tool to satisfy monitoring needs. This is a critical attribute for determining the success of the monitoring program.

Source: SPAWAR and ENVIRON (2010)

#### ***4. Identify the data analysis methods***

It is critical that the study design and data analysis methods be able to distinguish between natural variability in the data and actual response in the parameter being evaluated. Analysis of the monitoring data usually involves some form of statistical analysis. The selection of the statistical approach should be based on how well the assumptions of the statistical test (e.g., normal distribution) are met and how closely they are tied to the monitoring objectives, hypotheses and questions, and decision rules.

In general, analysis of the monitoring data will employ some combination of descriptive and inferential statistics (which typically involve a determination of the central tendency of the data, such as the mode, median or mean, and also identification of the dispersion (e.g., range, standard deviation) and frequency distribution (e.g., normal, bimodal) of the data) and time-series (or trend) analysis. Trend analysis evaluates data collected at specified intervals over a specified period to determine whether conditions are changing over time and, if they are, how they are changing. Trend analysis may also be employed to predict how parameters of interest might respond in the future, or how well an activity is progressing toward its stated objectives. The results of such trend analyses may be used to refine or revise site activities through adaptive management of the LTM plan.

Decision-making problems, such as comparisons of monitoring data with a defined action level to make a decision, are evaluated by performing statistical hypothesis tests. The most commonly used null hypothesis is that there is no difference between the measured data and the action level (Mapstone, 1995). For example, for measures of sediment contamination, the null hypothesis may be that there are no differences between the measured sediment contaminant levels for a monitoring area and the exit criterion. The alternative condition would be that the measured contaminant concentrations for the monitored area are higher than the exit criterion.

There are four possible outcomes from statistical hypothesis testing (Table 2; Zar, 1984). Two of these outcomes (accepting the null hypothesis if it is true, rejecting the hypothesis if it is false) lead to the correct decisions being made regarding the monitoring data. The other two outcomes represent decision errors. A false rejection decision error (also called a Type I error) occurs when the null hypothesis is true but is rejected. The probability of this error occurring is called the *level of significance* ( $\alpha$ ). A false acceptance decision error (also called a Type II error) occurs when the null hypothesis is false but is accepted; the probability that this error will occur is called beta ( $\beta$ ). The *statistical power* of the hypothesis test is defined as the probability of rejecting the null hypothesis when it is truly false (Zar, 1984; US EPA, 2006); it is equal to  $1 - \beta$ . Power is a measure of the likelihood that the collected data will lead to the correct conclusion that the alternative condition is true rather than the null hypothesis. For a given sample size, the values of  $\alpha$  and  $\beta$  are inversely related (i.e., lower probabilities of committing a false rejection decision error are associated with higher probabilities of committing a false acceptance decision error).

**Table 2: Possible outcomes from statistical hypothesis testing (from US EPA, 2006).**

Decision made by applying the statistical hypothesis test to the monitoring data	True condition (reality)	True condition (reality)
	Null hypothesis is true	Alternative condition is true
Decide that the null hypothesis is true	Correct decision	False acceptance (Type II) decision error
Decide that the alternative condition is true	False rejection (Type I) decision error	Correct decision

Setting appropriate limits on the likelihood of making decision errors is an important part of the DQO process for monitoring programs. Biological studies typically use a significance level of 0.05 and a statistical power of 0.80, but these arbitrary criteria may not be sufficient to protect from the risks of making incorrect decisions in some cases. Alternatively, the increased sampling effort and costs required to meet these criteria may not be justified if the risks associated with potential incorrect decisions are low. Accordingly, Mapstone (1995) and the US EPA (2006) recommend that the consequences of making wrong decisions be taken into account when deciding on a level of significance and statistical power for decision rules. Using the null hypothesis example described above, a false acceptance decision error would assume that the exit criteria for the monitoring objective had been achieved, when in reality sediment concentrations for the monitoring area exceed the target level. The consequences may be continued human health and ecological risks that are not addressed. In contrast, a false rejection decision error would assume that the exit criteria had not been achieved, when in fact sediment concentrations for the monitoring area have reached the target level. The consequences for this scenario are unnecessary costs associated with additional monitoring. More stringent controls may be placed on the probability of making false acceptance decision errors in this case if the potential human health and ecological risks could be appreciable. Detailed guidance on setting tolerable limits for hypotheses tests when comparing data with an action level is provided in US EPA (2006).

It is important that the statistical design of the sampling program be robust and able to detect change if present. Power analysis is a valuable statistical technique that may be used to test the suitability of data sets to meet monitoring requirements. Detailed guidance for completing power analysis may be found in Cohen (1988). This statistical technique enables calculation of the minimum sample size and minimum sampling frequency required to be able to detect spatial or temporal changes for a particular effect size (i.e., minimum detectable spatial or temporal difference); knowledge of the variability around the mean is also necessary, and a pilot monitoring study may be required to acquire this. Power analysis has been applied, for example, in guidance for fish and benthic invertebrate monitoring programs to assess environmental effects from metal mining in Canada (EC, 2011). Additional guidance on using power analysis in monitoring programs is provided in Appendix C and references cited therein.

### ***5. Finalize the monitoring plan***

The final stage in development of a LTM plan is to integrate the previous steps, optimize the monitoring plan for any new or revised assumptions and finalize the monitoring plan to be implemented. Optimization of the sampling program design should include review of potential alternative approaches for data collection that would achieve the DQOs for the list of monitoring objectives (Clark et al., 2010). Existing environmental data for the site should be examined to assess the data quality, the sources of variability and the cost-effectiveness of conducting pilot sampling to attain estimates of variability. Alternative designs for data collection and analytical



measurement should be explored to identify the most cost-effective balance of level of sampling effort and measurement performance, taking into consideration the site-specific constraints on spatial and temporal sample designs and measurement methods. Assumptions used to develop the monitoring program should be documented and examined critically for their adequacy and relevance (Clark et al., 2010). The final choice of monitoring program design, as well as the main assumptions and rationale for its selection, should also be documented at this stage. Suggested contents of an LTM plan are provided in Appendix D, LTM Plan Template. Appendix E provides an example of an LTM plan checklist that may be used to review the contents of an LTM plan.

## **F. Step 5: Conduct Monitoring Analyses and Characterize Results**

The LTM plan has been finalized and implementation is underway. As the monitoring data are collected, the first stage in data review is to determine whether the data meet the DQOs for the monitoring plan design. These DQOs include the spatial and temporal boundaries defined for monitoring each objective, as well as the data collection and data analysis methods and the QA/QC criteria defined in the monitoring quality assurance project plan. If the data do not meet the DQOs, the underlying reasons for the deviations should be assessed. In general, these will be due either to errors in the monitoring plan implementation or to uncertainties in the assumptions about the remedial strategy outcomes or the monitoring conceptual model (US EPA, 2004). Once the cause of the deviations is identified, either the remedial strategy or the monitoring plan may be revised.

Activities included under this step are listed below.

- Conduct data collection and analysis: Do the data meet the DQOs? If so, will the available data support a decision rule? If not, why not, and what changes should be made so that the data collected in the future will meet the DQOs?
- Evaluate results according to the monitoring DQOs developed in Steps 1–4, and revise data collection and analysis as necessary. This revision may be of the site activity itself or of the implementation of that activity.
- Characterize analytical results and evaluate the results in relation to the decision rules.

A flowchart that may be used to guide decisions regarding the monitoring program as the data are collected is provided in Figure 7. Further guidance for evaluating monitoring results is provided in US EPA (2004).

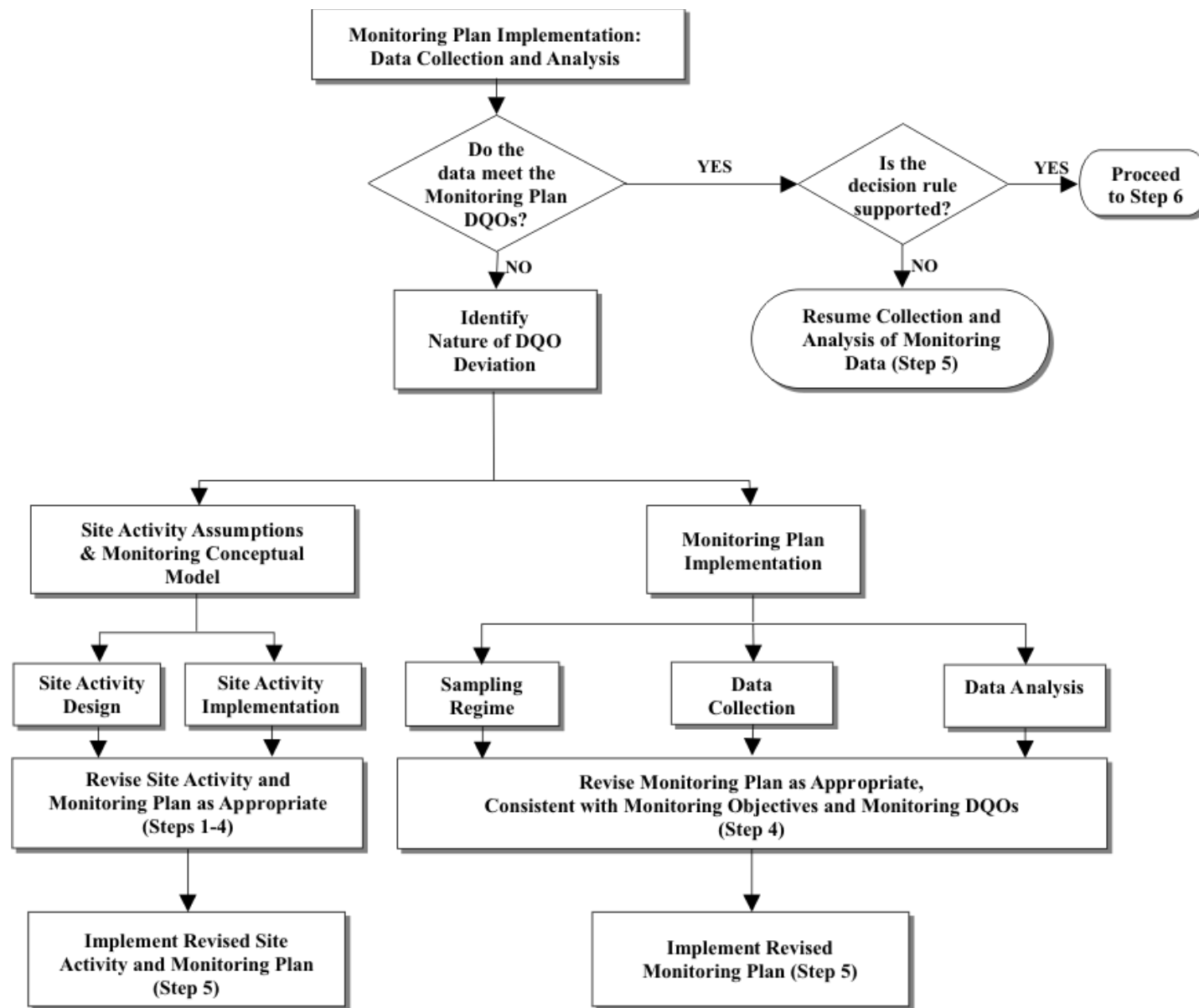


Figure 7: Decision path during monitoring implementation and data collection and analysis (from US EPA, 2004).

It is important to document any changes to the Monitoring Plan, including altered sampling regimes, monitoring objectives, hypotheses, conceptual models, data collection and analytical methods, or decision rules. The changes and rationale for the altered approach should be documented as an addendum or revision of the Monitoring Plan and Monitoring QAPP.

## **G. Step 6: Establish the Management Decision**

In Step 6, the monitoring results are evaluated in relation to the monitoring decision rules, and an assessment of how well the site activity has met its stated objectives is made. If the monitoring data meet the DQOs, the data are evaluated using the decision rules to identify further actions for the monitoring objective.

An adaptive management approach (see Section IV) should be used to adjust the monitoring program design, the level of effort for sampling, and/or the remedial strategy throughout the post-remediation monitoring period as the monitoring data are collected (SPAWAR and ENVIRON, 2010). The predicted outcomes of remedial actions and monitoring activities are not always realized because of uncertainty regarding the assumptions about remedial strategy performance and efficacy, and about the monitoring conceptual models, or inherent natural variability in the metrics used for monitoring ecosystem recovery that may mask short-term data trends (US EPA, 2004; SPAWAR and ENVIRON, 2010). The adaptive management approach allows for continual modification of the remedial strategy and monitoring plan if necessary, maximizing the chances of achieving successful completion of the monitoring objectives in the shortest possible time.

In addition to evaluating the data in relation to the monitoring decision rules, project managers should also assess the continued performance of the R/RM action for protecting human health and the environment. The US EPA (2001) has developed guidance for Five-Year Reviews of Superfund sites that have undergone remediation using a risk management approach which resulted in contaminants of concern being left on site, whether as a residue or within a containment facility, or implemented other remediation technology such as permeable reactive barriers or water treatment facilities. Three key questions are used to evaluate continued performance of the R/RM action implemented at the site; they are detailed in Table 3 below.

**Table 3: Three Questions Used to Determine Remedy Protectiveness (after Exhibit 4-1 in US EPA, 2001).**

When you ask...	you should consider whether...
<p><b>Question A:</b></p> <p>Is the remedy functioning as intended by the R/RM plan?</p>	<ul style="list-style-type: none"> <li>• performance standards (e.g., cleanup levels, plume containment, pumping rates) are or will likely be met;</li> <li>• there are problems with the remedy that could ultimately lead to the remedy not being protective or could suggest that protectiveness is at risk (e.g., shrubs or bushes growing on a landfill cap that was designed to have a grass vegetative cover, extent of plume not fully delineated);</li> <li>• access (e.g., fencing, security guards) and institutional controls needed at the particular stage of the remediation are in place and prevent exposure;</li> <li>• other actions (e.g., removals) necessary to ensure that there are no exposure pathways that could result in unacceptable risks have been implemented; and</li> <li>• maintenance activities (e.g., pumping and treating, monitoring slurry walls, mowing cap), as implemented, will maintain the effectiveness of response actions.</li> </ul>
<p><b>Question B:</b></p> <p>Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives used at the time of the remedy selection still valid?</p>	<ul style="list-style-type: none"> <li>• there are changes in standards that could call into question the protectiveness of the remedy;</li> <li>• there are changes in land use or the anticipated land use on or near the site;</li> <li>• new human health or ecological exposure pathways or receptors have been identified;</li> <li>• new contaminants or contaminant sources have been identified;</li> <li>• there are unanticipated toxic byproducts of the remedy not previously addressed by the R/RM plan;</li> <li>• there are changes in the physical site conditions; and</li> <li>• there are changes in the toxicity factors for contaminants of concern.</li> </ul>
<p><b>Question C:</b></p> <p>Has any other information come to light that could call into question the protectiveness of the remedy?</p>	<ul style="list-style-type: none"> <li>• ecological risks have been adequately addressed at the site, and/or there is a plan to address them through a future action; and</li> <li>• the site is/was subject to natural disasters, such as a 100-year flood.</li> </ul>

A framework for evaluating monitoring data with respect to site closure is provided in Figure 8. When exit criteria are achieved for a particular monitoring objective, related monitoring activities may be concluded. Site closure is achieved when the exit criteria have been met for all of the monitoring objectives. At this point, the remedial strategy and the monitoring program for the site may be concluded. The monitoring program outcomes and the scientific rationale used to determine that the site no longer poses unacceptable human health and ecological risks should be documented as part of the site closure tool and reporting framework developed by PWGSC.

Final site closure may not be attainable for those sites at which contaminants remain in place (e.g., capped sites and those with engineered containment facilities) and ongoing maintenance and performance monitoring are required. However, once the exit criteria for monitoring objectives related to ecosystem recovery are achieved, the scale and frequency of monitoring may be greatly reduced. As successive monitoring events demonstrate achievement of the action levels related to remedy performance (e.g., indicators of physical stability or chemical integrity for a landfill), monitoring events should be scheduled less frequently. In addition, monitoring data may be used to identify the scale of disruptive events that could impact remedy or risk management performance. For example, a five-year flood may have had minimal effects on the physical stability of sediments at a risk-managed site, while a 50-year flood poses potential risk to physical stability. As confidence in the performance of the R/RM strategy under disruptive events increases, monitoring during less extreme events may be discontinued.

Further guidance for evaluating decision rules is provided in US EPA (2004).

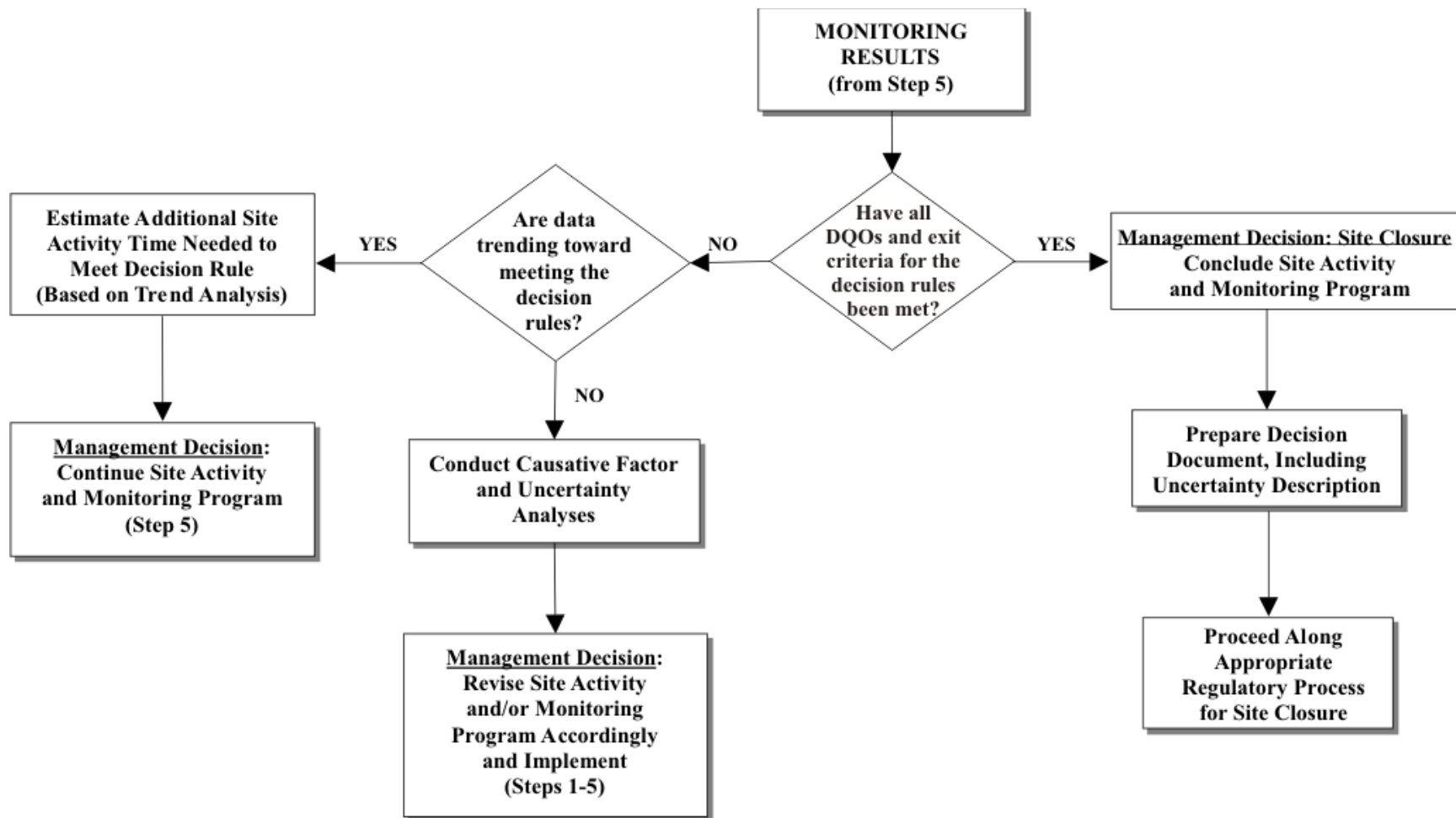


Figure 8: Framework for evaluating monitoring data for progress towards site closure (modified from US EPA, 2004).

## **IV. PROJECT MANAGEMENT AND POLICY CONSIDERATIONS**

### **A. Long-term Monitoring FCSAP Cost Eligibility**

To be eligible under FCSAP, the long-term monitoring plan must be a component of the RAP or the RMP. This means that the LTM requirements of a particular R/RM approach for a site must be considered and defined during Step 7 of the FACS ten-step process (Develop remediation/risk management strategy). The duration of the long-term monitoring should be included in the RAP and should align with the risk management work to be undertaken. It is expected that monitoring will be required for a specific amount of time once risk management work is complete. When that time has passed, if no response action has been triggered and there is no expectation that this will change, any further monitoring becomes part of the regular environmental program for managing the site.

Note that the FCSAP Eligible Costs Guidance document (EC, 2012) is the authoritative source on matters regarding the eligibility of project costs.

### **B. Roles and Responsibilities**

Current practice for developing LTM plans includes implementing recommendations of a qualified firm, as well as assembling a team including the client (custodian), consultant, expert support departments (DFO, EC, HC, PWGSC), provincial or territorial governments and other stakeholders to answer key questions, including:

- Is the plan sound?
- Is the plan efficient?
- What media should be monitored at what locations?
- What species and what parameters should be monitored?

It should be kept in mind that the role of the expert support departments in the process of developing LTM plans is to review plans and provide comments; however, they do not have a mandate to “approve” plans. It is therefore the custodian’s responsibility to ensure that an appropriate LTM plan is developed.

The questions listed above are difficult ones that must integrate best practice, professional experience, practicality of implementation, and stakeholder support. Answers to the questions may serve as a starting point for the project manager to determine reasonable, practical, defensible, and efficient monitoring rules and triggers. A large volume of expertise is accessible both within the federal government and through the network of industry consultants, researchers, and contractors affiliated with the FCSAP program. Project managers should not hesitate to seek input from an expert support department and any other members of the LTM planning team to

ensure that the decision rules they wish to implement have a strong scientific basis and are also based on a well-informed overview of site-specific conditions.

FCSAP does not currently define requirements for governance of management decisions for LTM. In the absence of program-wide direction related to LTM management decision-making, it will ultimately be the custodian's responsibility to make decisions. Some departments may have the authorities and governance for LTM management decisions established; others may not. It is recommended that, at a minimum, the LTM plan defines the governance structure for making these decisions (i.e., the LTM plan will document who gets to make these decisions). The "who" may be different depending on the scope and particularities of the remediation project.

## **C. Stakeholder Involvement**

Stakeholders typically include other levels of government, property owners, responsible parties, regulatory agencies, aboriginal groups, local interest groups or organizations ("community" representation), and technical experts. The breadth of participation, degree of involvement and timing of input from stakeholders will vary based on project-specific conditions and regulatory framework. Inclusion of stakeholders in LTM planning and reviewing of monitoring results is critical to ensure incorporation of stakeholder concerns and facilitate acceptance of management decisions.

For teams to be successful, participants must be committed to working through technical and non-technical issues in a collaborative, non-adversarial manner. The stakeholder involvement section of the LTM plan should highlight the importance of reporting back LTM findings in support of R/RM actions to maintain stakeholder engagement and support. While disagreements among stakeholders are not uncommon, proper planning and communication can mitigate those disagreements so that they can be resolved to the satisfaction of all interested stakeholders.

Governments in Canada have a duty to consult with aboriginal groups when making decisions that may adversely impact lands and resources subject to aboriginal claims. Guidance for aboriginal consultation is published in AANDC (2011). Other resources for stakeholder consultation are summarized in Appendix B.

## **D. Optimizing LTM Scope and Resource Use**

### ***1. Level of effort considerations***

Although commonalities often exist among federal contaminated sites (this is especially true for Distance Early Warning (DEW) Line sites and other abandoned military sites, from which much LTM experience has been gained and guidance has been developed), the fact remains that each site is unique, with its own particularities, whether geographical, social, regulatory, contaminant-related, or otherwise. As a result, it is not possible to provide definitive "one size fits all" guidance on the appropriate level of effort that an organization should allocate to the activities



associated with LTM of sites under its custodianship. A challenge federal custodian program and project managers face is to strike a balance between the level of effort required to develop and implement LTM at sites under their management and the complexity of the remediation or risk management strategy employed at the sites in question.

The level of effort required for the LTM plan is defined based on site-specific information (e.g., nature and impact of past human activities, stakeholder concerns), data quality information (e.g., tolerance for potential decision errors), and resource constraints such as budget. Specifically, the level of detail that should be included in an LTM plan must be scaled to meet the requirements of the project and contaminated sites program while addressing the remediation or contamination issues specific to the site. Project sponsors/leaders, project team members, other stakeholders and custodian organizational requirements will all influence the level of detail that will be required in developing an LTM plan leading to site closure. In scaling the level of effort for LTM planning, the following should be considered:

- The policy-driven requirements of the sponsor and project delivery organizations to document LTM should be considered. Some organizations may require specified levels of detail as part of an accountability framework; others may have fewer, different or undefined requirements.
- The size of the project in relation to the resources and time available to prepare LTM plans and documentation of LTM activities.
- The R/RM techniques selected, the nature of any remaining contamination on the site, public concern and the end land use.

Simply stated, the larger and more complicated an R/RM strategy for a particular site, the greater the level of effort that will be required when considering the appropriate LTM plan. The size of a contaminated site and scale of remedial or risk management action to address site risks is relative. Experience shows that the better developed an LTM plan, the greater the chance for ultimate site closure, and the better the chances that the site will not be reopened in the future and that repeat assessment and characterization work at the site will not be required.

## ***2. Adaptive management***

Adaptive management (Linkov et al., 2006) is defined as a planned and systematic process for continuously improving environmental management practices by learning about their outcomes. Adaptive management seeks to answer the question: How would we know if management under the LTM plan was actually achieving its objectives? In the context of FCSAP LTM planning, adaptive management is the concept that an LTM plan must be a living document, capable of adapting to a variety of potential changes in site conditions. If implementation of an LTM plan yields results that are not anticipated, the plan must be capable of adapting to meet the new concerns. The inclusion of alternative courses of action/contingency measures and definition of

their triggers based on scientific decision criteria are an important part of ensuring that LTM plans are capable of responding quickly and effectively to unforeseen or sudden changes to site conditions and have the capacity for adaptive management. An adaptive management approach facilitates completion of LTM activities and achievement of site closure within the shortest possible timeframe.

The level of planning required for adaptive management should be proportional to the scale of the project and to the sensitivity and complexity of the associated issues being addressed. Further guidance for adaptive management is found in Appendix B.

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**APPENDIX A:**  
**Main Findings of**  
**Custodian and Expert Support Consultation on FCSAP LTM**

## **A. Questionnaire findings:**

Challenges for long-term management of sites were identified through a review of the international policy guidance and through consultation with custodians and expert support departments (ESD). Key challenges are summarized in Table A-1.



**Table A-1: Six categories of long-term management challenges (as identified by the US EPA (2005) and in consultation with FCSAP custodian department representatives)**

EPA Long-Term Stewardship Task Force: Six Challenging Areas for Long Term Stewardship					
Ensuring Stakeholder Roles and Responsibilities are Clearly Understood	Ensuring LTM Information is Managed and Shared Effectively	Understanding and Considering the Full, Life-cycle Costs of LTM when making Cleanup Decisions	Ensuring the Effective Implementation of Institutional Controls	Ensuring the Effective Implementation and Evaluation of Engineering Controls	Ensuring that Funding and other Resource Needs are Adequate and Sustainable
Selection of LTM Challenges Identified in Consultation with FCSAP Custodian and Expert Support Departments					
Consultants, departmental staff and stakeholders are unwilling to sign-off that a certain level of residual risk is acceptable.	Information management and continuity; Defining the documentation required, the timing and making sure the information is transferred before site closure.	A need to define a conceptual monitoring plan and associated costs at the RAP/RMP stage (Step 7 in the FACS).	Lack of institutional controls to manage the residual risks into the long-term, uncertainty associated with devolution.	Ensuring the adaptability of LTM plan (to capture for e.g. changing technology or stakeholder concerns/tolerances) with sustainable core objectives.	Long-term funding and support (multiple custodian and expert support departments raised concerns).
Understanding the role of the regulatory framework to address ongoing risk management and therefore defined monitoring requirements and timelines.	Challenge in efficiently making information in project documentation available.	Current RAPs tend to be too focused on the here and now, need to have more thought to O&M and LTM requirements down the road.	Lack of framework to evaluate risk levels triggering implementation of a contingency action -when to act vs. wait for a reasonable size work load to warrant cost of mob/demob.	Defining trigger points and measures of success for LTM.	Communicating importance of continued implementation of LTM to Senior Management.
Remediation or risk management approaches acceptable to one stakeholder group may not be acceptable to another; requirement to manage stakeholder expectations and potential for change of perception post remediation	Review of historical site data not included in the scope of work for consultants implementing LTM plans.	Clarity in defining what constitutes LTM vs. Confirmatory Sampling vs. Operations and Maintenance.	Meshing science with traditional knowledge to arrive at triggers.	Defining LTM endpoint-very difficult to define quantitative objectives to be met.	FCSAP is finite; many sites don't have an exit/site closure/ LTM strategy.

**APPENDIX B:**  
**Terrestrial Contaminated Sites: Guide to Additional References  
for LTM Program Design and Management**

## **A. Best Practices and Resources for LTM of Terrestrial Sites**

This section presents examples of Best Practices employed by some federal custodians and provides further resources for the implementation of LTM for terrestrial contaminated sites.

### ***1. Landfills in northern regions***

The DND DEW line clean up (DLCU) project has resulted in the construction of a large number of landfills throughout the Canadian North. Early in the process of DEW line clean up, DND negotiated a number of agreements with stakeholder groups on the scope and frequency of monitoring landfills constructed as part of the risk management plan for the DEW line sites. Many of the accepted practices from DND's DLCU protocol were subsequently adopted by the Aboriginal Affairs and Northern Development (AANDC), Northern Contaminated Sites Program and are outlined in AANDC's 2009 Abandoned Military Sites Remediation Protocol (AMSRP) guidance document.

The DLCU and AMSRP protocols are founded on a targeted contaminant source and pathway remediation approach, originally developed by the Department of National Defence (DND) for the DEW line Clean-up (DLCU) protocol. The AMSRP provides detailed guidance for monitoring the engineered structures that typically remain on site at DEW line sites, such as landfills, as well as the natural environment. The phased approach to LTM of landfills for both DLCU and AMSRP is similar and represents current best practice for northern landfill monitoring associated with federal contaminated sites. This phased approach to landfill monitoring is presented below in Table 1.

**Table 1: Phased Approach to Landfill Monitoring (AANDC, 2009; Table 2 in Pike 2011).**

Monitoring Stage / Phase	Year(s)/ Frequency	Scope of Monitoring
Baseline	0	Baseline geochemical monitoring, including geochemical characterization of soil conditions and groundwater quality adjacent to landfills.
Phase I: Confirm thermal equilibrium and physical stability	Year 1, 3, and 5 post-remediation          Year 3 and 5	Landfill – visual (erosion features, settlement, seepage, vegetation stress, liner & overall cap integrity), groundwater and thermal (freezeback)   Natural environment – including wildlife sightings and use, revegetation, as well as traditional use of the site  Groundwater / leachate
Phase I: Evaluation	Year 5	Confirm thermal equilibrium achieved and landfill and area are physically stable
Phase II: Verification of equilibrium conditions	Depends on Phase I evaluation; Years 7, 10, 15, 25	Same scope as Phase I, or modified based on Phase I results
Phase II: Re-evaluation of the monitoring	~Year 25	To be carried out prior to initiating Phase III program. It is difficult to predict beyond 25 years how world events and improvements in technology may impact monitoring requirements
Phase III: Monitoring for long term issues	Years 25+	Monitoring for long term issues such as liner integrity, permafrost stability, and significant storm events

\* Note: for Phase I, a five-year term was selected on the basis that ground-temperature thermal regimes at these sites would require three to five years to reach equilibrium. It is anticipated that, if there is settlement or erosion within the initial years following remediation, it is likely attributable to construction quality. Changes after the first three to five years are more likely attributable to changes in the site conditions (i.e. warmer temperatures, changes in surface water drainage patterns). The Phase I monitoring program may be extended, if required.

The AMSRP specifies that LTM will not be less than five (5) years in duration with a minimum number (usually three) of monitoring events specified within the first phase of LTM (see Table 1). Upon completion of the first phase of LTM, an evaluation of the results is completed and documented in a Performance Assessment Report. With input from third party expert support a determination is made regarding the requirement to enter the scope of the next phase of monitoring.

The monitoring approach undertaken by the DEW Line Project for onsite containment structures (e.g. landfills), which represents a significant level of effort, sets the standard for LTM requirements in the North (Pike 2011). The AANDC landfill monitoring protocol for abandoned military sites is an example of how components of a contaminated site can be broken down and analyzed in terms of scope and frequency of monitoring. A similar protocol could be followed for a landfill at a mine site, and the phased approach can be used for any engineered structure such as a tailings cap, waste rock pile or other major earthworks component.

## ***2. LTM and Mine Site Reclamation and Closure***

Best practices for both regulatory and voluntary/non-regulatory efforts include policies, programs, technologies, reclamation research and other measures that have been found to be cost effective and environmentally appropriate. Best practices encompass and build on measures embodied within local, national and international initiatives. Mine site reclamation and closure plans are now requirements for regulatory approvals of mine development in Canada. The department of Aboriginal Affairs and Northern Development has developed both policy (<http://www.aadnc-aandc.gc.ca/eng/1100100036038>) and guidance (<http://www.ainc-inac.gc.ca/ai/scr/nt/ntr/pubs/MSR-eng.asp>) with respect to mine closure and reclamation planning for northern mines. The policy and guidance include LTM as a component of a mine closure and reclamation plan under the heading of post-closure monitoring. The guidance suggests that post-closure monitoring should include monitoring schedule and reporting frequencies, and for the monitoring program to be meaningful, it must include provision for appropriate progressive responses which trigger action whenever exceeded, including the establishment of thresholds or the identification of changes in circumstances. The guidance also highlights the importance of reporting the results of LTM back to stakeholders as a component of site closure (INAC 2007).

Other useful resources include the following:

- The National Orphaned/Abandoned Mines Initiative (NOAMI) conducts research and compiles information on abandoned mines enabling sound decision-making, cost-efficient planning, and sustainable rehabilitation as well as transparency in the decision-making process. NOAMI provides access to information by governments, civil society, industry and other stakeholders. NOAMI published *The Policy Framework in Canada for*

*Mine Closure and Management of Long-Term Liabilities* in 2010. This report provides a policy framework and guidance document which stakeholders and mining jurisdictions will find useful as a reference document in considering mine closure and the management of long-term liabilities. The document is available at the following address:

<http://www.abandoned-mines.org/pdfs/PolicyFrameworkCanforMinClosureandMgmtLiabilities.pdf>

- Acidic drainage is the largest environmental liability facing the Canadian and international mining industry. Since 1989, the Mine Environment Neutral Drainage (MEND) program, sponsored by Natural Resources Canada, has worked to develop technologies to prevent and control acidic drainage. The program is directed by a multi-stakeholder committee, with members from the mining industry, federal and provincial governments, and non-government organizations. The MEND program has published extensive guidance on the monitoring of acid generating mines. Reference to the following documents will assist federal project managers responsible for the development of LTM plans at sites with acidic drainage and metal leaching issues. These guides are listed below:

- *Guideline Document for Monitoring Acid Mine Drainage*

<http://www.mend-nedem.org/reports/files/4.5.4.pdf>

- *MEND Manual Volume 6 Monitoring*

<http://www.mend-nedem.org/reports/files/5.4.2f.pdf>

### ***3. Inspection of stabilized structures***

The INAC *Mine Site Reclamation Guidelines for the Northwest Territories* (2007) is an excellent resource and should be referenced when inspection of stabilized structures is a component of an LTM plan. This guideline document is mandated to be a living document in order to keep pace with the rapid political, legislative and technological developments as well as the operational environment of mining in the Canadian North. A revised 2011 draft version of these guidelines is currently under review and is likely to be finalized in 2012. The 2007 version can be viewed by following the link below.

<http://www.aadnc-aandc.gc.ca/eng/1100100024558>

Other Canadian reference sources which are relevant to determining LTM requirements and best practices for inspection of stabilized structures include the following.

- For mines that have dams, LTM planning should include a review of the Canadian Dam Association (2007) *Dam Safety Guidelines*, available for a fee of \$60 from the following link: [http://www.cda.ca/cda\\_new\\_en/main%20index.html](http://www.cda.ca/cda_new_en/main%20index.html)
- The Mining Association of Canada (MAC) has developed a set of guiding principles, called *Towards Sustainable Mining* (TSM), that govern key activities of companies in all sectors of the mining and mineral-processing industry. TSM includes performance indicators and protocols that set down specific measurement criteria in six key areas of operational performance: tailings management, energy and greenhouse gas emissions management, Aboriginal and community outreach, crisis management planning, safety and health, and biodiversity conservation. The tailings management protocol consists of five performance indicators: management policy and commitment, management system development, assigned accountability and responsibility, annual management review, and an operation, maintenance and surveillance (OMS) manual. The OMS manual represents current best practices in the Canadian mining industry and can provide valuable guidance for planning needs of long term management of mine tailings. MAC protocols for tailings management are available from the following link:

<http://www.mining.ca/site/index.php/en/towards-sustainable-mining/performance-measures-a-protocols.html>

## **B. LTM Project Management and Policy Resources**

### ***1. The US EPA Comprehensive Five-Year Review***

Superfund sites that have undergone remediation using a risk management approach which have resulted in contaminants of concern being left on site, whether as a residue or within a containment facility, or have implemented other remediation technology such as permeable reactive barriers or water treatment facilities, are all subject to a review of the performance of the R/RM measures every five years. Detailed directions for the implementation of the Five-Year Review is provided in the following document: *Comprehensive Five-Year Review Guidance* (US EPA 2001) available for viewing at

<http://www.epa.gov/superfund/accomp/5year/index.htm>

This document is laid out in a question and answer format, and provides useful, plain language responses outlining the process of the review, the roles and responsibilities of federal agencies and other stakeholders. The focus of the document is to provide guidance in assessing the continued protectiveness of the R/RM action to human health and the environment.

## ***2. Stakeholder Involvement***

Health Canada (HC) has developed a series of guidance documents that consolidate best practices in stakeholder engagement and provide advice and techniques that can aid federal project managers in planning communications with stakeholders; two of these HC documents are referenced below:

1. *Improving Stakeholder Relationships: Public Involvement and the Federal Contaminated Sites Action Plan: A Guide for Site Managers.*

The document includes information and tools to help answer the following questions:

- Why, when and how should the public be involved in contaminated site management?
- What are appropriate levels of stakeholder involvement?
- What lessons have been learned from other contaminated sites?
- Where can one find useful reference materials and resources?

This guide can be accessed at the following link:

<http://www.hc-sc.gc.ca/ewh-semt/pubs/contamsite/managers-guide-gestionnaires/index-eng.php>

2. *A Guide to Involving Aboriginal Peoples in Contaminated Sites Management.*

The purpose of this guide is to introduce managers of contaminated sites to the fundamentals of public involvement, the importance of Aboriginal involvement and best practices for involving Aboriginal peoples in contaminated sites management. This guide can be accessed at the following link:

<http://www.hc-sc.gc.ca/ewh-semt/pubs/contamsite/aboriginal-autochtones/index-eng.php>

The National Orphaned/Abandoned Mines Initiative (NOAMI) has produced a useful reference pamphlet which addresses stakeholder involvement in the process of mine site management: *Best Practices in Community Involvement: Planning For and Rehabilitating Abandoned and Orphaned Mines in Canada*. This guidance can be accessed at the following link:

<http://www.abandoned-mines.org/pdfs/CommInvolvePamphlet2003-e.pdf>



NOAMI also has a Community Involvement Task Group with the following objective:

*“To develop a plan to foster community involvement in decision-making about closure and reclamation standards, and to ensure that targeted end-use and reclamation standards are acceptable to local communities.”*

In 2003, this task group prepared a report entitled *Lessons Learned on Community Involvement in the Remediation of Orphaned and Abandoned Mines: Case Studies and Analysis*. This document provides an understanding of the community involvement process. It can be accessed from the following link:

<http://www.abandoned-mines.org/pdfs/LessonsLearned.pdf>

### ***3. Adaptive Management and Addressing LTM Plan Uncertainties***

Adaptive management is defined as a planned and systematic process for continuously improving environmental management practices by learning about their outcomes. It is based on the Plan-Do-Check-Act quality assurance paradigm. Adaptive management provides flexibility to identify and implement new mitigation measures or to modify existing ones during the life of a project (CEAA 2009). Adaptive management seeks to answer the question: How would we know if management under the LTM plan was actually achieving its objectives?

To address this question, many jurisdictions with environmental monitoring responsibility have set out to develop a practical system for monitoring and evaluating the effectiveness of their environmental monitoring and management plans. Adaptive management is an iterative (cyclical) process. As new knowledge is gained, the conceptual models will be updated. Management actions will be adjusted to reflect the new knowledge. In this sense, the science represented by the conceptual models is never "finalized" and will be available for future updates.

Some factors which may influence the application of adaptive management to FCSAP LTM have been adapted from CEAA's approach to environmental impact assessment (CEAA 2009) and are as follows:

- The amount of prior experience with the specific type of project in the specific type of environment;
- The possibility that a R/RM measure may not function as intended;
- The possibility that some aspects of the proposed R/RM approach may not actually be needed, or that they are no longer required;

- The extent of knowledge and understanding of key environmental indicators and action thresholds;
- The likelihood of broad-scale environmental change that would affect the project or influence the nature of R/RM and its environmental effects;
- The likelihood that advances in scientific knowledge or technology over the life of the project may enable improved R/RM measures;
- The extent to which public concern about specific issues could be alleviated or reduced through a commitment to follow-up or adaptive management as appropriate; and
- The opportunity to learn from the results of follow-up or adaptive management and improve the current project or the quality of future remediation projects.

The level of planning required for adaptive management should be proportional to the scale of the project, and to the sensitivity and complexity of the associated issues being addressed.

#### ***4. Monitoring Optimization***

Monitoring optimization is concerned with increasing efficiency, reducing cost, identifying uncertainty, and/or increasing reliability of long-term monitoring programs. Depending on the scope, scale and projected duration of monitoring activities associated with a particular remediation or risk management project, significant cost savings may be realized through implementing a process to optimize the LTM activities.

A variety of decision support tools for optimization of LTM have been developed to assess the ongoing performance of an LTM plan and inform project managers of redundancies in information being collected as well as other efficiencies that can be realized by adjusting LTM plans based on the results of LTM optimization studies. A suggested reference in this field, particularly applicable to large petroleum hydrocarbon impacted sites, is the 2005 document Roadmap to Long-Term Monitoring Optimization produced by the US Army Corp of Engineers. This report is available at:

<http://www.clu-in.org/download/char/542-r-05-003.pdf>

Another valuable reference, published in 2006, by the US Air Force Center for Environmental Excellence (AFCEE) Restoration Division, Long-Term Monitoring Optimization Guide, provides comprehensive guidance on the optimization of long term groundwater monitoring. It can be viewed at:

<http://www.afcee.af.mil/shared/media/document/AFD-070831-016.pdf>

A third relevant reference from the US EPA (1999) on improving LTM and remedial system performance for subsurface remediation can be viewed at:

<http://nepis.epa.gov/Adobe/PDF/P1000NI3.PDF>

The Monitoring and Remediation Optimization System (MAROS) is a database application developed for the AFCEE to assist users with groundwater data trend analysis and long term monitoring optimization at contaminated groundwater sites. The software provides site managers with a strategy for formulating appropriate long term groundwater monitoring programs that can be implemented at lower costs. MAROS applies statistical methods to answer the following questions:

- Are the temporal trends in groundwater data statistically significant?
- Are there redundant wells in the groundwater monitoring network?
- What is the suggested frequency of future sampling?
- Do new wells need to be added to adequately characterize the plume?

The MAROS software is free and can be accessed at the following web address:

<http://www.gsi-net.com/en/software/free-software/maros.html>

## ***5. Custodial Lessons Learned***

### **a. Remedial design for northern disposal facilities**

Defence Construction Canada (DCC) provides project management for Federal Contaminated Sites under the custodianship of the Department of National Defence. DCC noted technical lessons learned with respect to landfill design and slope stability. Based on the results of their landfill maintenance program DCC now encourage design of landfill slopes to be 5:1 rather than the original 2:1 grading. The steeper landfill slopes resulted in increased requirement for maintenance due to formation of deeper erosion channels.

The landfills constructed at DEW line sites incorporate permafrost freezeback into the design specifications. The LTM plans for these landfills involve a thermal monitoring program, using automated data loggers and series of thermistor strings, the results of which resulted in the commissioning of a climate change study. This study recommended that after three consecutive years of thermal data indicating landfill thaw below the liner, action to add more cover should be taken. Also, landfills constructed after 2006 have increased the cover thickness requirement by one metre to account for future climatic change. This is a prime example of adaptive management in practice.

## **b. Contracting**

Consultation with the DCC project manager responsible for LTM of DND DEW line sites highlighted several lessons learned over the course of implementing the LTM program at these sites to date. The most significant lesson communicated was with respect to combining the LTM activities required at several sites into a single contract and tendering process implemented based on packaging of sites by region. By preparing multi-site and multi-year LTM contract and tender packages, the following benefits were realized:

- Reduction of the administrative burden of contracting;
- Improved continuity of monitoring information; and
- Overall cost savings due to greater contractor interest in tenders.

AANDC has also implemented multi-site contracts for LTM, with the same benefits realized.

An additional resource to be consulted in regards to contracting LTM activities is available in the 2008 US EPA Memorandum: *Post Construction Completion Considerations in Superfund State Contracts*. For the purposes of comparison between the US and Canada, terminology in this document referring to O&M is analogous to the FCSAP equivalent of LTM and the State is analogous to federal Custodian Departments. This short document can be viewed by following the link below:

[http://www.epa.gov/superfund/cleanup/postconstruction/ssc\\_guidance.pdf](http://www.epa.gov/superfund/cleanup/postconstruction/ssc_guidance.pdf)

## **c. Maintaining accurate site records**

Aboriginal Affairs and Northern Development Canada is another federal department with a large amount of experience implementing the FCSAP program. During consultation with AANDC representatives in developing this guidance document, the importance was noted of implementing measures to maintain as much continuity in site-related information as possible. Having accurate and accessible information about both the management decisions and technical details of sites entering LTM can help to ensure the continued implementation of institutional controls at a site. The Northern Contaminated Sites Program at AANDC has adopted the strategy of taking out a ‘reserve’ on former contaminated sites properties, with direction on the land use planning file as a way to ensure departmental obligations continue to be met and that engineered structures (landfills, tailings caps, etc.) are protected from future activity.

## **APPENDIX C:**

### **Aquatic Contaminated Sites: Scientific and Technical Guidance for Developing LTM Programs and a Case Studies Review**

## EXECUTIVE SUMMARY

Federal aquatic contaminated sites are managed using the 10-step *Framework for Addressing and Managing Aquatic Contaminated Sites under the Federal Contaminated Sites Action Plan (FCSAP)* (Chapman, 2010). Under this framework, site closure is attained when the remedial goals for a project have been achieved, the contaminated site no longer poses unacceptable human health and ecological risks, and these conditions are expected to continue into the foreseeable future. Attaining site closure is important for FCSAP to demonstrate program and site-level achievements, as well as to document the achievement of the remedial and/or risk management objectives. A site closure process and reporting framework is currently under development. However, the scientific basis for determining when site closure is achieved for aquatic contaminated sites is needed.

The following document addressed this need through a review of the relevant scientific literature, guidance frameworks, and international policy documents on monitoring plan development and site closure for aquatic contaminated sites. The overall intent of the review was (1) to summarize the state of science and international policy on long-term monitoring and closure of aquatic contaminated sites, and (2) to present the information in a format that facilitates subsequent development of a guidance framework for evaluating the attainment of site closure for FCSAP aquatic sites. Although the approach presented here can be applied to all contaminated sites, the focus of this document is on sediment remediation.

Site closure is closely tied to the design of the monitoring program: the monitoring objectives, monitoring tools and exit criteria decided at the start of the program are used to determine when the remedial goals have been achieved. Information needed to develop monitoring plans for site closure of aquatic contaminated sites is integrated in this document with the USEPA (2004) six-step process for monitoring plan development, as well as the Data Quality Objectives process (USEPA, 2006) for monitoring plan design; an overview of these frameworks is presented in **Section II**.

**Section III** reviews the process for determining monitoring objectives for an aquatic contaminated site, which are goals to guide the focus of the monitoring program toward site closure. Monitoring objectives are developed based on the site conceptual model, expected outcomes and mode of action of the remedial strategy, and the identified risks to human and ecological receptors. General objectives are identified for monitoring remedy performance (i.e., is the remedial strategy functioning as designed?) and ecosystem recovery (i.e., are human health and ecological risks decreasing?). The general objectives may be used to facilitate a consistent approach to developing monitoring programs that are capable of achieving FCSAP site closure.

Physical, chemical, and/or biological monitoring tools that are appropriate to address each monitoring objective are discussed in **Section IV**. A decision matrix of screening

criteria is presented to aid in the selection of tools and design of monitoring programs. Monitoring objectives and tools for assessing remedy performance, as well as associated design considerations, are discussed for four sediment remedial strategies: monitored natural recovery (MNR), capping, dredging, and *in situ* treatments.

Appropriate tools are also identified for ecosystem recovery monitoring objectives that are not addressed in the on-line Interactive Sediment Remedy Assessment Portal (ISRAP; SPAWAR and ENVIRON, 2010; see Table III-1).

Key to the attainment of site closure is the development of strong decision rules for interpreting monitoring data. These include definition of quantitative scientifically defensible exit criteria that represent the attainment of the desired condition for a particular monitoring objective. When all of the exit criteria for the monitoring objectives have been met, site closure is achieved. **Section V** provides guidance for developing decision rules that facilitate site closure, as well as identifying examples of exit criteria for specific monitoring tools.

Addressing uncertainty in monitoring data is important as these data will be used to make management decisions regarding the site (**Section VI**). Statistical approaches to address uncertainty in monitoring data include defining a desired level of significance and statistical power for the monitoring plan design, which are selected based on evaluation of the consequences of incorrect decision-making. Minimizing inherent variability through appropriate monitoring plan design, as well as using a detailed Quality Assurance Project Plan (QAPP), also serve to decrease monitoring data uncertainty. The level of effort required for monitoring plans for site closure should be determined based on the balance between resource constraints and the desired level of statistical precision regarding uncertainty in decision-making (**Section VII**).

Finally, an adaptive management approach should be used to evaluate monitoring data as they are collected and revise the monitoring program and remedial strategy if needed (**Section VIII**). The first step in evaluating data is to assess if the data meet the desired data quality objectives and address any deviations. The data are then compared to the monitoring decision rules as outlined in Figure VIII-1. Site closure is achieved when all of the exit criteria for the monitoring objectives have been attained. At this point, site activities and the monitoring program may be concluded, and the reporting and regulatory process for site closure completed.

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## I. INTRODUCTION

Aquatic sites comprise a wide variety of habitats and environmental conditions. Under the Aquatic Sites Working Group (ASWG), a sub-committee of the Contaminated Sites Management Working Group (CSMWG), aquatic sites are defined as “a water lot, or land or part of land, completely or occasionally submerged by water” (Chapman, 2010). They include both freshwater and marine environments as well as the hyporheic zone (where shallow groundwater and surface water mix), but exclude deep groundwater. Aquatic sites may be contaminated through physical means (e.g., siltation, debris, temperature changes) or by the addition of chemicals (e.g., pesticides, inorganic elements, solvents). The environmental fate, transport, and ecological impacts of contaminants on aquatic sites vary greatly.

The main objective of the FCSAP program is to reduce risks and impacts to human health and the environment, as well as reducing federal liability. The ASWG has recently developed the *Framework for Addressing and Managing Aquatic Contaminated Sites under the Federal Contaminated Sites Action Plan (FCSAP)* (Chapman, 2010), to provide a consistent and scientifically rigorous risk-based approach for identifying and addressing federal contaminated aquatic sites. It is closely based on the 10-step process established for the management of terrestrial contaminated sites under federal custody (CSMWG 1999), with modifications and updates relevant for aquatic sites.

Long-term monitoring (LTM) is designated as Step 10 of the Aquatic Contaminated Sites Framework and begins after the remedial/risk management goals are achieved. In the context of contaminated sites, monitoring is best defined as “the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective” (Elixinga et al., 1998; cited in USEPA, 2004). The overall goal of LTM for aquatic contaminated sites is the need to ensure that remedial and risk management controls remain protective of human health and the environment. The types of monitoring employed and the level of effort undertaken will differ depending on the nature, size, and complexity of the contaminated site and the chosen remedy.

Site closure is attained when all management objectives for the LTM program have been successfully achieved. Site closure is not listed as a discrete step in the FCSAP aquatic sites framework (Chapman, 2010), but corresponds to the final decision point on the achievement of remedial goals; i.e., when the contaminated aquatic site no longer poses human and ecological risks, and these conditions are anticipated to continue for the foreseeable future such that no further management action is required. Attaining site closure is important for FCSAP to demonstrate program and site-level achievements, as well as to document the achievement of the remedial and/or risk management objectives. Public Works and Government Services Canada has developed the site closure tool

(SCT), which is a procedural checklist and reporting framework. The scientific basis for determining when site closure is achieved for aquatic contaminated sites is needed, and is the focus of this paper.

Site closure is intimately tied to the design of the monitoring program: the monitoring objectives, measurement endpoints and associated monitoring exit criteria decided at the start of the program are ultimately used to determine when the remedial goals have been achieved. To document progress toward site closure, quantifiable measurement endpoints and action levels that indicate when the monitoring objective has been successfully achieved must be defined as part of the monitoring program design. A time frame within which site closure is expected to be reached must also be identified for the statistical design of monitoring programs (e.g., the monitoring frequency and sample size required to detect temporal trends). Therefore, a key focus of this document is on the definition of monitoring objectives, appropriate monitoring tools to address the objectives, temporal considerations for monitoring, and associated exit criteria. This paper also addresses uncertainty in monitoring data and determining the level of effort required for monitoring programs to achieve site closure.

The ability to achieve site closure is governed in part by policy decisions. For example, in cases in which contaminants remain in place on site, U.S. regulatory agencies require five-year reviews in perpetuity, precluding the achievement of site closure (USEPA, 2004). Furthermore, some jurisdictions also set the timeframe during which site closure is expected to be achieved following remedial/risk management of a contaminated site (e.g., USEPA, 2003b). Current international policy on long-term monitoring and closure of contaminated aquatic sites has been reviewed and discussed in this paper in the applicable sections.

The overall purpose of this document is to review the state of science and international policy on long-term monitoring and closure of aquatic contaminated sites, with a focus on sediment remediation. The document is intended to provide the information needed to formulate a guidance framework for developing long-term monitoring programs for aquatic sites that will lead to site closure. This guidance framework will provide a standardized approach for evaluating remedy effectiveness, ecosystem recovery, and the attainment of site closure for aquatic sites under the FCSAP.

## A. Document organization

This document is organized as follows:

1. **Section I:** *Introduction.*
2. **Section II:** *Overview of steps for developing a long-term monitoring plan.* This section outlines the role of monitoring and the basic steps required for developing a monitoring plan that is capable of achieving site closure.
3. **Section III:** *Defining monitoring objectives.* This section describes the process for determining monitoring objectives for a site. General objectives for monitoring remedy performance and ecosystem recovery are defined.
4. **Section IV:** *Selection of monitoring tools for aquatic sites.* An overview of physical, chemical, and biological monitoring tools for aquatic sites is provided. This section identifies subsets of tools appropriate for monitoring remedy performance for four remedial strategies (Monitored Natural Recovery, capping, dredging, and *in situ* treatments), as well as monitoring objectives related to ecosystem recovery. Spatial and temporal design considerations and screening criteria for tool selection are also discussed.
5. **Section V:** *Developing decision rules and exit criteria.* This section describes the process of defining decision rules for the monitoring program and identifying appropriate exit criteria for the monitoring objectives.
6. **Section VI:** *Addressing uncertainty in monitoring plans for site closure.* This section describes statistical considerations for addressing uncertainty in monitoring data and decision rules.
7. **Section VII:** *Level of effort considerations for monitoring plans.* This section describes methods used to define the level of effort required for monitoring programs to achieve the desired confidence in outcomes given resource and feasibility constraints.
8. **Section VIII:** *Evaluating monitoring data for management decisions.* This section provides an overview of the process used to evaluate monitoring data and make subsequent management decisions. A flowchart outlining the steps needed to attain site closure is included.
9. **Section IX:** *Conclusions and recommendations.*
10. **Section X:** *References.*
11. **Section XI:** *Case Studies.* This section provides an overview of approaches used for monitoring remedy performance and ecosystem recovery for 10 case studies of aquatic sites.



## II. OVERVIEW OF STEPS FOR DEVELOPING A LONG-TERM MONITORING PLAN

Long-term monitoring programs following aquatic site remediation serve to document that the remedy is functioning as designed and that remedial action objectives for ecosystem recovery are being achieved. A primary goal of long-term monitoring is to verify that the remedial objectives will be met for the foreseeable future (Chapman, 2010). Overall monitoring goals for sediment remediation sites include: 1) assessing compliance with design and performance standards for remedial strategies; 2) assessing short-term remedy performance and effectiveness in meeting sediment cleanup levels; and 3) evaluating long-term remedy effectiveness in achieving remedial action objectives and in reducing human health and/or ecological risks (USEPA, 2005).

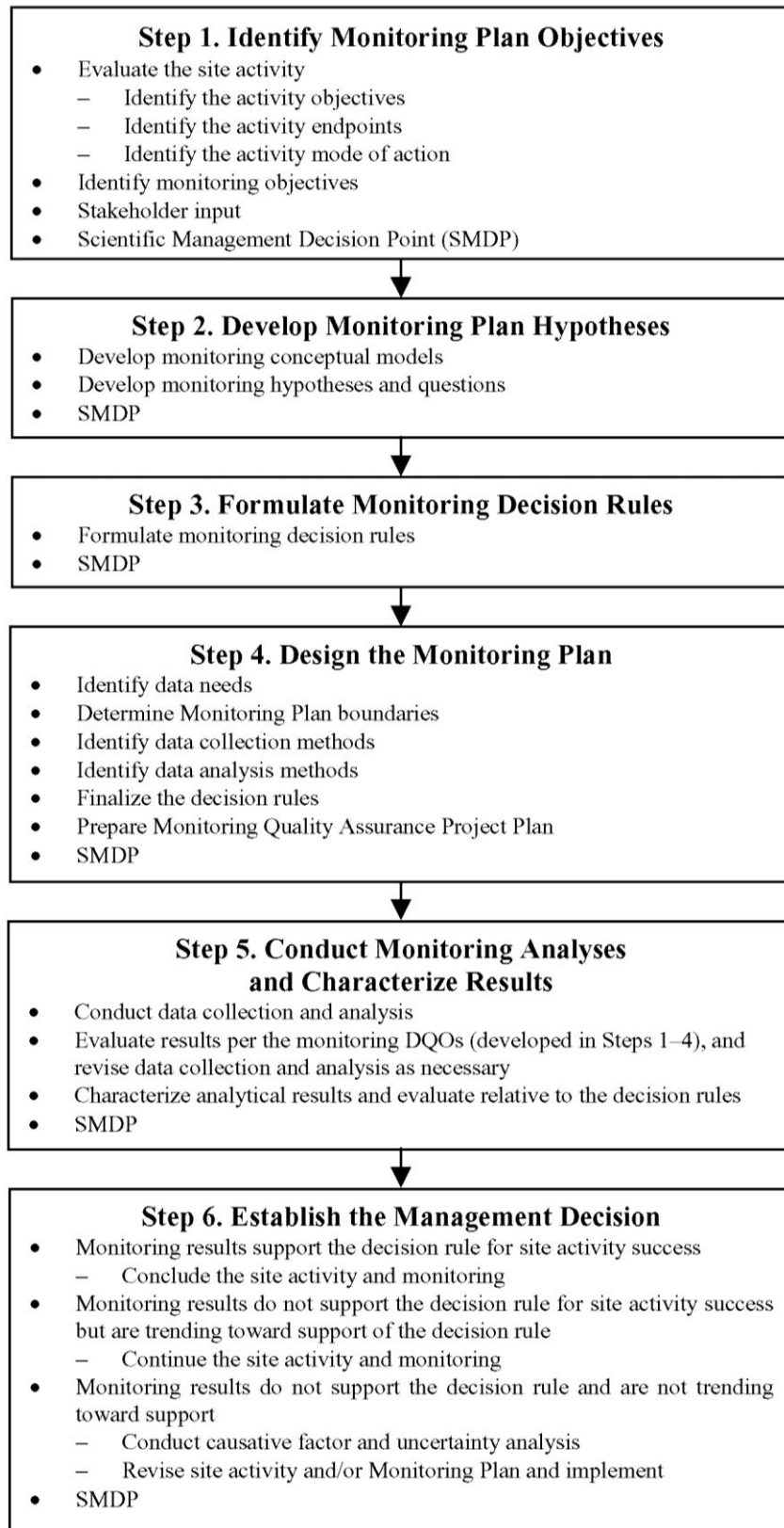
Monitoring activities for aquatic contaminated site remediation at FCSAP sites may be grouped into several different categories. These are summarized briefly below.

- **Construction monitoring:** Construction monitoring occurs during the completion of remedial activities. This type of monitoring includes confirmatory sampling to ensure that short-term remedial objectives were obtained and that design criteria were achieved, as well as assessing potential short-term adverse conditions associated with remedial activities.
- **Operation and Maintenance (O&M):** O&M involves the operation of sediment or surface water remediation measures that are meant to reduce contaminant concentrations to pre-established cleanup goals within a reasonable timeframe (e.g., 10 years). Monitoring activities can include multiple rounds of confirmatory sampling to show that contamination has been removed or stabilized effectively and that the R/RM cleanup objectives have been attained.
- **Monitored Natural Recovery (MNR):** MNR is a remediation strategy that relies on physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentrations of contaminants in sediments. A well-designed monitoring program is essential to confirm that these processes are occurring as expected to achieve site remedial objectives and that the results are irreversible.
- **Performance monitoring:** Performance monitoring occurs after construction is complete and addresses the specific remedy mechanism used at a site. Data collected during this phase are used to determine whether the remedy mechanism is performing as designed (SPAWAR and ENVIRON, 2010). Performance monitoring can be undertaken over long timeframes following implementation of the remedial strategy to ensure the physical, chemical, and ecological integrity of the mechanism, especially following high-energy disturbances (e.g., storm events).

- **Ecosystem recovery monitoring:** (also called remedial goal monitoring or long-term monitoring; SPAWAR and ENVIRON, 2010). This assesses the overall goal of reducing risks to human health and the environment. Data collected during this phase are used to determine whether the remedy is continuing to achieve risk reduction and ecosystem recovery goals. Ecosystem recovery monitoring may require long timeframes for completion due to transport and fate processes and lag periods for ecosystem response to decreased contaminant loading.

Under the FCSAP Aquatic Contaminated Sites Framework, LTM is defined as beginning after the remediation/risk management (R/RM) goals have been attained. The first two categories of monitoring activities listed above (construction monitoring and operation & maintenance) are addressed under Steps 8 and 9 of the FCSAP Aquatic Contaminated Sites Framework and are therefore NOT considered to be part of LTM. Monitoring activities associated with MNR also occur for the most part before the achievement of R/RM goals and are therefore not considered LTM. The present document focuses on defining long-term monitoring programs that can achieve site closure following site remediation/risk management activities (i.e., performance and ecosystem recovery monitoring).

General guidance for the development of monitoring plans for contaminated sites is provided in *Guidance for Monitoring at Hazardous Waste Sites: Framework for Monitoring Plan Development and Implementation* (USEPA, 2004). This framework is based on a six-step process outlined in Figure II-1. The process focuses on the critical components necessary for developing a monitoring plan with appropriate objectives, methods, and decision criteria for evaluating remedy effectiveness and ecosystem recovery. Guidance for planning LTM programs for FCSAP sites is also based on the USEPA six-step process (ESG and Franz Environmental Inc., 2013).



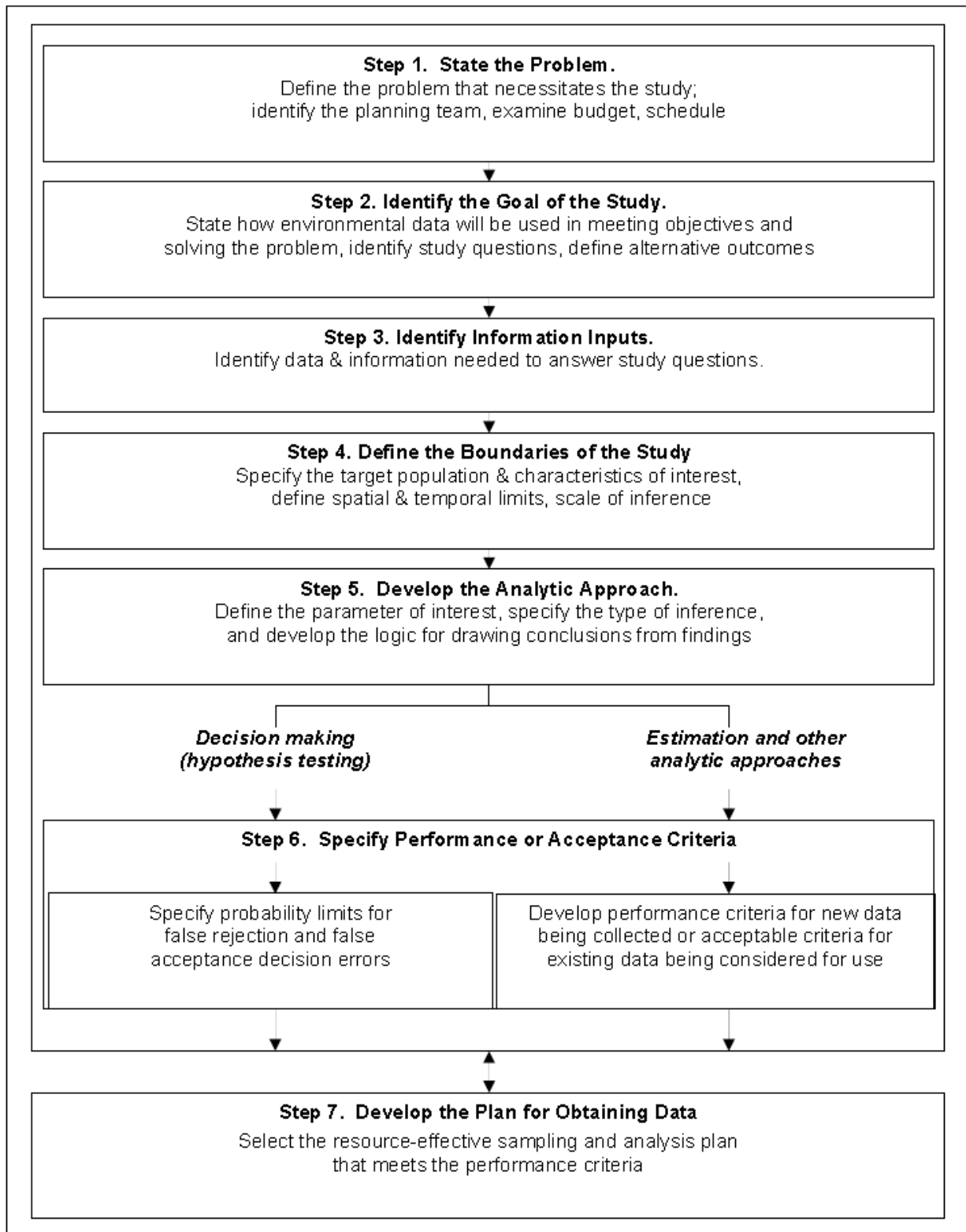
**Figure II-1: Six-step process for developing and implementing a monitoring plan (from USEPA, 2004)**

Although site closure is not specifically addressed in the USEPA (2004) framework, it can easily be modified to facilitate development of monitoring programs that can achieve closure. Of particular importance is the definition of scientifically defensible exit criteria for monitoring decision rules in Steps 3 and 4, which may be used to determine when a monitoring objective has achieved success. As monitoring data support the decision rule for site activity success (Step 6), monitoring for that objective can be concluded. When exit criteria have been achieved for all of the monitoring objectives, site closure is attained. Accordingly, the present document uses the USEPA (2004) framework as its main basis for monitoring plan development, but adds specific information needed for aquatic sites to ensure that monitoring programs will lead to site closure.

The Data Quality Objectives (DQO) Process developed by USEPA (2006) complements the USEPA (2004) monitoring framework and provides specific guidance for developing the monitoring plan design. The DQO process determines the type, quality, and quantity of data necessary to support defensible management decisions based on the monitoring outcomes. This process is used to identify sampling locations, sample numbers, sampling frequency, analytical methods and associated performance criteria, methods for interpreting results relative to the monitoring objectives, and the level of uncertainty acceptable regarding monitoring decision outcomes (USEPA, 2004). The DQO process consists of seven steps as outlined in Figure II-2. The relationship between the steps in the USEPA (2004) framework and the DQO process are summarized in Table II-1.

The USEPA (2004) monitoring framework and DQO process have been widely applied in the development of monitoring programs (e.g., USEPA, 2005; ASTSWMO, 2009; MacDonald et al., 2009; Clark et al., 2010). They provide a consistent and rigorous scientific approach to developing monitoring programs that ensures the data collected will support the management decision needs. Both frameworks are iterative, allowing for evaluation of the monitoring plan design and monitoring data as they are generated. This enables adaptive management of the site activity and monitoring program and accounts for uncertainty in the assumptions used to develop the initial monitoring plan.

The present document adopts the USEPA (2004) monitoring framework and DQO process for use in developing long-term monitoring programs that are capable of achieving site closure for aquatic contaminated sites. Relevant information necessary for completing the steps of both frameworks is summarized in the following sections.



**Figure II-2: Overview of the Data Quality Objective (DQO) process (from USEPA, 2006)**

**Table II-1: Integration of Data Quality Objectives (DQOs; USEPA, 2006) into the development of monitoring plans using the USEPA (2004) guidance framework (modified from USEPA, 2004)**

<b>Monitoring framework step (USEPA 2004)</b>	<b>Associated DQO step (USEPA 2006)</b>
Step 1. Identify monitoring plan objectives	Step 1. State the problem. Step 2. Identify the goal of the study.
Step 2. Develop monitoring plan hypotheses	Step 2. Identify the goal of the study.
Step 3. Formulate monitoring decision rules	Step 2. Identify the goal of the study.
Step 4. Design the monitoring plan	Step 3. Identify information inputs. Step 4. Define the boundaries of the study. Step 5. Develop the analytic approach. Step 6. Specify performance or acceptance criteria. Step 7. Develop the plan for obtaining data.
Step 5. Conduct monitoring analyses and characterize results.	Implement design optimized in Step 7.
Step 6. Establish the management decision.	Step 2. Identify the goal of the study. Step 5. Develop the analytic approach.

**Section II Summary**  
**(Overview of steps for developing a long-term monitoring plan)**

- Performance monitoring assesses whether the remedial strategy is functioning as designed, while ecosystem recovery monitoring assesses the on-going reduction of risks to human health and the environment. Both types of monitoring programs are complementary components of long-term monitoring following the implementation of remedial/risk management strategies at aquatic contaminated sites.
- Specific information needed to develop monitoring plans for site closure of aquatic contaminated sites is integrated in the present document into the USEPA (2004) six-step process for monitoring plan development, as well as the Data Quality Objectives process (USEPA, 2006) for monitoring plan design.

### **III. DEFINING MONITORING OBJECTIVES**

*Monitoring goals* represent the overall aims for management of the ecosystem (e.g., the reduction of human health and ecological risks to acceptable levels). *Monitoring objectives* are specific statements that clarify the scope and intent of the monitoring goals (e.g., to assess the reduction in human health risks due to fish consumption; MacDonald et al., 2009). Identification of monitoring objectives is the first step in developing a monitoring plan capable of achieving site closure. The following section reviews approaches used to define monitoring objectives for site closure in previous studies, as well as outlining a process for developing site-specific monitoring objectives. Examples of general objectives for monitoring remedy performance and ecosystem recovery are also provided.

#### **A. Beneficial use impairment approach**

A traditional approach used in water quality management is to define monitoring objectives based on a set list of beneficial uses (i.e., the designated roles that a water body fulfills, such as fish and wildlife habitat, safe drinking water sources, or recreational use). If the physical, chemical, or biological integrity of a water body deteriorates to the point that a particular beneficial use is no longer possible, the water body is classified as being impaired. The main goal for management in this approach is to restore beneficial uses. Monitoring programs therefore focus on assessing recovery for the specific beneficial-use impairments following management actions; delisting criteria are used to identify when the beneficial use has been restored.

The importance of providing clear guidance for delisting criteria and procedures was demonstrated by Keller and Cavallaro (2008): a review of listing and delisting processes for impairment of a water body under the U.S. Clean Water Act found that there were large inconsistencies amongst the states in impairment determination. These inconsistencies were largely attributed to differences in data quality and quantity, the frequency of monitoring, interpretation of water quality standards, and the specificity of implementation and monitoring plans.

The beneficial use impairment approach is applied for management of the Great Lakes Areas of Concern (AOCs). In 1991 the International Joint Commission (IJC) drafted a list of 14 beneficial use impairments (BUIs) and associated delisting guidelines used as criteria for delisting Great Lakes AOCs (IJC 1991; Hartig and Zarull, 1992). Recently, these BUIs and delisting guidelines have come under review: some are considered redundant or no longer relevant to current Great Lakes issues, while others require additional expert guidance to develop a clear measurement endpoint that may be used to determine when the delisting guideline has been achieved (George and Boyd, 2007;

Grapentine, 2009; Blazer et al., 2009; Rafferty et al., 2009). Furthermore, there have been large advances in the human and ecological risk assessment field since the IJC delisting guidelines were developed; most jurisdictions are moving toward a site specific risk-based approach for contaminated site management.

## **B. Risk-based approach**

Review of the scientific and policy literature from North America, Australia and New Zealand, and the European Union indicates that these jurisdictions generally use a risk-based approach for contaminated site management (Ferguson, 1999; Apitz and Power, 2002; USEPA, 2002a; European Communities, 2003; Allan et al., 2006b; ACT EPA, 2009). For example, the European Sediment Research Network SedNet has identified four objectives for sediment risk management: (1) to meet regulatory criteria; (2) to maintain economic viability; (3) to ensure environmental quality and nature development; and (4) to secure quality of human life (Joziassse et al., 2007). A main requirement for achievement of site completion in the United States is when the site is deemed to be protective of human health and the environment (USEPA, 2000a). Detailed procedural and reporting frameworks for closure and delisting of contaminated sites have been developed in the U.S. (see for example USDOD, 1999; USEPA, 2000a). However, specific guidance for the development of site closure guidelines does not appear to be available.

The FCSAP aquatic sites framework is also founded on a risk-based approach (Chapman, 2010). Monitoring objectives should therefore meet the overall FCSAP management goal of protecting human health and the environment, as well as being in accord with provincial and federal legislation (e.g., Species at Risk Act, Canada's Fisheries Act). The process for identifying monitoring objectives is outlined in the following paragraphs; specific guidance is provided in USEPA (2004) and in Step 1 of the DQO process (USEPA, 2006).

Monitoring objectives are directly related to the expected outcomes of the site activity (e.g., capping of contaminated sediments), and are closely linked with remedial/risk management objectives identified in Step 7 of the FCSAP Aquatic Sites Framework. Examination of the remedial action outcome (what it intends to accomplish and the expected effects on specific biological and environmental parameters) and mode of action (how the remedial strategy is expected to meet its objectives) are important for identifying the objectives of the monitoring program (USEPA, 2004). Stakeholder involvement in the definition of monitoring objectives allows stakeholder issues and concerns to be incorporated into the subsequent monitoring plan design (USEPA, 2004; Gerrits and Edelenbos, 2004).



In a risk-management context, the development of monitoring objectives is closely linked with the conceptual site model (CSM) for a particular site. The linkages between contamination, exposure and risk are highly complex and involve a unique combination of physical, chemical, and biological processes at each site. Therefore, the monitoring objectives and associated measurement endpoints and decision criteria for site closure vary depending on applicable exposure pathways and site conditions. A well-developed CSM that identifies important cause-effect relationships among contaminant sources, transport mechanisms, exposure pathways and receptors is crucial for the identification of site closure targets and an associated monitoring program (NRC 2007; USEPA, 2005). Much of this information should be available from previous site characterization, risk assessment, and remedial/risk management studies. Guidance for developing a CSM can be found in Appendix C of the FCSAP aquatic contaminated sites framework (Chapman, 2010).

Key monitoring questions are identified by reviewing the remedial strategy and its intended outcomes; the contaminants of concern (COCs) and associated remedial objectives outlined in the remedial/risk management plan; and the human health and ecological endpoints determined to be at risk for the site (USEPA, 2004). Activities that are not a direct consequence of the remedial strategy but are associated with its use should also be addressed at this point, such as the restoration of benthic habitat quality at dredged or capped sites. The resulting list of questions is used to formulate monitoring objectives for the monitoring plan to address.

Although the list of monitoring questions is specific to each site, general categories of monitoring objectives can be identified for remedy performance and ecosystem recovery monitoring. Not all of the general objectives will be relevant for all sites, and the list may not be comprehensive of all aspects of remedy function or important monitoring questions for a specific site. However, this document identifies general monitoring objectives to facilitate a consistent approach to developing monitoring plans for FCSAP site closures. General monitoring objectives for remedy performance and ecosystem recovery monitoring are discussed in more detail in the following sections.

### **C. General objectives for monitoring remedy performance**

Performance monitoring focuses on the specific remedy mechanism used at a site and collects data to evaluate whether the remedial strategy is functioning as designed (SPAWAR and ENVIRON, 2010). The following list of general objectives for monitoring remedy performance can be identified:

- 1. Any contaminated sediment remaining on site is chemically and physically stable and does not pose unacceptable risk to human or ecological health through chemical flux.*

An important aspect of demonstrating remedy effectiveness is ensuring that no significant residual sources of contamination are in the aquatic environment. These residual sources may result from incomplete removal or containment of contaminated material (e.g., sediments that are difficult to access by dredging, or are missed during the application of a sediment cap). Alternatively, they may represent previously undiscovered sources of contamination that were not taken into account during the remedial/risk management plan.

2. *The chemical and physical integrity of any engineered remedial structures or added materials are maintained over time and following disturbance events.*

Many active remediation techniques involve the installation of a containment facility or barrier to isolate contaminated sediments from the surrounding aquatic environment. Examples of these include an engineered containment facility for *in situ* contaminated sediment disposal; a dam for a tailings pond to prevent release of contaminated material; and an engineered cap to isolate contaminated sediments from overlying waters. A primary goal for monitoring programs is to ensure that the integrity of these engineered structures is maintained over time and is effective in preventing migration of constituents of concern (e.g., chemical contaminants or silt).

Although the above objectives are general aspects of performance monitoring, questions for monitoring plans are specific to the particular remedial strategy employed at the site. Examples of monitoring objectives for monitored natural recovery (MNR), capping, dredging, and *in situ* remediation techniques are discussed in Section IV.C below. Tables 3.2 to 3.4 in SPAWAR and ENVIRON (2010) also provide examples of monitoring questions related to sediment remedy processes for MNR, capping and dredging.

#### **D. General objectives for monitoring ecosystem recovery**

Long-term monitoring following remediation also involves monitoring ecosystem recovery and ensuring that human and environmental risks remain at acceptable levels. Similar needs related to ecosystem recovery may be identified for all of the remedial strategies employed (i.e., monitoring needs for ecosystem recovery are generally not strategy-specific). General objectives for monitoring ecosystem recovery, along with a description and rationale, are summarized in Table III-1. Tables 3.2 to 3.4 in SPAWAR and ENVIRON (2010) list examples of monitoring questions related to ecosystem recovery under remedial goal monitoring. The monitoring objectives in Table III-1 were selected to be consistent with the remedial goal monitoring objectives identified in SPAWAR and ENVIRON (2010) to facilitate use of the on-line sediment monitoring tools matrix (Interactive Sediment Remedy Assessment Portal (ISRAP); described in Section IV.B below).

**Table III-1: Examples of general monitoring objectives that may be used to monitor ecosystem recovery, their description and rationale**

Monitoring objective	Description and rationale
From ISRAP <sup>1</sup>	
Assessment of bioaccumulation potential to benthic and/or pelagic species	Ecological risk is often driven by contaminant bioaccumulation and biomagnification in aquatic food webs. This objective assesses reduction of risks to aquatic organisms from bioaccumulation.
Assessment of bioaccumulation potential to aquatic-dependent, terrestrial wildlife, including birds and mammals	Ecological risks due to contaminant bioaccumulation in prey items are often found for terrestrial ecological receptors that include a large proportion of aquatic prey in their diet (e.g., osprey, mink). This objective assesses reduction of risks to terrestrial aquatic wildlife consumers from bioaccumulation.
Assessment of benthic and/or pelagic ecological recovery over time	This objective assesses recovery for aquatic organisms through evaluation of community structure (e.g., benthic macroinvertebrate analyses, fish community census).
Assessment of toxicity to benthic and/or pelagic species	This objective assesses decreases in the ecological risks to aquatic organisms related to sediment or water toxicity.
Assessment of human exposure to bioavailable contaminants via consumption of aquatic organisms	Human health risks are often related to the consumption of contaminated aquatic organisms. This objective assesses reduction of human health risks related to aquatic organism consumption.
Developing long-term monitoring programs that lead to site closure for FCSAP aquatic contaminated sites: state of science review and technical guide	
Assessment of human exposure to contaminants via contact with abiotic media (e.g., dermal exposure, drinking water)	Human health risks also occur through other exposure pathways, such as dermal contact with sediments or drinking water ingestion. This objective assesses reduction of human health risks related to abiotic exposure.
Amelioration of physical impacts on the water body resulting from site use (e.g., increased suspended solids)	Physical constituents such as increased suspended solids can also harm aquatic organisms. This objective assesses decreases in physical impacts on water bodies following remedial activities.
Assessment of physical and chemical aquatic habitat	Site activities or the implementation of remedial strategies may result in degraded habitat for aquatic organisms. This objective assesses the recovery of physical and chemical aquatic habitat following remediation or mitigation strategies.
Assessment of recovery of aquatic productivity	Site activities or the implementation of remedial strategies may result in decreased aquatic productivity. This objective assesses the recovery of aquatic productivity through evaluation of community structure and production.
Improved conditions for Species at Risk	This objective assesses the effectiveness of mitigation measures carried out during remedial activities to address Species at Risk, as well as improved habitat quality for Species at Risk following remediation.

<sup>1</sup>Interactive Sediment Remedy Assessment Portal (SPAWAR and ENVIRON, 2010)

Not all of the monitoring objectives listed in Table III-1 will be appropriate for every site. The CSM and risk assessment for the site should be used to identify which human and ecological receptors are at risk from site contamination, and the main exposure pathways contributing to the risk. For example, the risk assessment may have identified that human receptors are at risk due to fish consumption from the site, but that risks from water consumption and dermal sediment contact are negligible. Therefore, the monitoring objective for assessing risks to exposure of bioavailable contaminants to humans via consumption of aquatic organisms would be selected for inclusion in the monitoring plan. Assessing risks to exposure of contaminants to humans via contact with abiotic media (e.g., dermal exposure, drinking water) would not be necessary unless there is reason to believe that these risks may be increased to unacceptable levels through remedial activities.

Selecting monitoring objectives for ecosystem recovery must also account for the linkages between measured ecological effects and the anticipated remedial outcomes. For example, when biota tissue contamination reflects exposure from a number of sources throughout a large area and is not strongly linked with contamination at a site, remedial/risk management activities at the site are unlikely to lead to significant declines in biota tissue contamination concentrations. Including monitoring of bioaccumulation in pelagic species (i.e., species that spend most of their time in the water column) as an objective for the monitoring plan may be inappropriate in this case. The contribution of site exposure to ecological risk compared with background sources should have been documented in the risk assessment and/or remedial action plan. The United States Policy Committee (2001) identifies several situations where a site may be delisted without monitoring for a particular ecosystem recovery objective as follows:

- Degradation is due to natural rather than human causes;
- Degradation is not limited to the aquatic contaminated site but is typical of lakewide, region-wide, or area-wide conditions; and
- Impairment is caused by sources outside the aquatic site boundaries.

Finally, the selection of monitoring objectives for ecosystem recovery should also take into account stakeholder decisions regarding the remedial objectives for the site. For example, despite evidence for toxicity effects on the benthic community, stakeholders may have agreed to remediate the site to reduce unacceptable risks to human health and upper-trophic-level aquatic consumers rather than the benthic community. In this case, it would be inappropriate to include the monitoring objective of assessing toxicity to the benthic community as it was not addressed in the remedial strategy. An effective project management structure that provides opportunities for stakeholder involvement and input is important for facilitating agreement on decisions regarding risk management/remedial strategies and subsequent long-term monitoring objectives.

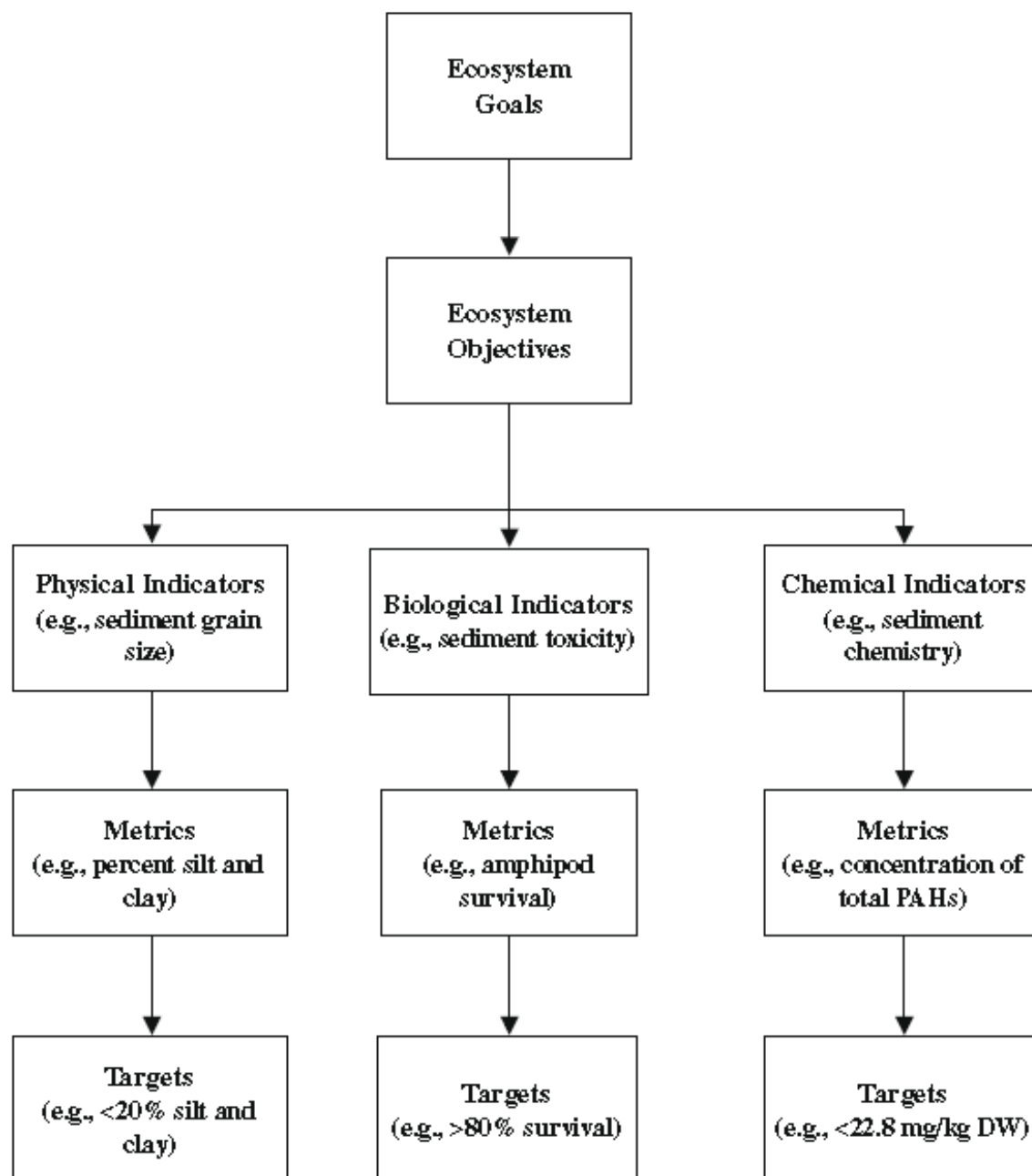
**Section III Summary**  
**(Defining monitoring objectives)**

- Monitoring objectives are developed based on the site management goals, conceptual site model, expected outcomes and mode of action of the remedial strategy, and the identified risks to human and ecological receptors. They represent goals to guide the focus of the monitoring program and lead to site closure.
- Monitoring objectives should be developed on a site-specific basis, taking into account information from previous site characterization, risk assessment, and remedial/risk management planning. Stakeholder input is important to ensure incorporation of stakeholder issues and concerns.
- Monitoring objectives should be in accordance with the federal and provincial regulatory framework, and should meet the overall aims of FCSAP to protect human health and the environment and ensure remedy effectiveness.
- General objectives for monitoring remedy performance and ecosystem recovery are identified. These may be used to facilitate a consistent approach to developing monitoring programs that are capable of achieving FCSAP site closure.

#### **IV. SELECTION OF MONITORING TOOLS FOR AQUATIC SITES**

Once the monitoring objectives are defined for a site, the next step in developing a monitoring program is to identify appropriate monitoring tools to address each objective. An *indicator* is a measurable variable that can be used to provide information related to a specific monitoring objective. *Metrics* are the quantifiable measurement units used for the indicators. The relationship between monitoring goals, objectives, indicators, and metrics is shown in Figure IV-1. Generally a set of indicators may be appropriate to address a specific monitoring objective; one or several of these can be selected for use in the monitoring program. The following section identifies sets of appropriate monitoring tools for the monitoring objectives defined in Section III. Important considerations for monitoring plan design and screening criteria that may be used to select indicators for use in a monitoring program are also discussed.

*Targets* are action levels for decision-making and are used to determine when the monitoring objective has been successfully completed. As shown in Figure IV-1, targets are specific to each metric chosen for the monitoring program. Section V of this document discusses target action levels for site closure (i.e., *exit criteria*) that may be used for decision-making in monitoring programs.



**Figure IV-1: Relationship between management goals, monitoring objectives, indicators, metrics, and targets for decision rules (Figure 2 in MacDonald et al., 2009)**

## **A. Overview of monitoring tools**

Monitoring tools for aquatic sites include physical, chemical and biological measurements. In general, physical and chemical endpoints are easier to measure and interpret than biological endpoints (USEPA, 2005). However, biological indicators integrate the effects of environmental stressors and provide a direct measure of site-specific exposure and ecological risk. A combination of measurement endpoints is usually appropriate for monitoring the success of remedial measures, especially at complex sites. The following sections provide a general description of the physical, chemical and biological monitoring tools available for aquatic sites.

### ***1. General overview of physical monitoring tools***

Physical measurements for an aquatic site can evaluate sediment erosion and deposition patterns, ground water advection, surface water flow rates, and sediment characteristics such as particle size, porosity, specific gravity, bulk density, organic carbon content and heterogeneity. The following physical monitoring methods are identified by USEPA (2005) and ASTWMO (2009), and summarized in Appendix A of SPAWAR and ENVIRON (2010). Detailed methodologies for their application are found in USEPA (1995; 2001c; 2003a; 2007c).

- ***Sediment geophysical properties***: used for modelling fate and transport, evaluating contaminant bioavailability, and characterizing habitat.
- ***Water column physical measurements*** (e.g., turbidity, total suspended solids): used to monitor resuspension of sediment during dredging and cap placement.
- ***Bathymetry data***: used to evaluate sediment stability over time, navigable depths, bottom surfaces for remedy design, and post-remediation bottom elevations.
- ***Side scan sonar data***: used to monitor the distribution of sediment types and bedforms, as well as to evaluate the presence of debris or bottom formations.
- ***Sediment settlement plate data***: used to monitor cap consolidation and measure changes in cap thickness over time.
- ***Critical shear stress data***: used to monitor sediment stability, erosion potential and contaminant resuspension.
- ***Sediment profile camera data***: used to monitor changes in thin layering within sediment profiles, sediment grain size, bioturbation and oxidation depth, and presence of gas bubbles.
- ***Sub-bottom profiler data***: used to measure density changes in surface and subsurface sediment bedding layers, surface mixing depths and presence of gas bubbles.



- ***Physical habitat data:*** used to identify physical structures or measure environmental variables related to benthic habitat quality (e.g., depth, sediment particle size)

## ***2. General overview of chemical monitoring tools***

Chemical measurements involve the collection and analysis of sediment, pore water and surface water samples for contaminant concentrations. These analyses can be useful to evaluate total contaminant concentrations in abiotic media, assess contaminant bioavailability, biodegradation and partitioning to pore water, and provide information on specific phases of contaminants (ASTSWMO, 2009). Supplementary information such as salinity, dissolved oxygen, pH, nutrient concentrations (e.g., nitrate, total phosphorus), acid volatile sulfide (AVS) and total organic carbon (TOC) may also be evaluated to support the design and interpretation of data from the monitoring program. The following sampling tools in support of chemical measurements are identified by USEPA (2005) and ASTSWMO (2009) and are summarized in Appendix A of SPAWAR and ENVIRON (2010). Detailed methodologies for their application are found in USEPA (2001c; 2003a).

- ***Sediment grab samples:*** used to collect samples for analyses of surface sediment chemistry.
- ***Sediment coring:*** (e.g., vibracore, gravity, piston, or drop tube samples). used to obtain a vertical profile of sediment chemistry or detect migration of contaminants through a cap.
- ***Direct water column measurements:*** used for measuring water quality parameters such as pH, dissolved oxygen, conductivity, salinity, pH and temperature.
- ***Surface water samplers:*** used to collect and measure dissolved or total chemical concentrations in water.
- ***Passive sampling devices:*** used for measuring dissolved chemicals in water, especially low-solubility chemicals.
- ***Porewater sampling devices:*** used for measuring contaminant concentrations in sediment porewater.
- ***Seepage meters:*** used for measuring aqueous chemical flux and groundwater advection through sediment and into the water column.

## ***3. General overview of biological monitoring tools***

Biological measurements for an aquatic site can be used to evaluate ecological risks and habitat restoration effectiveness; monitor sensitive populations such as species at risk; and determine bioaccumulation of contaminants in the aquatic food web. Living organisms integrate the cumulative effects of all environmental stressors to which they

are exposed: they can provide data for an assessment of long-term exposure and effects that may be difficult to model using physical and/or chemical data. However, data interpretation is complicated by the need to separate effects related directly to site activities from those related to natural variables or other sources of stressors in the watershed (e.g., hydrological changes or contamination influx associated with general urban activities). Consideration and measurement of other potentially important environmental variables (e.g., grain size, organic carbon content, salinity, redox conditions, etc.) is often crucial for interpreting the results of biomonitoring studies.

Biological monitoring tools can generally be divided into four categories: 1) biological surveys; 2) toxicity testing; 3) measurement of tissue contaminant concentrations; and 4) biological indicators of organism health (ASTSWMO, 2009). A brief description of and general considerations for each of these categories are outlined below.

#### **a. Biological surveys**

Biological surveys include determination of the presence/absence, diversity, percent cover, and abundance of various aquatic organisms. Common examples include benthic invertebrate community analyses, fish community censuses, and vegetation surveys. These can be used to evaluate ecosystem recovery, restoration of aquatic habitat productivity, and improved conditions for species at risk. The ability of the survey to detect measurable changes depends on the selected community to be monitored and the primary contaminants of concern (ASTSWMO, 2009). Survey data must be paired with physical habitat evaluations to provide information on natural factors that influence community structure. Decisions regarding the timing and frequency of monitoring are complex, as community composition will change seasonally due to organism life habits (e.g., migration, breeding/reproductive patterns) and over the long term based on population attributes. Finally, sampling and data interpretation generally require specialized expertise for taxonomic identifications and interpretation of the monitoring data in a form that supports decision making. Detailed methodologies and guidance for completing biological surveys in aquatic ecosystems are contained in Rosenberg and Resh (1993), Hill et al. (2005), NAVFAC (2007) and USEPA (2003a; 2007a; 2007c; 2007d). Johnston and Roberts (2009) reviews the effects of contaminants on marine communities.

Several approaches and metrics can be used to summarize and interpret biological community data for use in a monitoring program. Univariate approaches quantify the state of the community in a single summary measure. Examples include simple measures such as biomass, abundance, or species richness, or an index of community structure combining elements of abundance and species number (e.g., species diversity), different indicator species, and/or supplementary environmental data (Norris and Georges, 1993). A large number of indices have been developed to summarize the state of the

environment with respect to a particular monitoring aspect (e.g., ecological integrity, degree of organic enrichment). Accordingly, there is much discussion in the scientific literature regarding the appropriateness and applicability of these indices to different environments (see reviews in Diaz et al. (2004) and Pinto et al. (2009)).

Multivariate statistical methods allow an alternative approach to data interpretation, where species presence/absence or abundance is related to a set of measured environmental variables, usually on a species-by-site or species-by-sampling period matrix. Although statistical expertise is required to apply the multivariate approach, the advantage is that it allows for the examination of spatial and temporal trends in communities influenced by several environmental variables (Clarke and Ainsworth, 1993). These methods are generally more sensitive than indices for detecting differences between test and reference sites, especially when the dominant stressor is not known (Grapentine, 2009). A detailed review of multivariate statistical methods for the analysis of community data is found in Norris and Georges (1993).

#### **b. Toxicity testing**

Toxicity testing is used to assess acute or chronic effects of chemicals on biota, and may be used to monitor ecosystem recovery. Tests can be carried out using caged organisms *in situ*, but are most commonly performed with test organisms under laboratory conditions using abiotic media from site (water or sediments). Protocols have been developed for invertebrates, fish, and amphibians (see USEPA, 2000c; 2001c; 2008; Rosen et al., 2009). It is generally recommended that lab bioassays be carried out with sensitive test organisms that are reasonably similar to those that would be found at the study site. A weight-of-evidence approach using several test organisms is desirable, as this approach accounts for the varying sensitivity and exposure pathways of different organisms to different contaminants. Long-term toxicity tests that evaluate chronic effects such as test organism growth and reproduction are generally considered more appropriate for monitoring longer-term ecosystem recovery (SPAWAR and ENVIRON, 2010). Measurements of natural environmental variables that may affect toxicity endpoints (e.g., TOC, grain size, ammonia, salinity, pH) and an assessment of other stressors in the watershed are important in determining if toxicity effects are due to site-specific factors or other stressors. Toxicity testing should be paired with chemical testing of sediment or water samples so that exposure-response relationships may be understood. A rigorous QA/QC program is essential to ensure that effects detected are caused by the test sediments and are not a result of toxicity generated by test conditions.

#### **c. Measurement of tissue contaminant concentrations**

Measurement of tissue contaminant concentrations in aquatic organisms is a commonly used monitoring approach for assessing bioaccumulation of contaminants and potential risks to human and wildlife consumers. Analyses may be carried out on free-ranging

indigenous species, test organisms exposed to site media under controlled laboratory conditions or, less commonly, test organisms caged *in situ* for a defined exposure time. The choice of species for monitoring requires careful consideration, as different species show different patterns in contaminant uptake because of varying lipid contents, life history traits and exposure scenarios. For example, lipid-soluble persistent organic contaminants such as PCBs and DDT generally bioaccumulate in fish, but easily biodegradable contaminants such as PAHs and chlorinated phenols do not accumulate at levels that reflect environmental exposure (van der Oost et al., 2003). Furthermore, tissue contaminant concentrations in fish species that are resident year-round at the site more closely reflect site-specific exposure compared to contaminant concentrations in migratory fish that may only spend a fraction of their time at the site. Detailed guidance for the selection of monitoring species is provided in NAVFAC (2007) and in Goodsell et al., (2009). In addition to meeting these characteristics, species chosen to be monitored should also be relevant to the monitoring objective: monitoring reduction in human health risks would focus on species consumed by humans, while important wildlife prey items may be chosen for monitoring reduction of risks to wildlife consumers.

Detailed guidance for developing and conducting tissue monitoring programs is provided in NAVFAC (2007) and USEPA (2001b; 2007a; 2008). An overview of fish contaminant monitoring programs in Canada and other jurisdictions is provided in Golder Associates (2007).

Aquatic organisms such as fish are good integrators of varying sediment conditions over an area of concern, and are therefore useful monitoring indicators for site-specific exposure and bioaccumulation. However, biological uptake of contaminants is influenced by a number of factors including age, sex, home range, feeding regimes, contaminant excretion rates, as well as other life history parameters (USEPA, 2008; SPAWAR and ENVIRON, 2010). Seasonal changes in tissue lipid content (which generally is low in the spring and around spawning time) and surface water conditions may also influence bioaccumulation. Monitoring programs should be planned to limit these sources of natural variability as much as possible to provide the best chance for detecting small changes in contaminant uptake. Particularly at low chemical concentrations, these factors can hinder the interpretation of relationships between sediment and biota concentrations and complicate efforts to evaluate remedy success and the achievement of site closure goals (USEPA, 2005).

#### **d. Biological indicators of organism health**

Biomarkers can be defined as biological responses (e.g., molecular or cellular modifications) in taxa that occur as a result of exposure to environmental stressors such as pollutants (Goodsell et al., 2009; van der Oost et al., 2003). They can be used as early warning indicators to assess the effects of exposure to contaminants, and are potential

tools for monitoring the ecological recovery of an exposed population. Examples of biomarkers include biotransformation enzymes such as hepatic CYP1A protein levels or EROD (ethoxyresorufin *O*-deethylase) activity; measures of oxidative stress; presence of metabolites; reproductive or endocrine parameters such as imposex (the development of male sexual characteristics in female gastropods); and physiological or morphological parameters such as lesions and tumours (van der Oost et al., 2003). Some biomarkers respond to the presence of certain chemicals and are therefore useful as general indicators of exposure, while other biomarkers react to individual chemicals or classes of chemicals (NAVFAC 2007). Reviews of available biomarkers for aquatic organisms, including criteria for the selection and development of biomarkers for use in ecological risk assessment and monitoring, are presented in van der Oost et al. (2003) and Martin-Diaz et al. (2004).

One of the limitations of using biomarkers for monitoring is that often there is an unclear relationship between changes in biomarker responses and whole-organism endpoints that affect population status, such as survival or reproductive effects (Boskar et al., 2010), which are important for assessing ecosystem recovery. In addition, some biological responses assessed by biomarkers are thought to be irreversible (e.g., imposex or tumours); this limits the ability to track ecological recovery and separate effects due to current and prior exposure to environmental stressors. Despite this, the prevalence of fish tumours has been used as a measure of ecosystem recovery at Great Lakes AOCs and other sites, particularly where polycyclic aromatic hydrocarbons (PAHs) were the main contaminant of concern (e.g., Baumann et al., 1996; Lin et al., 2001; Myers et al., 2008; Rafferty et al., 2009). Like other biological indicators, biomarker responses are influenced by confounding factors such as the overall health of the organism, condition, sex, age, nutritional status, metabolic activity, migratory behaviour, reproductive and developmental status, and population density, as well as environmental factors such as seasonal changes in temperature and water quality (van Oost et al., 2003). For many biomarkers, more understanding is needed of these confounding factors to calibrate the dose-response relationship; the linkage between biomarker response, whole organism health, and ecosystem risks must also be understood before the biomarker can be applied in monitoring programs to assess ecosystem recovery. However, the development and calibration of biomarkers is a rapidly expanding research field, and more application of biomarkers in monitoring programs will likely occur in the future.

## **B. Criteria for the selection of monitoring tools**

The first step in selecting monitoring tools is to identify which subset of tools is appropriate for achieving a particular monitoring objective. General guidance frameworks for sediment monitoring are available, as are detailed handbooks on monitoring tools (e.g., USEPA, 2003a; USEPA, 2004; Apitz et al., 2005; USEPA, 2005;

ASTSWMO 2009); however, there is no formal guidance document that provides a standardized framework for selecting monitoring tools specific to an individual monitoring need. To fulfill this objective, the U.S. Space and Naval Warfare Systems Center Pacific (SPAWAR: SSC Pacific), with technical assistance from ENVIRON International Corporation, has recently developed the on-line sediment monitoring tools matrix (Interactive Sediment Remedy Assessment Portal (ISRAP): <http://www.israp.org/Default.aspx>). The ISRAP interactive matrix promises to be useful for project managers and others charged with developing long-term monitoring plans for aquatic contaminated sites.

ISRAP consists of a series of interactive menus designed to identify and compare appropriate monitoring tools for monitoring needs related to capping, dredging, and monitored natural recovery (MNR) strategies. Potential monitoring needs and general site closure goals are identified for each strategy, including both those associated with monitoring remedy performance and those related to long-term ecosystem and habitat recovery. Selection of a particular monitoring need identifies a list of monitoring tools that can be appropriate for providing information relevant to that need, with linkages to detailed guidance for their application. The identified monitoring tools may then be compared using a series of screening attributes (described in more detail below) to facilitate selection of the most effective combination of monitoring tools. Further description and guidance on the ISRAP matrix can be found in Appendix B of SPAWAR and ENVIRON (2010), as well as on the ISRAP web site.

The screening criteria used in the ISRAP tool are as follows (SPAWAR and ENVIRON, 2010):

- ***Commonality of tool use:*** frequency of tool use in addressing the monitoring need (very rare to very common).
- ***Special considerations:*** significant restrictions and other important information about the tool that may limit or enhance its application.
- ***Spatial experimental design complexity:*** the complexity and level of expertise required to identify the location and number of monitoring points required for successful application of the monitoring tool.
- ***Temporal experimental design complexity:*** the complexity of making decisions on the timing and frequency of the monitoring tool use, including time constraints associated with the monitoring tool.
- ***Monitoring tool logistical complexity:*** the difficulty associated with using the proposed monitoring tool.
- ***Difficulty in locating tool in marketplace:*** whether it is widely available or likely unavailable from commercial sources.

- ***Relative cost***: relative cost ranking for various tools that fulfill the same monitoring need.
- ***Level of expertise required for data interpretation***: level of analyst expertise required to interpret and use data to address the monitoring need within a decision-making framework.
- ***Uncertainty in addressing monitoring need***: the level of uncertainty associated with using data collected with a specific monitoring tool to satisfy the monitoring need. This ranges from high to low confidence in the ability of the monitoring tool to satisfy monitoring needs. This is a critical attribute for determining the success of the monitoring program.

A decision-making matrix summarizing rankings (low, medium or high) of all the above screening criteria (except commonality of use and special considerations) is generated in ISRAP as a final outcome to compare monitoring tools appropriate to a particular monitoring need. Selection of monitoring tools requires consideration of all these screening factors. For example, a simple low-cost tool may also have high uncertainty associated with the data relative to a particular monitoring need (i.e., it is easy to collect the data but difficult to assess whether the monitoring objective is being met). In this case, it would be better to select a more complex tool with lower uncertainty. The ISRAP matrix is a good tool to identify potential monitoring needs and associated monitoring tools, and to focus attention on important considerations for the development of a monitoring plan. Ultimately, however, selection of the best monitoring tools for a project requires knowledge of site-specific conditions and good professional judgment.

Validation and refinement of the ISRAP matrices through comparison with monitoring tools selected in two aquatic monitoring case studies identified several additional considerations for the selection of monitoring tools (Appendix C, SPAWAR and ENVIRON, 2010). First, it may be important to take into account monitoring tools used in prior assessment and characterization studies for the site, as using the same tool allows for comparison of results with pre-remedial baseline data. Second, the same monitoring tool may be useful for addressing several different monitoring needs, which enhances the cost-effectiveness of monitoring programs. Alternately, several different monitoring tools may be selected to address a single monitoring need, as each tool offers its own advantages and disadvantages relative to site-specific monitoring conditions. For example, some tools may be appropriate for some areas of the site and not others; the use of several tools may provide complementary information to strengthen data interpretations and limit uncertainty. These observations highlight the importance of considering site-specific conditions and understanding the limitations of each monitoring tool when selecting tools and developing long-term monitoring programs.

### **Summary**

#### **Section IV-A (Overview of monitoring tools)**

#### **Section IV-B (Criteria for the selection of monitoring tools)**

- A suite of physical, chemical, and biological monitoring tools can provide information relevant for addressing monitoring objectives. Physical and chemical monitoring tools are generally easier to measure and interpret, but may be less representative for assessing ecological risks than biological indicators.
- Biological monitoring tools include biological surveys, toxicity testing, measurement of tissue contaminant concentrations, and indicators of organism health. They integrate environmental exposure and effects over time and space, but require careful monitoring plan design and results interpretation to separate out the influence of site-specific activities from other environmental stressors.
- A number of screening criteria may be used to select which monitoring tools are most appropriate to address a particular monitoring objective. The on-line Interactive Sediment Remedy Assessment Portal (ISRAP) is useful for selecting and comparing monitoring tools to address performance and ecosystem recovery monitoring objectives for aquatic contaminated sites.

### **C. Tools for monitoring the performance of aquatic remedies**

A primary objective of post-remedial monitoring plans is to ensure that the remedial strategy is functioning as designed. This type of monitoring may be termed “performance monitoring” (SPAWAR and ENVIRON, 2010), but has also been classified as monitoring for long-term remedy performance (USEPA, 2005). Performance monitoring focuses on assessing the success of the remedial mechanisms by examining indicators of remedy processes. Performance monitoring is critical to ensure that the remedial strategy employed is effective; results from this monitoring component complement monitoring programs to document ecosystem recovery (discussed in Section IV.D).

The following section summarizes potential performance monitoring objectives and associated subsets of appropriate monitoring tools for four categories of aquatic remedies: monitored natural recovery, capping, dredging, and *in situ* remediation technologies. Strategy-specific considerations for the level of effort required for performance monitoring, as well as site closure considerations, are discussed for each remedy.



## ***1. Capping***

### **a. Strategy overview**

Capping is an *in situ* remedial technology that involves the controlled placement of clean material over contaminated sediments without disturbing the original bed (NRC, 1997). By physically and chemically isolating contaminants and stabilizing the sediment to prevent resuspension, the risks posed by the contaminated sediments to human health and the environment are reduced (Palermo et al., 1998; SPAWAR and ENVIRON, 2010). Cap design varies to meet the needs of different site conditions, such as water depth or hydrodynamic flow. Multiple or single layers of materials may be used to cover the sediment and can include fine-grained material, sandy material to aid with sediment stability and geotextile membranes or armour stone used to prevent erosion (SPAWAR and ENVIRON, 2010). Greater experience with capping remedies has been gained over the last decade; cap performance can now be better predicted and quantified, and this has led to greater acceptance among agencies (NRC, 2007).

### **b. Performance monitoring indicators**

Caps are designed and constructed to withstand stresses related to existing and probable human activities and hydrodynamic conditions in the site environment. However, since contaminated sediments remain on site, they are subject to long term risks of disruption by natural or human activity as well as upward diffusion of contaminants through the cap (SPAWAR, 2003). It is crucial to monitor cap performance (i.e., physical and chemical integrity) over time to determine if the remedial solution is functioning as expected or if further maintenance is required. Assessment of the impact of the constructed cap on site hydrodynamics and sediment transport is also important, as changes in these processes may affect other areas of the site that contain some fugitive contamination (Blake et al., 2007). A summary of the performance monitoring objectives for capping is presented in Box IV-1.

**Box IV-1: Performance monitoring objectives for capping (after SPAWAR and ENVIRON, 2010)**

1. Is the chemical integrity of capping material maintained over time and following disruptive events to ensure that risk posed by the contaminated sediment does not pose concern?
2. Is physical integrity of capping material maintained over time and in variable site conditions?
3. Is the impact of the cap on site hydrodynamics and sediment transport acceptable and as predicted?

Important indicators to detect processes of concern for each performance monitoring objective recommended for capping strategies are summarized in Box IV-2. A detailed description of monitoring indicators and methodology for sampling the chemical and physical integrity of the cap is found in ASTSWMO (2009) and Palermo et al. (1998), as well as in the on-line ISRAP sediment monitoring matrix (SPAWAR and ENVIRON, 2010).

**Box IV-2: Indicators for performance monitoring of capping remedial strategies to detect processes of concern**

**Physical integrity**

- Cap thickness, monitor for erosion
- Cap placement, monitor for cap movement
- Cap cohesiveness, monitor for disruption

**Chemical integrity**

- Water (pore and surface) and sediment (at and below surface) contaminant concentrations, monitor potential flux

**Impact of cap on hydrodynamics and sediment transport**

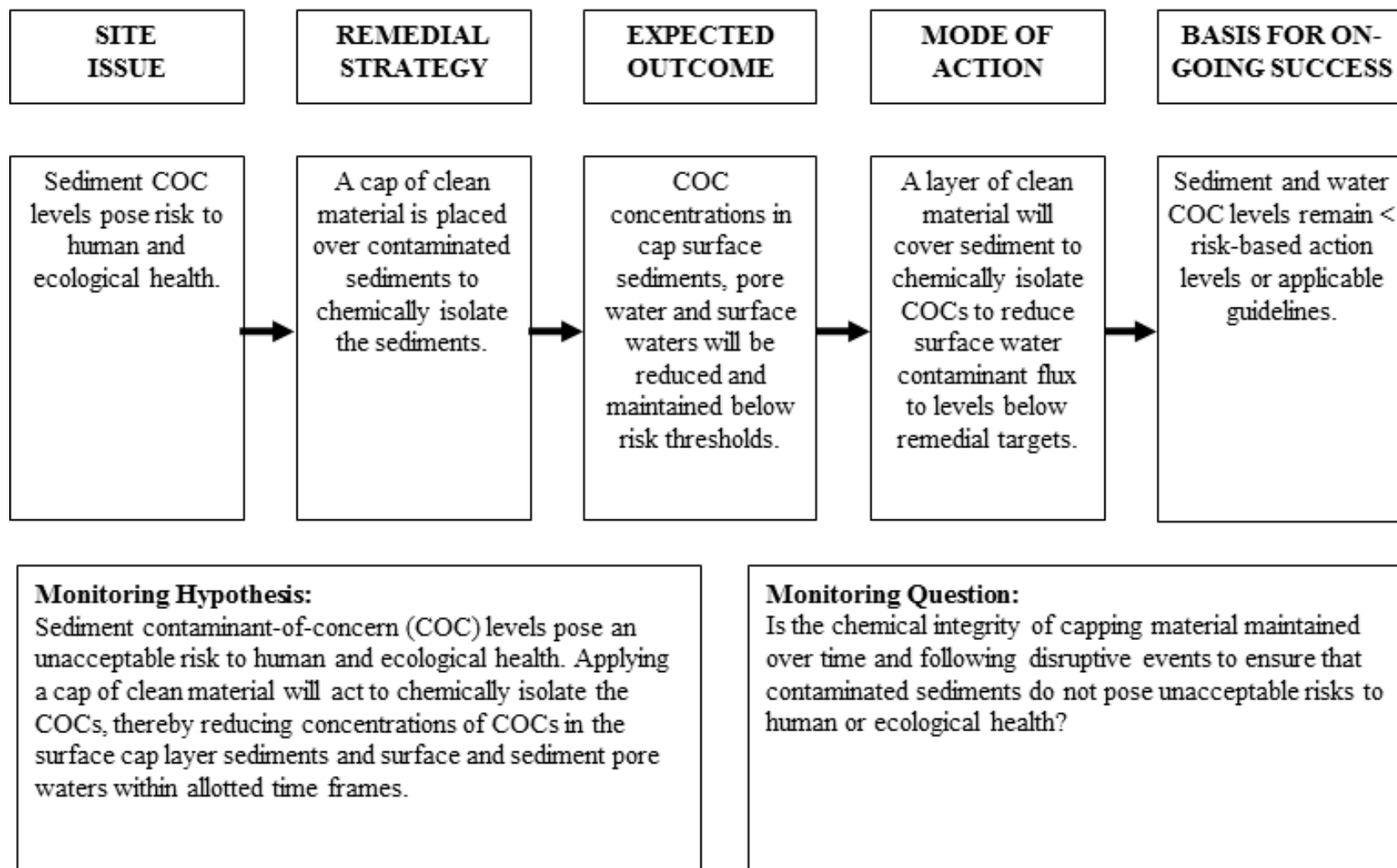
- Assess erosion, water column transport and deposition changes on site

*Adapted from ASTSWMO, 2009; Blake et al., 2007; Palermo et al., 1998; SPAWAR and ENVIRON, 2010; SPAWAR, 2003; USEPA, 2005.*

The physical integrity of the sediment cap is monitored by indicators of cap thickness, placement and consistency. The cap is expected to undergo consolidation following its initial construction, which involves compression of the cap material and some erosion depending on site conditions and cap design. However, maintenance may be required if there is an indication erosion rates are greater than expected. The thickness should be assessed in multiple locations to ensure consistency across the cap (ASTSWMO, 2009). In addition to erosion, the softer layers of the cap are also at risk of penetration and disruption by submerged aquatic vegetation, groundwater recharge and bioturbation by burrowing animals, which affect the cap's character (also described as its cohesiveness or consistency; Palermo et al., 1998). Cap character can be monitored using strategies similar to those used for determining cap thickness (SPAWAR and ENVIRON, 2010; USEPA, 2005). Unintended cap material movement may also occur after the initial placement and should be monitored, especially at the cap edge (Palermo et al., 1998; ASTSWMO, 2009).

The chemical integrity of the cap is also monitored to ensure that the surface water contaminant flux does not pose risk (USEPA, 2005). To do this, contaminant concentrations in the surface and cap layer sediments as well as pore water and surface water can be examined as indicators. An example of a monitoring conceptual model for chemical integrity is provided in Figure IV-2.

The impact of the cap on site hydrodynamics and sediment transport processes, including erosion, water column transport and deposition changes, is important to assess as these can impact exposure risks associated with any contamination remaining on site. Detailed information regarding hydrodynamics and sediment transport monitoring can be found in the User's Guide for Assessing Sediment Transport at Navy Facilities (Blake et al., 2007) and in the ISRAP on-line tool (SPAWAR and ENVIRON, 2010). Habitat restoration and recolonization of the benthic (sediment-dwelling) and macrophyte community on the cap surface are also important to monitor.



**Figure IV-2: Example of a monitoring conceptual model for assessing the chemical integrity of a sediment cap (after USEPA, 2004)**

### **c. Spatial and temporal considerations for performance monitoring**

Specific site characteristics affecting risks to the cap integrity (see Box IV-3) should also be accounted for in the monitoring plan, as they will affect the level of monitoring effort required. For example, the frequency of low magnitude physical disturbances such as tidal and wave pumping as well as boat propeller wash will also impact the expected rate of erosion for the cap; any changes to these frequencies may require monitoring plan adjustments (USEPA, 2005; SPAWAR and ENVIRON, 2010). Differences in cap design can subject the cap to different risks regarding physical integrity. For example, if a cap has an armouring layer, it may be subject to cracking and weathering, which need to be monitored. Caps at shallow water depths will also require greater monitoring following storm or erosion events compared to deeper water situations (Palermo et al., 1998).

#### **Box IV-3: Site characteristics affecting level of effort required for monitoring**

##### **Site Condition Considerations**

- Frequency of low magnitude disruptions such as wave and tidal pumping, as well as erosion impacts as a result of navigational activity surrounding the cap:
  - Boat and ship propellers
  - Direct hull contact
  - Anchoring
  - Bottom drag fishing
- Altering flow patterns or erosion forces due to factors such as damming or breakwater modifications
- Seasonal weather conditions affecting ability to conduct monitoring and maintenance activities

##### **Cap Design Considerations**

- Sediment cap height and water depth above cap
- Incorporation of an armouring layer
- Incorporation of a gravel layer

*Adapted from: Palermo et al., 1998; SPAWAR and ENVIRON, 2010; USEPA, 2005*

The USEPA (2005) outlines recommendations regarding the frequency and time commitment required for long-term monitoring following capping. The US EPA suggests annual checks of the physical integrity in selected areas as well as a survey over the entire

area every five years. Evaluation of the cap chemical integrity every five years using a defined grid and monitoring ecological re-colonization based on local expectations is also recommended. Similar temporal recommendations for cap performance monitoring are provided by SPAWAR and ENVIRON (2010) in the on-line ISRAP sediment matrix and are summarized in Table IV-1. Cap settlement and stability should be monitored beginning weeks after the cap's placement and continuing until there is enough data to be certain of the cap's sediment stability in face of potential site disturbances (several years). The chemical flux through the cap, which reflects cap chemical integrity, should be monitored every one to five years beginning in the first weeks after placement and continuing until remedial goals have been achieved. An event-based monitoring program should also run congruently, requiring the examination of cap integrity following major physical disturbances such as storms, ice scour, floods and earthquakes. Palermo et al. (1998) explain that it is after these events when repair or replenishment may be needed and that acquiring an understanding of the impact of events of different scales will help tailor later monitoring and maintenance efforts.

**Table IV-1: Recommendations regarding the frequency of performance monitoring required for capping**

Monitoring objective	Monitoring timeframe	Monitoring approach	Monitoring frequency
Physical integrity	Perpetually	Temporal or event-based	Every 1–5 years, or following disruptive events
Chemical integrity	Perpetually	Temporal	Every 1–5 years
Cap impact on hydrodynamics and sediment transport	After 1 monitoring round	N/A	Once

#### **d. Site closure considerations**

Although capping is viewed as a permanent remedy, long term monitoring is required since contaminants remain on site (ASTSWMO, 2009). Ongoing maintenance and monitoring of the cap's structure is generally required in the US and Canada, meaning that site closure is likely not feasible. The US EPA requires that while contaminants remain on site as they do in the case of capping, monitoring must be conducted at least once every five years into perpetuity. However, as greater certainty is gained regarding the stability and chemical flux associated with the cap in face of site disturbances, the level of effort required for performance monitoring can be decreased.

## 2. Monitored natural recovery

### a. Strategy overview

Monitored natural recovery (MNR) is an *in situ* strategy that uses processes naturally occurring on the contaminated site to permanently contain, destroy or reduce the sediment contamination as well as the corresponding bioavailability and toxicity (ASTSWMO, 2009; Magar and Wenning, 2006; SPAWAR and ENVIRON, 2010). There are multiple physical, chemical or biological processes that may be employed to remediate sediment contamination in MNR, as shown in Box IV-4.

Numerous lines of evidence are used to support the decision to utilize MNR on a site, as discussed in ENVIRON (2006) and Förstner and Aplitz (2007). This technology is often combined with other remedial solutions such as dredging, capping or *in situ* treatment (ENVIRON, 2006; Förstner and Aplitz, 2007). MNR has received growing recognition as an alternative to active remedies by the US Environmental Protection Agency (US EPA, 2005a).

#### **Box IV-4: Chemical, physical and biological remedial processes used for MNR**

##### **Physical Processes**

- Burial and isolation of contaminants in environments with net deposition
- Progressive sediment mixing to dilute surface sediment contaminants
- Contaminant erosion, dispersion and off-site transport

##### **Chemical Processes**

- Contaminant transformation
- Contaminant weathering
- Contaminant sorption, precipitation and sequestrations

##### **Biological Processes**

- Contaminant biodegradation
- Contaminant biotransformation

*Adapted from ASTSWMO (2009); ENVIRON (2006); Magar and Wenning (2006); SPAWAR and ENVIRON (2010); USEPA (1998); USEPA (2005).*

MNR may be supported by engineered means to accelerate natural recovery processes to achieve risk reduction and ecological recovery (Merritt et al., 2010; SPAWAR and ENVIRON, 2010). Although enhanced monitored natural recovery is an accepted remedial strategy, it has not been as comprehensively reviewed as other remedial approaches (Magar et al., 2009; Merritt et al., 2010; NRC, 2007). Enhanced monitored natural recovery primarily involves thin-layer sediment application of approximately 15-30cm of clean sand, sediment or gravel materials at specific site locations (Merritt et al., 2010; SPAWAR and ENVIRON, 2010). The installation of flow structures to increase

natural sedimentation rates can also be a part of enhanced monitored natural recovery strategies (Förstner and Apitz, 2007). The aim of these approaches is not to seal over a contaminated area, as is done during traditional capping, but to accelerate physical isolation processes such as contaminant burial and isolation and sediment mixing to dilute surface sediment concentrations. These strategies also facilitate the re-establishment of benthic organisms to minimize benthic community disruption (SPAWAR, 2003; USEPA, 2005).

**b. Performance monitoring indicators**

Performance monitoring objectives for MNR are summarized in Box IV-5. Monitoring MNR performance involves ensuring that MNR processes are occurring over the long term to sequester contaminants, as well as short-term considerations regarding the chemical flux from contaminated sediments into the water column (SPAWAR and ENVIRON, 2010). The natural recovery processes that are applicable for a particular site should have been identified as part of the Remedial Action Plan, along with estimates of the time frame for MNR. Under the FCSAP context, many of the monitoring activities associated with MNR occur before the remedial goals are achieved and are therefore NOT considered to be part of LTM for a site. However, LTM may be required following achievement of the remedial goals to confirm on-going protectiveness of the risk management strategy. For example, at sites that rely on physical isolation and burial of contaminated sediments, monitoring during extreme events is recommended to ensure that contaminated sediments are not exposed.



**Box IV-5: Performance monitoring objectives for monitored natural recovery (MNR) (after SPAWAR and ENVIRON, 2010)**

1. Have natural chemical transformation processes proceeded to meet remedial goals and is there confidence that this is irreversible?

Given current and future site geochemical conditions, has the stability of naturally occurring applicable contaminant binding, precipitation or sequestration processes been demonstrated?

Have naturally occurring biological transformation processes proceeded to meet remedial goals and is there confidence in their irreversibility?

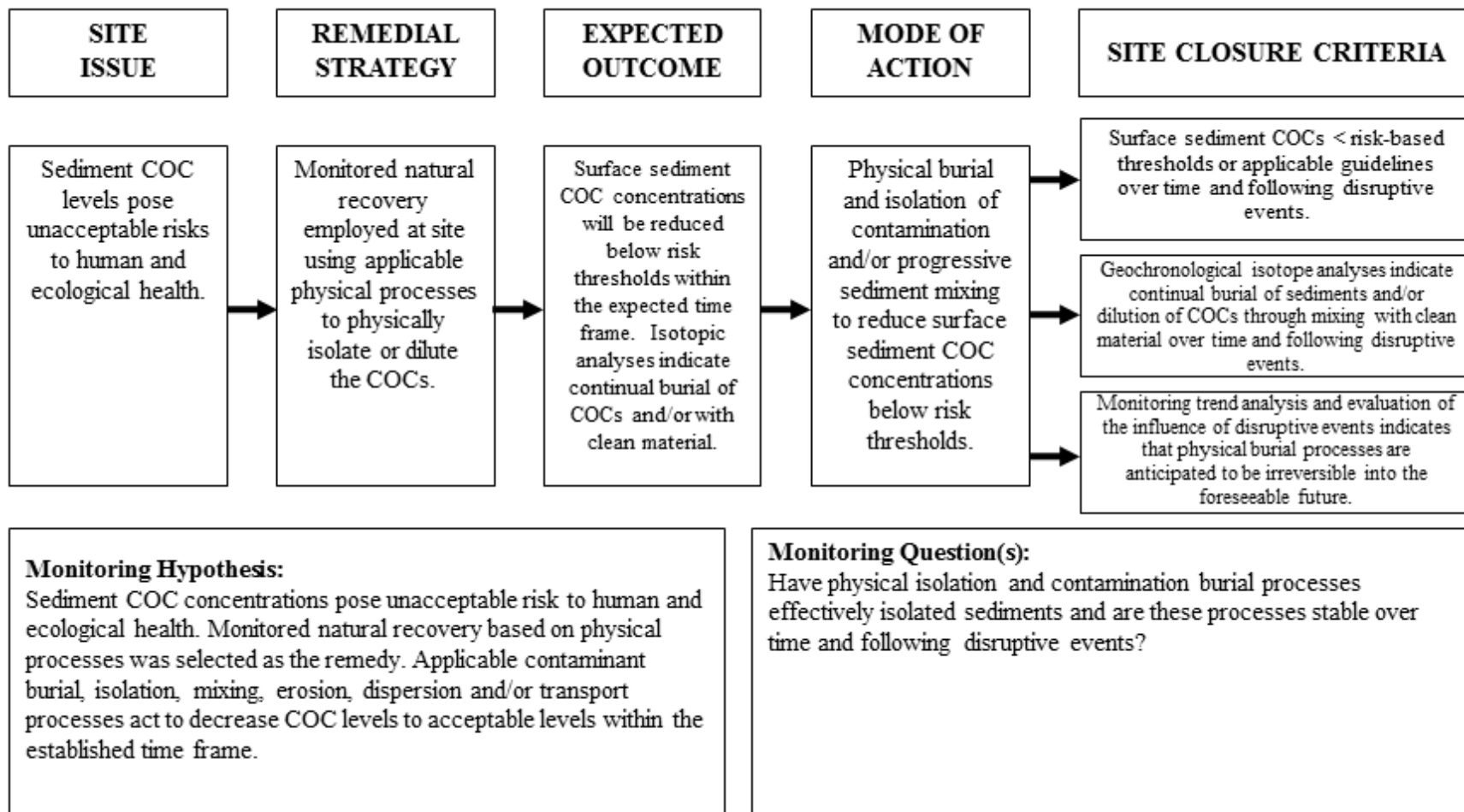
Have physical isolation and contamination burial processes effectively isolated sediments and been observed to be stable? 5. Does the chemical flux from the remaining contaminated sediment into the water column stay within acceptable site risk levels?

For each of the relevant processes, the rate at which it is occurring may be compared to site-specific estimates to determine if remedial performance is proceeding as predicted to meet risk-based goals within an established time period (Magar et al., 2009). For example, if physical natural recovery processes such as burial and isolation were involved in the MNR strategy for a site, the sediment stability could be monitored using cohesiveness and shear strength indicators to ensure that there is not a risk of contaminant breakthrough after erosion (Magar and Wenning, 2006). Alternatively, if chemical or biological transformation was a component of the MNR strategy, monitoring would be undertaken to deduce the toxicity of generated species from the transformation as well as their geochemical stability in the site environment and their likelihood for reactions to reverse given specific site conditions. Regardless of specific physical natural recovery processes applicable for the site, the sediment's physical stability during recovery should be monitored (SPAWAR and ENVIRON, 2010). More information regarding the specific lines of evidence that could be incorporated into MNR can be found in Magar et al. (2009). Lists of monitoring tools that are appropriate for assessing physical and chemical processes of natural recovery are found in the on-line ISRAP sediment monitoring matrix (SPAWAR and ENVIRON, 2010). An example of a monitoring conceptual model for physical isolation natural recovery processes is found in Figure IV-3.

In addition to monitoring these site-specific processes, monitoring should also be carried out to assess the chemical integrity of remaining contaminated sediments by monitoring

the chemical flux from these sediments into the water column. Monitoring data is used to fully characterize the chemical flux process and evaluate risk reduction as MNR progresses. A list of monitoring tools to assess this monitoring objective is also found in the on-line ISRAP sediment monitoring matrix (SPAWAR and ENVIRON, 2010). Common indicators include the chemical analysis of sediment or porewater samples.

Additional long-term monitoring considerations may be incorporated for enhanced monitored natural recovery processes. If thin-layer sediment application is utilized, indicators for physical processes such as cap material mixing with underlying sediments, cap erosion and consolidation would also be considered (Merritt et al., 2010; SPAWAR and ENVIRON, 2010). Supplementary ecological recovery indicators would also be incorporated to consider the effects of capping materials on benthic community recovery. Unlike traditional capping, the cap thickness may not be monitored since containment is not a concern and partial or complete sediment cover will encourage physical isolation processes (SPAWAR and ENVIRON, 2010).



**Figure IV-3: Example of a monitoring conceptual model for performance monitoring of Monitored Natural Recovery (MNR) using contaminant burial and isolation (after USEPA, 2004)**

### **c. Spatial and temporal considerations for performance monitoring**

Monitored natural recovery will require more monitoring during the initial recovery phase (*i.e.*, before attainment of the remedial goals), which may last years or decades, and can be reduced during later performance and remedial goal monitoring (SPAWAR and ENVIRON, 2010; USEPA, 2005). The US EPA recommends period reviews every five years during long term monitoring of aquatic risk-indicators (USEPA, 2005). Event-based monitoring should also be incorporated to investigate possible risk associated with contaminant release following high-energy site disruptions, such as storms, high winds or ice scour, especially if burial or isolation processes were dominant on the site (Magar et al., 2009; SPAWAR and ENVIRON, 2010; USEPA, 2005). Recommendations regarding the temporal level of effort required for specific monitoring considerations are also outlined in the ISRAP sediment monitoring matrix on-line tool and are summarized in Table IV-2. For all objectives, monitoring is undertaken on a temporal basis during the natural recovery process until the processes being monitored can be fully characterized or the consequences of the examined process for risk reduction can be predicted (SPAWAR and ENVIRON, 2010). Magar et al. (2009) also emphasizes the importance of event-based monitoring until certainty has been achieved regarding the resiliency of natural recovery processes to disruptive events.

Spatially, long term monitoring efforts should be focused in areas that are most susceptible to the slowing or reversal of MNR processes (Magar et al., 2009). While a site may have only one or all natural recovery processes operating, the dominant natural recovery mechanism often differs within the site depending on the specific location. For example, in a high energy, main channel area of a water body, dispersal may be the dominant mechanism operating, and thus monitoring efforts should focus on indicators of dispersion success for that location. In contrast, in low energy environments within the site, deposition resulting in a high rate of sedimentation should be monitored as it is facilitating burial of contaminated sediment (Magar et al., 2009). Monitoring should also be undertaken downstream of the contamination hot spots to ensure that any dispersal processes are not introducing substantial risk to off-site locations (ASTSWMO, 2009).

**Table IV-2: Recommendations regarding the timeframe and frequency of performance monitoring required for Monitored Natural Recovery (MNR) monitoring objectives**

Monitoring indicator	Monitoring timeframe	Monitoring frequency
Chemical integrity (chemical flux)	Temporal	Annually or more frequently to establish long-term trend
Chemical recovery processes	Temporal or event-based	Every 1–5 years, or following disruptive events
Physical recovery processes	Temporal or event-based	Every 1–5 years, or following disruptive events

*Adapted from Magar et al., 2009; SPAWAR and ENVIRON, 2010; USEPA, 2005*

#### **d. Site closure considerations**

Generally, if the site has met remedial goals and performance-based objectives, long-term monitoring of an MNR site can proceed to closure. Process-specific considerations also need to be taken into account for site closure. For sites remediated using natural chemical transformation processes, site closure can proceed if the contaminant is degraded to meet remedial goals and there is confidence that the transformation is irreversible. If binding, precipitation or sequestration processes were used to reach remedial goals, site closure can be achieved when binding processes are demonstrated to be stable given the site's current and future geochemical conditions. Sites that rely on physical isolation and contamination burial processes and still have contamination on site may be able to terminate performance monitoring after the isolated contaminated sediment has been observed to be stable for many years and after numerous high-energy events (Magar et al., 2009).

### **3. Dredging**

#### **a. Strategy overview**

Dredging is used to remove contaminated sediments from a water body and is often applied as part of navigational and environmental management strategies (NRC, 2007). The environmental dredging process involves equipment mobilization and set up, site preparation, and sediment removal and rehandling (Palermo et al., 1998). Removed sediment can then be treated or destroyed, although it is often disposed in landfills, near-shore confinement facilities or in confined aquatic disposal facilities (USEPA, 2005; SPAWAR, 2003).

Although there has been a historic preference of contamination removal, dredging alone is presently viewed as an ineffective strategy for low sediment concentration goals due to unavoidable residual contamination, resuspension, and contaminant release (Bridges et

al., 2010; NRC, 2007; SPAWAR and ENVIRON, 2010). Thus, environmental dredging often necessitates follow-up management technologies such as backfilling, monitored natural recovery or capping to meet remedial goals (ASTSWMO, 2009; NRC, 2007; SPAWAR and ENVIRON, 2010). Backfilling adds clean material to cover and mix with residual contaminated sediments to reduce risk (NRC, 2007).

#### **b. Performance monitoring indicators**

Long-term monitoring to address the effectiveness of sediment replacement strategies or on-site contaminated sediment disposal facilities is recommended. Dredging can lead to specific processes that generate on-site risks, as outlined in Box IV-6. The resuspension and release of contaminated sediments creates short-term risks, while residual contamination is of potential concern over the long-term (NRC, 2007). The presence of residual contamination would typically be identified through confirmation sampling during remedial activities. If residual generation is a concern, it is usually addressed by secondary strategy application such as MNR or capping and their respective performance monitoring strategies.

#### **Box IV-6: Contaminant resuspension, release and residual generation processes**

- Resuspension: Dislodgment of embedded sediment
- Release: Movement of contaminants from sediment and pore water into the water column.
- Residual Generation: Generated residuals result from the redeposition of dislodged or suspended sediments from resuspension and release processes. Undisturbed residuals were not uncovered or removed by dredging.
- For information about site conditions that influence these processes, see NRC (2007).

*Adapted from: NRC, 2007; Palermo et al., 1998; Bridges et al., 2010.*

Potential performance monitoring objectives related to dredging are shown in Box IV-. Biological monitoring would be incorporated into monitoring programs for ecosystem recovery. If follow-up methods such as capping, backfilling or MNR are utilized to address residual contamination, monitoring should be conducted to ensure that the remedial strategy is functioning as designed to reach site goals, as discussed in earlier sections of this report. If sediment replacement is used to restore water levels following dredging, monitoring of water depth and replacement material thickness, consolidation and stability is recommended on a regular basis until the sediment has achieved the

stability of the original location (ASTSWMO, 2009). Any in-water or upland disposal facilities utilized should also be monitored to ensure no contaminant release occurs and that the structures remain intact. Specific indicators recommended for monitoring these facilities include: disposal unit integrity, groundwater, surface water, and sediment or soil monitoring (USEPA, 2005a; NRC, 2007); an example of a monitoring conceptual model is provided in Figure IV-4.

**Box IV-7: Performance monitoring objectives for dredging (after USEPA 2004)**

1. Do aquatic or land-based engineered contaminant disposal facilities on site effectively contain contamination and remain intact?
2. Have sediment-replacement initiatives proceeded successfully to achieve the depth, thickness and stability of original sediment bed?

**c. Spatial and temporal considerations for performance monitoring**

Compared to other remedial technologies, dredged locations require the least level of effort for monitoring because contaminated sediments are generally removed from the site (ASTSWMO, 2009; NRC, 2007). However, greater monitoring effort would be required in situations where an engineered containment facility (ECF) is used for dredged sediment disposal *in situ*. Regardless of ECF use on site, sites located near or in shorelines, at shallow water depths or in wetland areas generally require more monitoring than deeper areas as they are more likely to have diverse biota populations as well as be susceptible to weather events (ASTSWMO, 2009). Additional spatial considerations for monitoring include: sampling beyond silt curtains used at the dredging perimeter; conducting studies both up and downstream of dredging areas; and monitoring chemical indicators in deeper locations of lower energy (ASTSWMO, 2009; NRC, 2007).

The EPA requires that monitoring be conducted at a minimum of every five years (USEPA, 2005). However, monitoring of ECFs should also be conducted following extreme weather events (e.g., floods) and other erosion events. Under adaptive management protocols, it is recommended that a review of monitoring decision points for site closure should be conducted on a regular basis, as shown in Table IV-3.

**Table IV-3: Recommendations regarding the frequency of performance monitoring required for dredging**

<b>Monitoring objective</b>	<b>Monitoring timeframe</b>	<b>Monitoring approach</b>	<b>Monitoring frequency</b>
Integrity of contaminated disposal facilities	Perpetually	Temporal or event-based	Every 1–5 years or following disruptive events
Sediment replacement initiatives	After one monitoring round	N/A	Once

*Adapted from ASTSWMO, 2009; NRC, 2007; US EPA, 2005.*



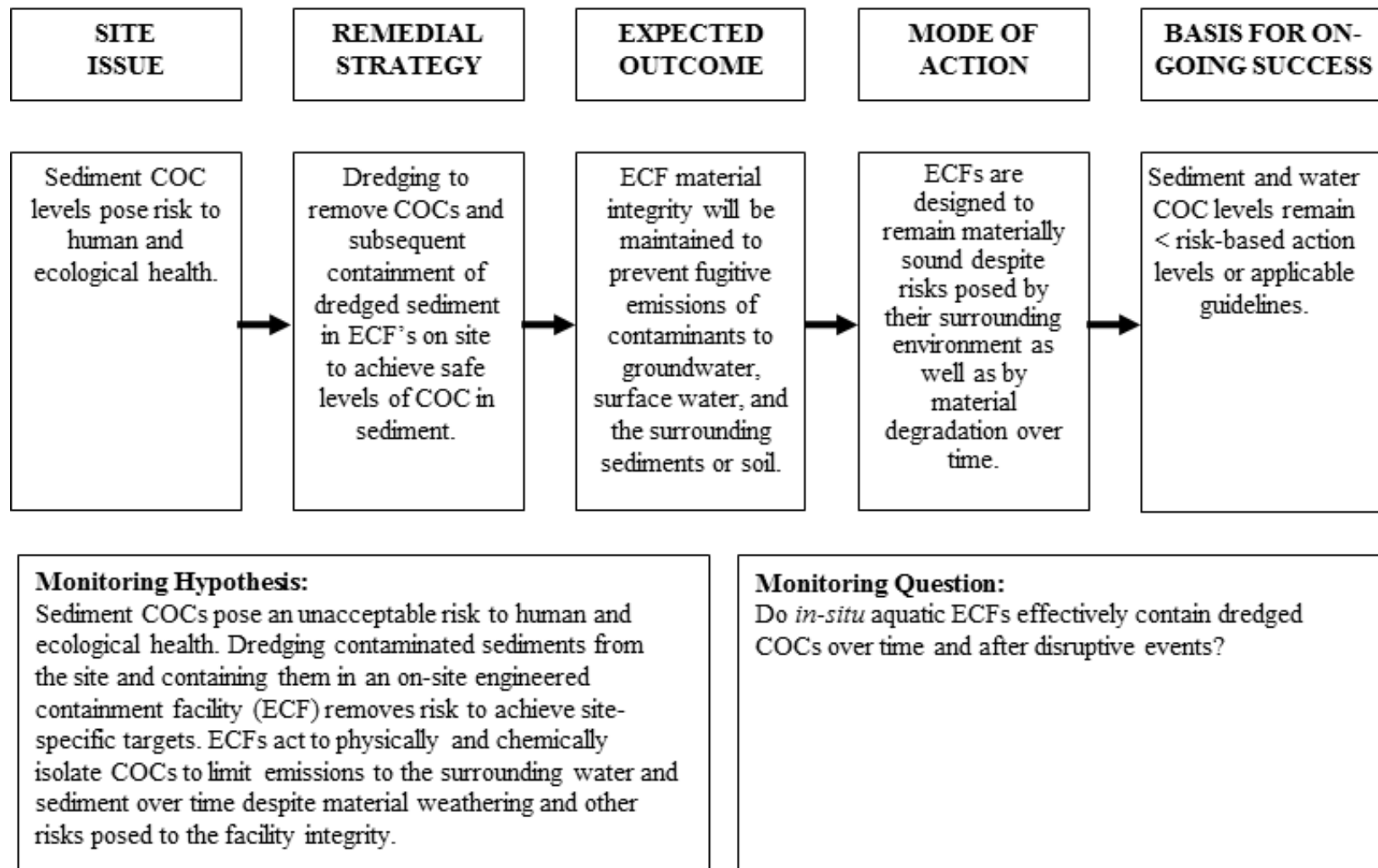


Figure IV-4: Example monitoring conceptual model for monitoring the integrity of on-site disposal facilities for dredged sediments (after USEPA, 2004)

#### **d. Site closure considerations**

Monitoring will be ongoing if any contamination remains on site that poses risk above the remediation guidelines or if monitoring structures, such as ECFs, exist that require ongoing maintenance (ASTSWMO, 2009; USEPA, 2005). Policy in the US (Comprehensive Environmental Response, Compensation and Liability Act, CERCLA, and the National Oil and Hazardous Substances Pollution Contingency Plan, NCP) requires that if these conditions exist, performance monitoring should be conducted at least once every five years into perpetuity. Otherwise, once performance-specific goals have been reached, long term performance monitoring can be concluded.

### ***4. In situ treatment***

#### **a. Strategy overview**

*In situ* treatment encompasses a variety of physical, chemical and biological technologies that can be used to amend sediments in place by reducing or eliminating their toxicity or bioavailability (ASTSWMO, 2009; SPAWAR, 2003). While there are advantages to treating sediment in place, such as a reduced contaminant handling, risk of resuspension and volatilization, as well as an ability to address fluid-phase contaminants, *in situ* treatment options have been used at few contaminated sites to date (Renholds, 1998; SPAWAR, 2003). Their current limitation is a result of the complicated nature of sediment treatment compared to soil treatment or other non-treatment remedial options.

*In situ* remediation technologies that are currently in practice include immobilization by solidification or stabilization, chemical treatment, and bioremediation. Although solidification and stabilization are not considered accepted sediment treatment approaches, they have been utilized on small scales to treat metal contamination by injecting agents such as cement or fly ash to sediments (USEPA, 1994; NRC, 1997; Renholds, 1998). Bioremediation provides amendments such as oxygen, nutrients or microorganism inoculants to stimulate microbial degradation of organic contaminants in the sediment (Knox et al., 2008; NRC, 1997; SPAWAR, 2003). Sediment bioremediation demonstrations have been undertaken at the experimental and field scales, although further research is needed to address microbial, geochemical and hydrological issues associated with this strategy (USEPA, 1994; NRC, 1997). Chemical treatment methods deliver agents to detoxify contaminants by means of direct injection, gas-permeable membranes or chemically reactive caps. Reactive capping aims to stabilize contaminants, lower contaminant bioavailability and reduce contaminant release into the water column by placing layers containing active amendments, possibly mixed with natural substrates or other inert materials, over contaminated sediment (Paller and Knox, 2010). Imbedded amendment layers contain sequestering agents to target specific contaminants and can include rock phosphates, organoclays, zeolites, clay minerals or biopolymers (Knox et al., 2010). While chemical treatment technologies are not considered reliable compared to

traditional remediation methods, reactive capping has been utilized in field trials and is perceived to have great potential as a permanent remedial solution (Knox et al., 2006).

**b. Performance monitoring indicators**

*In situ* treatments cover a large range of methods and processes, and the set of appropriate monitoring indicators would depend on which treatment is used at the site. Considering the limited application of *in situ* treatment technologies and doubts regarding their long-term effectiveness, performance monitoring is crucial to ensure the achievement of remedial objectives. To develop an appropriate long-term monitoring plan to address performance-based success, it is important to consider possible risks associated with each technology and subsequently develop relevant monitoring objectives and approaches to address them. Examples of common treatment processes, associated potential site risks, and general monitoring considerations have been highlighted in Table IV-4. An example of the monitoring objectives and a monitoring conceptual model for reactive capping is provided in Box IV- and Figure IV-5.

**Table IV-4: Main categories of *in situ* treatment and associated processes of concern and monitoring considerations**

Category and general aim		Description	Strategy-associated processes of concern	Comparable traditional technology	General monitoring considerations
Immobilization - Reduce contaminant mobility in place	Solidification	- Additions to physically bind contaminants and convert sediment to block with high structural integrity	- Erosion - Increase in sediment volume, possible impact on dissolution and advection processes (site geochemical conditions) - Flux of contamination from sediment surface to water column	Capping	- Physical integrity - Chemical integrity (chemical flux) - Impact on site hydrodynamics and sediment transport
	Stabilization	- Additions to reduce solubility or mobility of contaminants, with or without changing the physical characteristics of the treated material			
Bioremediation - Promote natural biological processes to reduce toxicity		- Addition of microorganisms and/or chemicals to sediments to initiate or enhance bioremediation	- Changes in site conditions inhibiting processes - Product toxicity, bioavailability and mobility - Transformation reversibility - Achievement of desired transformation rates - Flux of contamination from sediment surface to water column	MNR	- Chemical recovery processes - Chemical integrity (chemical flux)
Chemical treatment - Detoxify or immobilize contaminants in place	Reactive capping	- Place layers containing active amendments, possibly mixed with natural substrates or other inert materials, over contaminated sediment	- Erosion - Flux of contamination from sediment surface to water column - Impact of additions on dissolution and advection processes (site geochemical conditions) - Reversibility of detoxification and immobilization reactions - Achievement of bioavailability and toxicity reduction	Capping and MNR	- Physical integrity - Chemical integrity (chemical flux) - Impact on site hydrodynamics and sediment transport - Chemical recovery processes
	Direct injection	- Inject reactors for abiotic treatment into sediment subsurface			
	Gas-permeable membranes	- Reactants delivered using gas-permeable membranes			

*Adapted from ASTSWMO, 2009; Madalski, 2008; Magar et al., 2009; Magar and Wenning, 2006; NRC, 1997; Renholds, 1998; SPAWAR and ENVIRO*

**Box IV-8: An example of performance monitoring objectives for *in situ* treatment using reactive capping (after USEPA 2004)**

1. Is the chemical integrity of capping material maintained over time and following disruptive events to ensure that risk posed by the contaminated sediment does not pose concern?
2. Is physical integrity of capping material maintained over time and in variable site conditions?
3. Is the impact of the cap on site hydrodynamics and sediment transport acceptable and as predicted?
4. Have chemical transformation processes occurred as expected to meet remedial goals and is there confidence that they are irreversible?

As outlined in Table IV-4, effective indicators for *in situ* treatments generally include those used for MNR, such as monitoring applicable chemical or biological transformation, binding, precipitation or sequestration processes stimulated by a specific treatment method. In the case of immobilization as well as chemical sediment treatment, similar considerations to traditional capping would be incorporated to monitor the stability and contaminant flux of the engineered components, in addition to their possible impact on hydrodynamics. Additional ecological considerations would be incorporated into ecological and habitat recovery monitoring to consider the potential ecological impacts of chemically active amendments, such as toxicity and pH changes as well as changes in sediment texture and particle size (Paller and Knox, 2010).

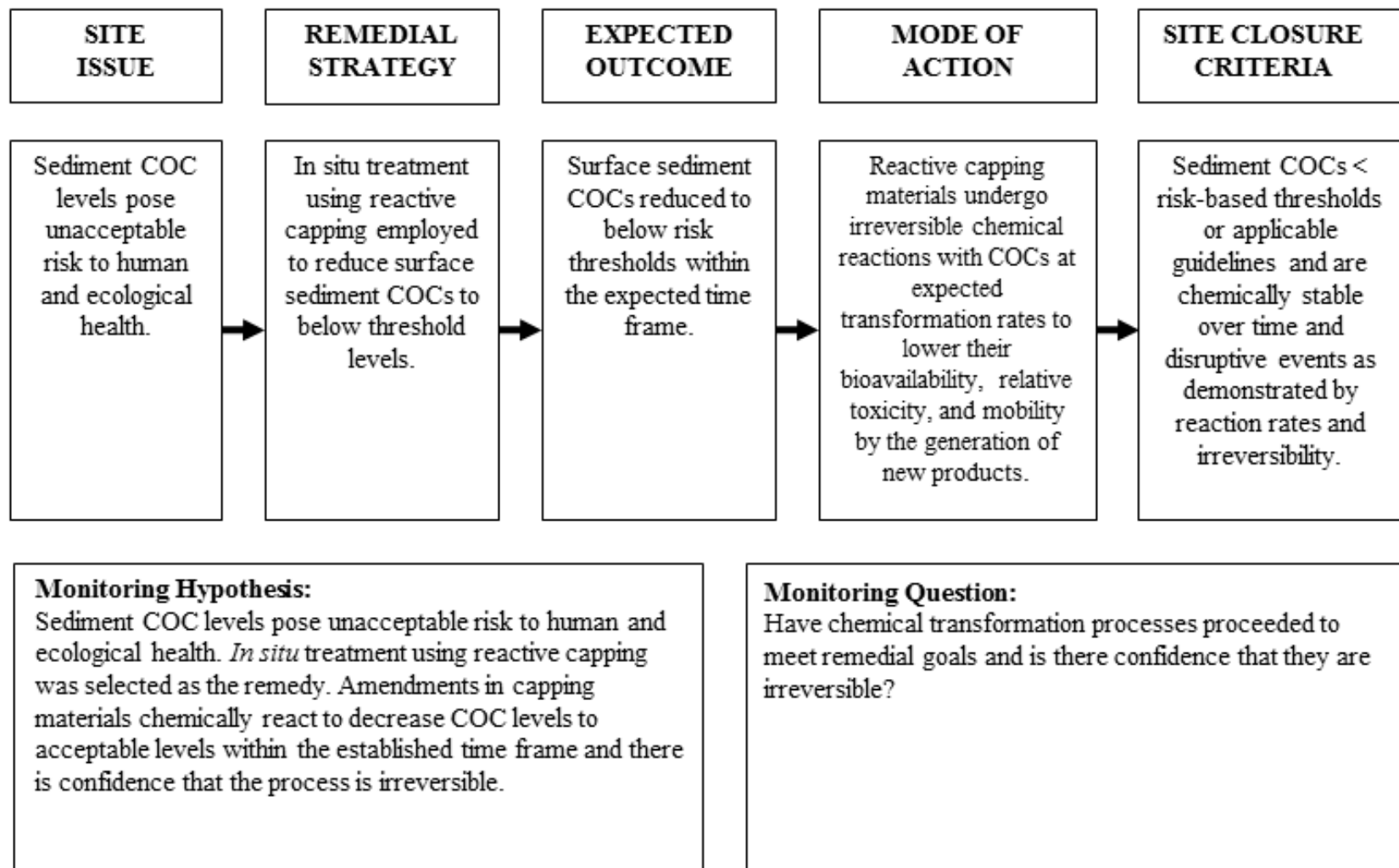


Figure IV-5: Example of a monitoring conceptual model for reactive capping as an *in situ* treatment (after US EPA, 2004)

**c. Spatial and temporal considerations for performance monitoring**

Given the broad range of methods covered by *in situ* treatment strategies and the complementary range of performance-based monitoring objectives, there are also many factors affecting the spatial and temporal level of effort required for monitoring. Generally speaking, event-based and temporally based monitoring should be undertaken to monitor any applicable chemical recovery processes as well as the physical stability or integrity of any amendments associated with the technology. Temporal monitoring should be conducted regarding the possible contaminant flux from sediment into the water column and a one-time only assessment should be done regarding the potential impact of sediment amendments on hydrodynamics and sediment transport. These temporal considerations for monitoring are summarized in Table IV-5. Spatial considerations for monitoring would also be specific to the treatment approach utilized. For example, if amendment addition was a component of the treatment process, monitoring should be conducted both upstream and downstream of the amended area as well as within the amended sediment and along its edge.

**Table IV-5: Recommendations regarding the temporal level of effort required for performance monitoring of *in situ* treatments**

<b>Monitoring objective</b>	<b>Monitoring timeframe</b>	<b>Monitoring approach</b>	<b>Monitoring frequency</b>
Physical integrity	Perpetually	Temporal or event-based	Every 1–5 years, or following disruptive events
Chemical integrity	Perpetually	Temporal	Every 1–5 years
Amendment impact on hydrodynamics and sediment transport	After one monitoring round	N/A	Once
Chemical recovery processes	Until contaminant in irreversibility	Temporal or event-based	Every 1–5 years, or following disruptive events

*Adapted from Magar et al., 2009; SPAWAR and ENVIRON, 2010; USEPA, 2005*

#### **d. Site closure considerations**

Generally, if the site has met remedial goals and performance-based objectives, long-term monitoring following *in situ* remediation can proceed to closure. Performance goal completion and subsequent site closure procedures will be specific to the type of *in situ* treatment used. Due to the limited application of these technologies outside of a research setting, little guidance is available regarding site closure procedures following *in situ* treatment. Generally, process-specific considerations would need to be geared to support the specific treatment strategy utilized. Performance monitoring completion would be based on the achievement of objectives established to address performance-associated risks outlined in Table IV-4 such as those provided in the example in Box IV-. Monitoring objectives for various *in situ* capping technologies can be similar to those for traditional treatment technologies, especially for capping and MNR processes.

The US EPA requires that while contaminants remain on site, prior to the completion of *in situ* treatment performance-monitoring objectives, monitoring must be conducted at least once every five years. For sites remediated using chemical or biological transformation treatment methods, site closure can proceed if the contaminant is degraded to meet remedial goals and there is confidence that the transformation is irreversible. If isolation treatment methods were used to reach remedial goals, site closure for performance monitoring can be achieved when binding processes are demonstrated to be stable given the site's current and future geochemical conditions.

#### **D. Tools for monitoring ecosystem recovery**

Long-term monitoring following remediation also involves monitoring ecosystem recovery and ensuring that human and environmental risks continue to meet the remedial objectives. Similar needs related to ecosystem recovery may be identified for all remedial strategies employed (i.e., monitoring needs for ecosystem recovery are generally not strategy-specific). The following section identifies common monitoring objectives for ecosystem recovery and the associated subset of monitoring tools appropriate for each objective.

The on-line ISRAP sediment monitoring tools matrix (see description in Section IV.B above) addresses the following list of monitoring objectives for ecosystem recovery (listed as remedial goals; SPAWAR and ENVIRON, 2010):

- Assessment of bioaccumulation potential to benthic and/or pelagic species
- Assessment of bioaccumulation potential to aquatic-dependent, terrestrial wildlife, including birds and mammals
- Assessment of benthic and/or pelagic ecological recovery over time



- Assessment of toxicity to benthic and/or pelagic species
- Assessment of exposure of bioavailable chemicals to humans via consumption of aquatic organisms
- Assessment of benthic physical habitat

Selection of each of these monitoring objectives identifies a list of monitoring tools that are appropriate for each; these tools can then be compared using the decision matrix outlined in Section IV.B.

While the monitoring objectives for ecosystem recovery contained in ISRAP are comprehensive, there are several additional needs that can be added to the list as follows:

- Assessment of human exposure to contaminants via contact with abiotic media (e.g., dermal exposure, drinking water)
- Amelioration of physical impacts on the water body resulting from site use (e.g., increased suspended solids)
- Assessment of physical and chemical habitat recovery
- Assessment of recovery of aquatic productivity
- Improved conditions for Species at Risk

Many of these needs provide Canadian context to the ISRAP sediment monitoring matrix, such as compliance with the Fisheries Act and Species at Risk legislation, as well as Health Canada guidance for conducting Human Health Risk Assessments. They also reflect the mandate of DFO ES to provide specialized advice to custodians of federal contaminated sites concerning the management of aquatic habitat, populations of fish and other aquatic organisms, and fisheries resources. These additional monitoring needs and associated monitoring tools are discussed in the following sections.

#### ***1. Assessment of human exposure to contaminants via contact with abiotic media***

The applicable exposure pathways and associated human health risks for contaminants of concern at the contaminated site should have been identified prior to remediation/risk management through a human health risk assessment. In some cases, dermal contact with sediments or consumption of water from the site may represent a potential risk for human receptors. The goal for monitoring and site closure, therefore, is the on-going reduction of risks from these pathways to acceptable levels. The appropriate monitoring tool for doing so is the measurement of COC concentrations in media related to the exposure pathway of concern (e.g., sediments for assessing risks through dermal contact; surface water samples for assessing risks through water consumption); a summary is presented in Table IV-6.

Table IV-7 summarizes screening criteria related to monitoring plan design for assessing exposure of humans to chemicals via contact with abiotic media. In general, with respect to this monitoring objective, the chemical analysis of water and sediment samples is a very common and easily interpreted monitoring tool; however, the timing and frequency of sample collection (especially for surface water samples) is not always evident because of seasonal and environmental fluctuations in sediment and water quality. This variability should be taken into account in the monitoring plan design. Decisions regarding the number of samples to collect and monitoring locations (i.e., spatial complexity) require knowledge of the spatial patterns in contaminant distribution across the site. Information from previous site characterization studies and from the human health risk assessment should be used to guide development of the sampling plan for the monitoring program. In addition, using sampling locations and methodology similar to that used in previous studies enables the comparison of monitoring results to pre-remedial baseline data and facilitates detection of temporal trends.

**Table IV-6: Monitoring tools for assessing exposure of humans to chemicals through contact with abiotic media (based on the Interactive Sediment Remedy Assessment Portal sediment monitoring tools matrix; SPAWAR and ENVIRON, 2010)**

<b>Monitoring tool</b>	<b>Description</b>	<b>Type</b>	<b>Commonality of tool use</b>	<b>Special considerations</b>	<b>Methodology references</b>
Sediment and water chemical analyses	Chemical analysis of discrete sediment samples obtained by grab analysis or discrete water samples	Chemical	Very common	<ul style="list-style-type: none"> <li>• Sediments typically have high levels of heterogeneity in contaminant concentrations</li> <li>• Surface water chemical concentrations show high seasonal and temporal variability</li> </ul>	USEPA (1995; 2001c; 2003a; 2007d)

**Table IV-7: Screening criteria for the selection of tools for monitoring exposure of humans to chemicals through contact with abiotic media (based on the Interactive Sediment Remedy Assessment Portal sediment monitoring tools matrix; SPAWAR and ENVIRON, 2010)**

<b>Monitoring tool</b>	<b>Spatial complexity</b>	<b>Temporal complexity</b>	<b>Logistical complexity</b>	<b>Difficulty locating in market</b>	<b>Relative cost</b>	<b>Required interpretation expertise</b>	<b>Uncertainty addressing need</b>
Sediment and water chemical analysis	Medium	Medium	Low	Low	Low	Low	Low

## ***2. Amelioration of physical impacts on the water body related to site use***

Contaminated site activities may also impact aquatic environments through physical means. For example, increases in total suspended solids (TSS) in the water column may occur through shoreline erosion or sediment resuspension during the application of aquatic remedies such as dredging and capping. Increased TSS have been associated with a wide range of ecosystem effects, including declines in aquatic primary productivity through reduction in light penetration depth and abrasive damage to macrophytes and periphyton; decreased invertebrate abundance due to abrasive effects or substrate changes; and reductions in reproductive success of salmonid fish due to deposition of SS in gravel-bed river habitat required for developing eggs and larvae, as well as direct effects on fish due to clogging of gills and abrasive actions (Newcombe and MacDonald, 1991; Galbraith et al., 2006; Bilotta and Brazier, 2008; Collins et al., 2010). Factors determining the effect of TSS on aquatic biota include the concentration of SS; the duration of exposure to SS concentrations; the chemical composition of SS; and the particle-size distribution.

Monitoring tools appropriate for assessing changes in TSS concentrations in the water column are summarized in Table IV-8; a decision matrix comparing important monitoring plan design elements for the possible monitoring tools is presented in Table IV-9. A combination of both continuous monitoring using probes and the collection of discrete samples for TSS analysis can be appropriate, as the two methods provide complementary information. Decisions regarding the timing and frequency to collect discrete samples for TSS can be complicated because of the temporal variability in TSS concentrations within water bodies. Continuous suspended sediment monitoring captures this variability, but calibration of turbidity measures against TSS concentrations from discrete samples is needed for data interpretation. Biomonitoring methods (e.g., benthic macroinvertebrates) may also be appropriate for long-term monitoring of TSS in a water body as they integrate effects over time and space. However, the relationship between TSS concentrations and ecological effects is not always clear (Newcombe and MacDonald, 1991; Bilotta and Brazier, 2008) and a good understanding of potential confounding factors influencing ecological responses is needed.

**Table IV-8: Potential tools for monitoring the recovery from physical impacts related to increased total suspended solids (based on the Interactive Sediment Remedy Assessment Portal sediment monitoring tools matrix; SPAWAR and ENVIRON, 2010)**

<b>Monitoring tool</b>	<b>Description</b>	<b>Type</b>	<b>Commonality of tool use</b>	<b>Examples of possible measures</b>	<b>Special considerations</b>	<b>Methodology references</b>
Continued suspended sediment monitoring	Continuous water column sampling; uses optical or acoustic probes to monitor for exceedance of water quality criteria	Physical	Common	<ul style="list-style-type: none"> <li>- Turbidity</li> <li>- Total suspended solids</li> <li>- Particle size</li> </ul>	<ul style="list-style-type: none"> <li>- Optical and acoustic tools require calibration of outputs against physical measures of suspended sediment concentration</li> </ul>	USEPA (2003a; 2007b)
Discrete suspended sediment monitoring	Discrete water column sampling for physical measurements	Physical	Common	<ul style="list-style-type: none"> <li>- Turbidity</li> <li>- Total suspended solids concentration</li> <li>- Particle size</li> </ul>	<ul style="list-style-type: none"> <li>- Discrete water sample may not represent all conditions</li> <li>- Continuous monitoring is preferred, although discrete monitoring can be used to provide calibration data for continuous monitoring</li> </ul>	USEPA (2003a, 2007b)
Macro-invertebrate community analysis	Taxonomic census of benthic macro-invertebrate community analysis	Biological	Rare	<ul style="list-style-type: none"> <li>- Presence/absence</li> <li>- Diversity</li> <li>- Index of biotic integrity</li> <li>- Multivariate</li> </ul>	<ul style="list-style-type: none"> <li>- Sampling methods vary depending on substrate conditions</li> <li>- Must be paired with evaluation of physical habitat quality</li> </ul>	USEPA (2003a, 2007c)

**Table IV-9: Screening criteria for the selection of tools for monitoring the recovery from physical impacts related to increased total suspended solids (based on the Interactive Sediment Remedy Assessment Portal sediment monitoring tools matrix; SPAWAR and ENVIRON, 2010)**

<b>Monitoring tool</b>	<b>Spatial complexity</b>	<b>Temporal complexity</b>	<b>Logistical complexity</b>	<b>Difficulty locating in market</b>	<b>Relative cost</b>	<b>Required interpretation expertise</b>	<b>Uncertainty addressing need</b>
Continuous suspended sediment monitoring	Medium	Medium	Medium	Low	Medium	Medium	Low
Discrete suspended sediment monitoring	Medium	Low	Low	Low	Low	Low	Medium
Macro-invertebrate community analysis	Medium	High	Medium	Low	Medium	High	Medium to High

### ***3. Assessment of physical and chemical habitat recovery***

Physical disturbances and the presence of contaminants at aquatic contaminated sites often result in degraded habitat for aquatic organisms. Furthermore, active remedies such as dredging or capping alter the physical characteristics of the site bottom and remove or cover existing benthic communities, requiring re-establishment of benthic macroinvertebrates and algal communities. The need to monitor habitat recovery associated with these aspects of aquatic contaminated site remediation is separate from habitat compensation required for Fisheries Act authorization, which results from a potential harmful alteration, disruption or destruction (HADD) of fish habitat associated with construction activities. However, many of the principles used to determine the effectiveness of habitat compensation strategies (see summary in Pearson et al., 2005) can be applied in the design of monitoring programs for habitat recovery associated with the remediation of aquatic sites.

In its simplest definition, habitat has been equated with physical and chemical conditions, such as bottom substrate type or dissolved oxygen concentrations (Hayes et al., 1996; Maddock, 1999; Diaz et al., 2004). These physical and chemical characteristics are readily measured and easily compared between different locations. However, habitat quality, or “the ability of a habitat to sustain individuals of a particular species and support population growth” (Rosenfeld and Hatfield, 2006), also incorporates ecological parameters such as the availability of prey, abundance of competitors, predators, and

refuges. These parameters are much more difficult to quantify and compare. As a result, overall aquatic productivity is often used as a surrogate measure for habitat quality. In this document, monitoring tools for assessing the physical and chemical habitat for aquatic organisms are presented in the current section (Assessing physical and chemical habitat recovery); biological monitoring tools and metrics for assessing the recovery of aquatic habitat productivity are presented in Section IV.D.4. Both types of monitoring programs should be carried out concurrently as they provide complementary information to evaluate overall aquatic habitat recovery.

Several considerations are important when designing a program for monitoring habitat recovery. First, habitat requirements are species-specific: good quality habitat for macroinvertebrates may not necessarily be good quality habitat for fish species (Diaz et al., 2004). Target organisms or living resources for protection should therefore be identified before the monitoring program is developed, as this influences both the selection of monitoring tools and the sampling design. The monitoring program should also consider all life stages of the target organisms (e.g., eggs, larvae, juveniles, adults), as different life stages often have different habitat requirements (Rosenfeld and Hatfield, 2006). Second, scale is an important issue in habitat studies. For example, at the microhabitat level (e.g., patches of varying substrates, water depths, and current velocities), habitat characteristics are related to the growth, reproduction, and survival of individual fish (Maddock, 1999). As the scale of disturbance increases, the quantity of good habitat for different life stages, as well as the connectivity between habitats serving different ecological functions (e.g., spawning, feeding, migration, etc.), becomes important in regulating fish population productivity. Targets for habitat restoration and the spatial design for habitat monitoring programs will therefore be dependent on the size of the contaminated site.

Habitat recovery can be viewed as a process that occurs over a relatively long time (i.e., years to decades) and involves a number of different aquatic organism groups. Accordingly, several monitoring questions related to habitat recovery may be identified for monitoring programs. Examples of these are listed below.

- What are the substrate composition and bottom features of the remediated area? Have physical and chemical habitat attributes been established that are comparable to similar reference habitats?
- Are benthic communities (e.g., algae, macroinvertebrates) recolonizing the site? Are the species assemblages and densities/coverage comparable to similar reference habitats?

- Has habitat abundance and distribution (e.g., connectivity of habitats serving different ecological functions) that is protective of the target ecological resources (e.g., fish, shellfish) been restored?

The monitoring tools and time frame required to address these questions will differ, and are discussed in more detail in the following sections.

Under the monitoring need identified as “assessment of benthic physical habitat” (listed under Remedial Goals), the online ISRAP sediment monitoring tools matrix identifies a suite of tools that are commonly used for substrate mapping (see summary in Table IV-10, with decision matrix in Table IV-11). These tools are useful for identifying bottom features and substrate characteristics important for determining the distribution and composition of benthic macroinvertebrate and algal communities, as well as providing visual observations of macroinvertebrate recolonization through underwater photography.

The resolution of habitat characterization varies per monitoring tool: for example, remote sensing can be used to map large areas quickly ( $>1,000 \text{ km}^2 \text{ hr}^{-1}$ ) at low resolution (10 to 1,000 m), while underwater photography is a slower method ( $0.2 \text{ km}^2 \text{ hr}^{-1}$ ) but provides data at higher resolution (0.01 to 1 m; Diaz et al., 2004). The broad scale methods generally provide data regarding sediments and substrates and require ground truthing to verify details, while the small-scale methods are used for ground truthing and providing information about the biological aspects of the habitat (Kenny et al., 2003; Diaz et al., 2004). Medium uncertainty is identified for all of these tools, as most have limitations regarding which physical substrate characteristics can be quantified (see special considerations column in Table IV-10). Both Table IV-10 and Table IV-11 have been augmented with monitoring tools that can be used to provide additional important information regarding benthic physical habitat, such as sediment sampling for grain size and TOC analyses. Collection of these latter parameters should be considered when performing benthic macroinvertebrate and algal community surveys, as these physical and chemical analyses provide supplementary habitat information that is important for data interpretation.



**Table IV-10: Potential tools for monitoring benthic physical habitat recovery (based on the Interactive Sediment Remedy Assessment Portal sediment monitoring tools matrix; SPAWAR and ENVIRON, 2010)**

<b>Monitoring tool</b>	<b>Description</b>	<b>Type</b>	<b>Commonality of tool use</b>	<b>Special considerations</b>	<b>Methodology references</b>
Acoustic profiling	High-resolution cross-sectional survey to detect differences in sediment strata, including presence of worm tubes and fecal mounds	Physical	Rare	<ul style="list-style-type: none"> <li>• Presence of gas in sediment can complicate interpretation of acoustic data.</li> <li>• Ground truthing acoustic data with sediment sampling is recommended.</li> </ul>	USEPA (2003a)
Bathymetric survey	Bathymetric (plan-view) survey of an area	Physical	Rare	<ul style="list-style-type: none"> <li>• Often combined with other acoustic survey methods (e.g., side scan sonar, acoustic profiling).</li> <li>• Can include single-beam (point) or multi-beam (swath) survey.</li> </ul>	Kenny et al. (2003)
Laser line scan imaging	Laser line sediment surface scan to quantify availability and characteristics of habitat features	Physical	Rare	<ul style="list-style-type: none"> <li>• May only be useful for some physical habitat attributes (sea grass beds), but may be capable of viewing some organisms.</li> <li>• Provides higher resolution than acoustic methods, but less detail than sediment profile photography.</li> </ul>	Kenny et al. (2003)
Remote sensing	Remote sensing via satellites and aircraft for near-shore benthic and shallow reef habitats to provide information on seafloor features including corals, sea grass, sand, shellfish beds, and algae	Physical	Very rare	<ul style="list-style-type: none"> <li>• May be limited to shallow sediments and sites with high water clarity.</li> <li>• Detailed and careful ground-truthing is required to validate this method, most often on a site-by-site basis.</li> </ul>	Kenny et al. (2003)

Table IV-10: Potential tools for monitoring benthic physical habitat recovery (based on the Interactive Sediment Remedy Assessment Portal sediment monitoring tools matrix; SPAWAR and ENVIRON, 2010) (cont'd)

<b>Monitoring tool</b>	<b>Description</b>	<b>Type</b>	<b>Commonality of tool use</b>	<b>Special considerations</b>	<b>Methodology references</b>
Sediment coring/grab samples	Collection of sediment samples for geophysical and chemical analyses	Physical and chemical	Common	<ul style="list-style-type: none"> <li>• Limited to soft substrate types</li> <li>• Analysis of grain size and total organic carbon (TOC) useful for interpreting macroinvertebrate data</li> </ul>	USEPA (1995; 2001c; 2003a)
Sediment profile imaging	Sediment profile photography to assess physical habitat (e.g., presence of worm tubes and fecal mounds)	Physical	Common	<ul style="list-style-type: none"> <li>• May be limited to some sediment types (soft bottom sediments)</li> </ul>	USEPA (2003a)
Sediment surface photography	Benthic photography and videography to observe colonization of capped/dredged area by biota and changes in habitat structure at sediment surface; can include use of Remotely Operated Vehicles (ROVs) or SCUBA divers.	Physical	Common	<ul style="list-style-type: none"> <li>• Limited to sediment surface</li> <li>• Site conditions and water column turbidity may complicate utility of tool</li> </ul>	USEPA (2003a)
Side scan sonar	Plan-view scan of sediment surface to quantify availability and attributes of physical habitat	Physical	Rare	<ul style="list-style-type: none"> <li>• May only be useful for some physical habitat attributes (e.g., sea grass beds, snags, fecal mounds)</li> <li>• Ground truthing acoustic data with sediment sampling is recommended</li> </ul>	USEPA (2003a)

**Table IV-11: Screening criteria for the selection of tools for monitoring the recovery of benthic physical habitat (based on the Interactive Sediment Remedy Assessment Portal sediment monitoring tools matrix; SPAWAR and ENVIRON, 2010)**

<b>Monitoring tool</b>	<b>Spatial complexity</b>	<b>Temporal complexity</b>	<b>Logistical complexity</b>	<b>Difficulty locating in market</b>	<b>Relative cost</b>	<b>Required interpretation expertise</b>	<b>Uncertainty addressing need</b>
Acoustic profiling	Low	Medium	Medium	Low	Medium	Medium	Medium
Bathymetric survey	Low	Low	Low	Low	Medium	Medium	Medium
Laser line scan imaging	Low	Medium	Medium	High	High	Medium	Medium
Remote sensing	Low	Medium	Low	Low	Low	Medium	Medium
Sediment coring/grab samples	Medium	Low	Low	Low	Low	Low	Medium
Sediment profile imaging	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Sediment surface photography	Medium	Medium	Medium	Low	Medium	Medium	Medium
Side scan sonar	Low	Medium	Medium	Low	Medium	Medium	Medium

In the context of the Fisheries Act, fish habitat is defined as “the spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes” (DFO, 1986). Important physical and chemical aspects of fish habitat include environmental variables such as dissolved oxygen concentrations, pH, salinity, water temperature, water depth, and water current and flow. While it is unlikely that most of these characteristics would be affected by site activities, measurement of these parameters is important when carrying out fish community surveys to provide important supplementary information on habitat characteristics for data interpretation. In addition to these physical and chemical characteristics, biological parameters such as vegetative cover and prey density (e.g., macroinvertebrate abundance) could also reflect fish habitat quality; monitoring tools for the latter are discussed in Section IV.D.4. The functional use of the habitat (e.g., spawning, rearing young, feeding, migration) for target organisms should also be recorded as part of habitat mapping surveys. Physical methods for assessing fish habitat on a larger scale are discussed in Maddock (1999) and Minns and Wichert (2005).

#### *4. Assessing the recovery of aquatic productivity*

Conservation of aquatic habitat productivity and management of fisheries resources are primary objectives under the mandate of DFO. Productive capacity has been defined as “the maximum biomass of organisms that can be sustained on a long-term basis by a given habitat, analogous to carrying capacity,” or alternately, as “the measure of a habitat to produce fish and/or food organisms in natural or restored conditions” (DFO, 1998, as cited in Quigley and Harper, 2006). Defining and measuring productive capacity is challenging and has received much focus in the scientific literature (e.g., Jones et al., 1996; Minns, 1997; Randall and Minns, 2002; Minns and Moore, 2003; Quigley and Harper, 2006). It has been suggested that productive capacity has both quantitative (i.e., production) and qualitative (i.e., species composition) aspects (Randall and Minns, 2002); for example, two habitats may support the same fish production but different species assemblages. Both measures are therefore important for monitoring programs.

Potential monitoring tools for assessing aquatic habitat productivity and specific considerations for their use are listed in Table IV-12. Measurement endpoints for assessing aquatic production include biomass, abundance/density, catch per unit effort, and yield, while measurement endpoints for assessing community composition include species richness, diversity, and presence/absence of taxa. Univariate metrics, which integrate several measures into one value, may also be used as a measurement endpoint: for example, the Habitat Productivity Index (HPI) or Index of Biotic Integrity (IBI) may also be used to assess community data (Randall and Minns, 2002). Multivariate methods may also be used for data interpretation, although these have been used less commonly because of the need for related statistical expertise in applying these techniques. The use of several monitoring tools is preferable, as this allows for a more complete assessment of aquatic productivity due to the inclusion of organisms from different trophic levels (Minns et al., 1996; Quigley and Harper, 2006). Finally, the above measures of aquatic productivity should be accompanied by an assessment of physical habitat characteristics outlined in Section IV.D.3, as these are important for data interpretation.

The potential monitoring tools for assessing aquatic habitat productivity are compared using the ISRAP screening criteria (see Section IV.B) for monitoring plan design elements in Table IV-13. All of the identified tools show high temporal complexity, meaning that decisions regarding the timing and frequency of monitoring can be complicated by seasonal changes in biological community composition (i.e., different species are found at a site during different times of the year due to varying life history traits). Carrying out the surveys and interpreting the data also requires specialized expertise.

Several monitoring needs related to monitoring aquatic habitat productivity can be identified, with varying timeframes for completion. For example, initial surveys may

assess the re-establishment of benthic communities in capped or dredged areas following remediation. Monitoring of benthic macro-invertebrate and algal communities at sampling stations throughout these areas to ensure that the density and species assemblages were returning to pre-disturbance levels could be anticipated to take several months to several years. Once benthic communities are re-established, later monitoring activities may assess the overall recovery of aquatic habitat productivity (including fish) by performing comparisons with appropriate reference sites.

**Table IV-12: Potential tools for monitoring the recovery of aquatic habitat productivity (based on the Interactive Sediment Remedy Assessment Portal sediment monitoring tools matrix; SPAWAR and ENVIRON, 2010)**

<b>Monitoring tool</b>	<b>Description</b>	<b>Type</b>	<b>Commonality of tool use</b>	<b>Examples of possible measures</b>	<b>Special considerations</b>	<b>Methodology references</b>
Artificial substrate samplers	Artificial substrates to collect periphyton and/or benthic macro-invertebrates	Biological	Common	<ul style="list-style-type: none"> <li>• Biomass</li> <li>• Diversity</li> </ul>	<ul style="list-style-type: none"> <li>• For plants, may only be feasible in the euphotic zone (water depth where enough light penetrates that photosynthesis can occur) such as shallow areas or beaches</li> <li>• Method useful for biological community assessment at sites with hard substrates</li> <li>• Can control for substrate difference between stations</li> </ul>	USEPA (2003a)
Drift net sampling (Kick net sampling)	Macro-invertebrate drift net sampling in lotic (stream) environments	Biological	Rare	<ul style="list-style-type: none"> <li>• Density</li> <li>• Diversity</li> <li>• Index of Biotic Integrity</li> </ul>	<ul style="list-style-type: none"> <li>• Applicable only for the wadeable portion of small streams</li> </ul>	EC (2010); USEPA (2003a)
Fish community analysis	Census of fish population and biomass	Biological	Very common	<ul style="list-style-type: none"> <li>• Biomass</li> <li>• Yield</li> <li>• Diversity</li> <li>• Index of Biotic Integrity</li> </ul>	<ul style="list-style-type: none"> <li>• Sampling methods vary depending on water depth, salinity and/or turbidity</li> <li>• Must be paired with evaluation of physical habitat quality</li> </ul>	USEPA (2003a, 2007a)

Table IV-12: Potential tools for monitoring the recovery of aquatic habitat productivity (based on the Interactive Sediment Remedy Assessment Portal sediment monitoring tools matrix; SPAWAR and ENVIRON, 2010) (cont'd)

<b>Monitoring tool</b>	<b>Description</b>	<b>Type</b>	<b>Commonality of tool use</b>	<b>Examples of possible measures</b>	<b>Special considerations</b>	<b>Methodology references</b>
Macro-invertebrate community analysis	Taxonomic census of benthic macro-invertebrate community analysis	Biological	Common	<ul style="list-style-type: none"> <li>• Density</li> <li>• Diversity</li> <li>• Index of Biotic Integrity</li> </ul>	<ul style="list-style-type: none"> <li>• Sampling methods vary depending on substrate conditions</li> <li>• Must be paired with evaluation of physical habitat quality</li> </ul>	EC (2010); USEPA (2003a, 2007c)
Vegetation survey	Biological survey of algal biomass and taxonomy of periphyton and/or other vegetation in euphotic zone	Biological	Common	<ul style="list-style-type: none"> <li>• Chlorophyll <u>a</u></li> <li>• Biomass</li> <li>• Diversity</li> <li>• Cover</li> </ul>	<ul style="list-style-type: none"> <li>• May only be applicable for the euphotic zone (water depth where enough light penetrates that photosynthesis can occur)</li> </ul>	Hambrook-Berkmann and Canova (2007); USEPA (2007d)

**Table IV-13: Screening criteria for the selection of tools for monitoring the recovery of aquatic habitat productivity (based on the Interactive Sediment Remedy Assessment Portal sediment monitoring tools matrix; SPAWAR and ENVIRON, 2010)**

<b>Monitoring tool</b>	<b>Spatial complexity</b>	<b>Temporal complexity</b>	<b>Logistical complexity</b>	<b>Difficulty locating in market</b>	<b>Relative cost</b>	<b>Required interpretation expertise</b>	<b>Uncertainty addressing need</b>
Artificial substrate samplers	Medium	High	Low	Low	Medium	High	Medium
Fish community analysis	Low	High	Medium	Low	High	High	Low
Macro-invertebrate community analysis	Medium	High	Medium	Low	Medium	High	Medium
Vegetation survey	Medium	High	Low	Low	Medium	High	Medium

### ***5. Improved conditions for species at risk***

The Species at Risk Act (SARA) provides for the legal protection of listed wildlife species and the conservation of associated critical habitat, defined as “the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species’ critical habitat in the recovery strategy or in an action plan for the species.” (EC, 2009) When species at risk are present within the area of the aquatic contaminated site, or were formerly present and have the potential to be reintroduced, protection of rare species and restoration of critical habitat may become an objective of the monitoring program. Potential monitoring needs include monitoring the movement and reproductive success of individual organisms during remedial activities to ensure compliance with mitigation measures designed to protect rare species; or assessing improved habitat quality for rare species following remediation/risk management.

Where rare species are a concern, protection measures during remedial activities often involve relocation and monitoring of sensitive mobile species (e.g., fish, turtles) throughout the construction period. Before construction activities, a habitat survey is carried out to identify critical habitat for various life stages and ecological functions, such as breeding, nesting and feeding. Disturbance to these critical habitats is minimized during construction, and rare species exclusion zones may be established to prevent relocated individuals from entering the construction zone. Where nesting or breeding habitat is found within the construction area, surveys may be carried out to identify and



relocate nests established prior to construction activities. Monitoring activities may include acoustic or radio-tracking of relocated individuals to assess movement patterns; monitoring of hatchling success and egg viability for relocated nests and those nests close to the construction activities; and meander surveys in the remedial area to find individuals that may not have been previously relocated or outfitted with transmitters. Further guidance for monitoring rare species during remedial activities can be found in NAVFAC (2007).

Potential monitoring tools for assessing improved habitat quality for rare species following remediation/risk management actions are listed in Table IV-14. A detailed discussion of the information needs required for assessing critical habitat for freshwater fish, including examples of using fish community metrics to assess habitat quality, is contained in Rosenfeld and Hatfield (2006). Selection of an appropriate measure requires knowledge of the relationship between population limitation and habitat quality for a particular species of concern. For example, assessing the presence/absence of individuals of a particular species may be appropriate to monitor habitat quality for endemic species with highly restricted distributions, but be insufficient (and potentially misleading) as an indicator of habitat quality for broader endemic species that are found throughout a watershed (Rosenfeld and Hatfield, 2006). Because of the potential ecological and socioeconomic costs of designing an ineffective monitoring plan for rare species, it is particularly important that aquatic conservation biologists be involved in the development and design of a monitoring program for species at risk.

**Table IV-14: Potential tools for monitoring the recovery of species at risk (based on the Interactive Sediment Remedy Assessment Portal sediment monitoring tools matrix; SPAWAR and ENVIRON, 2010)**

Monitoring tool	Description	Type	Commonality of tool use	Examples of possible measures	Special considerations	Methodology references
Caged organisms	Deployment <i>in situ</i> of hatchery progeny or test organisms closely related to the species of concern	Biological	Rare	<ul style="list-style-type: none"> <li>• Growth</li> <li>• Survival</li> </ul>	<ul style="list-style-type: none"> <li>• Must be paired with evaluation of physical habitat quality</li> </ul>	USEPA (2003a)
Fish community analysis	Census of fish populations	Biological	Very common	<ul style="list-style-type: none"> <li>• Presence/absence</li> <li>• Density</li> <li>• Habitat-explicit population viability analysis (PVA)</li> </ul>	<ul style="list-style-type: none"> <li>• Sampling methods vary depending on water depth, salinity and/or turbidity</li> <li>• Must be paired with evaluation of physical habitat quality</li> <li>• Choice of measure requires good understanding of the relationship between population limitation and habitat quality</li> <li>• Use of PVA models limited for most rare species due to insufficient data</li> </ul>	USEPA (2003a, 2007a) Rosenfeld and Hatfield (2006)
Macro-invertebrate community analysis	Taxonomic census of benthic macro-invertebrate community analysis	Biological	Common	<ul style="list-style-type: none"> <li>• Presence/absence</li> <li>• Density</li> <li>• Diversity</li> </ul>	<ul style="list-style-type: none"> <li>• Sampling methods vary depending on substrate conditions</li> <li>• Must be paired with evaluation of physical habitat quality</li> </ul>	EC (2010); USEPA (2003a, 2007c)

Table IV-14: Potential tools for monitoring the recovery of species at risk (based on the Interactive Sediment Remedy Assessment Portal sediment monitoring tools matrix; SPAWAR and ENVIRON, 2010) (cont'd)

Monitoring tool	Description	Type	Commonality of tool use	Examples of possible measures	Special considerations	Methodology references
Meander surveys	Survey technique for covering large areas to search for the presence of rare species in likely habitat	Biological	Common	<ul style="list-style-type: none"> <li>• Presence/absence</li> <li>• Density</li> </ul>	<ul style="list-style-type: none"> <li>• Relies on visual observations and professional judgement, therefore most applicable to terrestrial or shallow aquatic environments</li> </ul>	
Reptile/amphibian analysis	Biological survey of reptile and/or amphibians	Biological	Common	<ul style="list-style-type: none"> <li>• Presence/absence</li> <li>• Reproductive success</li> </ul>	<ul style="list-style-type: none"> <li>• Must be paired with evaluation of physical habitat quality</li> </ul>	NAVFAC (2007)
Telemetry	Installation of acoustic or radio-transmitters to track movement of individual organisms	Biological	Common	<ul style="list-style-type: none"> <li>• Home range</li> <li>• Habitat use</li> <li>• Movement patterns</li> </ul>	<ul style="list-style-type: none"> <li>• Acoustic telemetry used for tracking underwater aquatic biota while radio telemetry is used for terrestrial species</li> <li>• Acoustic tracking requires animals to be within a few hundred metres of the receivers to be tracked</li> </ul>	Moll et al. (2007)
Vegetation survey	Biological survey of algal biomass and taxonomy of periphyton and/or other vegetation in euphotic zone	Biological	Common	<ul style="list-style-type: none"> <li>• Presence/absence</li> <li>• Density</li> </ul>	<ul style="list-style-type: none"> <li>• May only be applicable for the euphotic zone (water depth where enough light penetrates that photosynthesis can occur)</li> </ul>	Hambrook-Berkmann and Canova (2007); USEPA (2007d)

### **Summary**

#### **Section IV-C (Tools for monitoring the performance of aquatic remedies)**

#### **Section IV-D (Tools for monitoring ecosystem recovery)**

- Performance monitoring objectives and indicators are specific to the remedy mechanism used to address an aquatic contaminated site. Examples of monitoring tools and monitoring plan design considerations are summarized for monitored natural recovery (MNR), capping, dredging, and *in situ* remedial strategies. Where contaminants are left in place on site, on-going performance monitoring may be required.
- Monitoring tools for ecosystem recovery are summarized for all of the monitoring objectives not covered in the on-line Interactive Sediment Remedy Assessment Portal (ISRAP; see Table III-1). Most ecosystem recovery monitoring objectives are addressed using biological indicators.

## **V. ESTABLISHING DECISION RULES AND EXIT CRITERIA**

Once the monitoring tools and associated metrics have been selected for the monitoring plan, decision rules for interpreting the monitoring data can be developed. Decision rules are quantitative pass/fail statements that generally take the form of “if... then” statements (NAVFAC, 2007). The role of decision rules is to provide a basis for concluding that a desired condition has been or is being met; to facilitate adaptive management for the monitoring program and site activities; and to reduce the potential for unclear or incorrect decision-making. Each decision rule is composed of five main elements (USEPA, 2004; NAVFAC, 2007):

- The monitoring parameter being measured (e.g., a contaminant concentration in surface sediment);
- The metric used to measure the parameter (e.g., mg of a contaminant/kg of sediment);
- An action level (e.g., sediment quality remedial objectives) against which the monitoring results are compared and which results in an action when met or exceeded;
- The temporal considerations for the decision criterion (e.g., monitoring frequency) and timeframe within which the action level is expected to be reached; and
- The alternative actions to be considered for implementation when an action level has or has not been met or exceeded (e.g., assess causality and revise R/RM strategy and monitoring plan if necessary).

USEPA (2004, 2006) provides guidance on the process that may be used to develop decision rules for each monitoring objective and associated measurement endpoints. First, the spatial and temporal boundaries of the monitoring study should be defined (i.e., what is the smallest area where a decision rule will apply, and what timeframe is anticipated for completion of the monitoring objective). Once the boundaries of the study are set, action levels can be determined for each decision rule. Quantitative action levels are specific to each metric and are used to evaluate monitoring results and make a choice amongst management options. The development of scientifically defensible decision criteria, including exit criteria that indicate when the monitoring objective has been met, is essential for effective project management and decision-making. The following section reviews information specific to the development of decision rules that facilitate site closure of aquatic contaminated sites.

## **A. Defining spatial and temporal boundaries for monitoring**

Guidance for determining the spatial and temporal boundaries of the monitoring study is provided in Step 4 of the USEPA (2006) DQO process. Spatial boundaries delineate the entire geographical area of the site, and divide the site into relatively homogeneous subunits that can be used to define sampling locations. Data collected in previous site characterization, risk assessment, and remedial plan studies, as well as the site conceptual model, should be reviewed to define the spatial boundaries of the site.

Determining the temporal boundaries of the monitoring study involves identifying the index period for sampling, as well as the overall anticipated timeframe for monitoring. Many metrics are influenced by time-related factors, such as seasonal changes or weather patterns; therefore, the selection of a consistent sampling period (*index period*) for monitoring minimizes the influence of natural temporal variability on the monitoring outcomes. Relevant information to aid in the selection of an index period for sampling is summarized in Section IV for each monitoring tool discussed in the text.

The timeframe required for the achievement of site closure will vary greatly from site to site depending on site characteristics, the remedial strategy employed and the nature and scale of ecosystem impacts. The anticipated timeframe to achieve the decision rule exit criteria differs for each monitoring objective and associated indicators. Generally, the attainment of remedial goals associated with ecosystem recovery will require the most time. For example, in some cases several decades may be required for recovery of risks to upper-trophic-level and human receptors through bioaccumulation of persistent organic chemicals, such as PCBs. Estimates of the timeframe required for monitoring can be developed through review of the site conceptual model, comparisons with similar sites, and statistical and modelling analyses. Trend analysis of monitoring data can provide insight into rates of ecosystem recovery and allow for estimates of the timeframe required for site closure on an adaptive management basis. An indication of the monitoring timeframe for each objective is provided in Section IV and in Table V-1 and Table V-2, below.

The timeframe to site closure may also be governed by policy. A review of the available policy guidance documents for contaminated sites in the U.S., Canada, Australia/New Zealand, and the European Union found that no timeframe for site closure is specified. However, in the U.S. under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), the jurisdiction responsible for managing sites requiring groundwater and surface water restoration changes from the USEPA to the state level after 10 years if remedial goals have not been met (USEPA, 2003b). Sites transferred to state control enter into operation and maintenance (O&M) and are no longer eligible for federal funds.

The final stage in determining the monitoring study boundaries is to identify a scale of inference for decision making (USEPA, 2006). This is the way in which the planning team has delineated the smallest unit of area, volume, or time over which data will be collected, analysed, compiled, and interpreted for decision-making. The consequences of making incorrect decisions should be considered so that an appropriate scale for decision-making can be identified. Decision units may be established using considerations such as risk, technological factors, temporal variability, financial scale, or other factors such as the presence of “hotspots” of contamination. Further guidance in setting an appropriate decision-making scale of inference is provided in USEPA (2006).

## **B. Defining exit criteria to achieve site closure for monitoring programs**

Setting quantitative monitoring endpoints and associated scientific exit criteria is critical for documenting progress toward achieving site closure. Recent reviews of progress made toward restoring the Great Lakes Areas of Concern (AOCs) have identified the lack of quantitative measures as a key factor preventing delisting of many AOCs (Krantzberg and Houghton, 1996; Krantzberg, 2003; George and Boyd, 2007). As George and Boyd (2007) state, qualitative descriptions of continuous improvement “describe the journey, but fail to establish the destination.”

To assess progress toward site closure, it is critical to determine scientifically defensible action levels that represent the attainment of the desired condition associated with a particular monitoring objective. These site closure action levels can then be used to establish exit criteria for each monitoring objective: when the exit criteria are met, monitoring for that objective can be concluded. Overall closure for a site would be achieved when the exit criteria have been met for all of the monitoring objectives. Final site closure may not be attainable for those sites where contaminants remain in place (e.g., capped sites, engineered containment facilities) and ongoing maintenance and performance monitoring are required. However, once the exit criteria for monitoring objectives related to ecosystem recovery are achieved, the scale and frequency of monitoring can be greatly reduced.

Site closure action levels for a monitoring objective are specific to each monitoring parameter and the associated metric used for measurement. Step 5 of the DQO process (USEPA, 2006) provides statistical guidance for the selection of a type of action level (e.g., mean, percentile, etc.). Stakeholder and FCSAP expert support involvement in the selection of site closure action levels is important to incorporate specific concerns, as well as achieve consensus on considerations regarding the timeframe and cost to achieve the proposed site closure goals.

The action levels should be strongly linked with the remedial objectives defined in the development of the remedial action plan. In some cases, the choice of action level is

straightforward, as the target action level may be chosen for compliance with a regulatory guideline (e.g., CCME water quality guidelines or sediment quality guidelines) used as the remedial objective for the site. However, remediation to sediment quality or water quality guidelines is often not warranted because of the conservative nature of the guidelines: the area of a site showing biological effects is often much smaller than the area exceeding the sediment quality guidelines. If regulatory guidelines were not adopted as the remedial objectives for a site, selection of these guidelines as site closure action levels for the monitoring program would be inappropriate as it is unlikely that these action levels could be attained.

In accordance with the FCSAP approach, site-closure action levels for ecosystem recovery should reflect previous risk assessment outcomes and risk-based remedial objectives where possible. For example, a human health risk assessment may have identified that fish tissue contaminant concentrations at a site represent a potential risk to sport anglers. Back-calculation of the risk assessment equations can identify a target fish concentration that is protective of sport anglers; this target fish concentration then becomes the action level for monitoring achievement of reduced risks to human health through fish consumption. Similar approaches may be used to determine action levels to assess reduced toxicity to aquatic organisms, as well as reductions in ecological risks to aquatic organisms through bioaccumulation. Examples of monitoring objectives with exit criteria derived from regulatory or risk-based target action levels are listed in Table V-1, along with the suggested monitoring frequency and timeframe for completion. Figure V-1 provides an example of a monitoring conceptual model using risk-based target action levels.



**Table V-1: Examples of exit criteria used for various monitoring objectives related to ecosystem recovery using regulatory or risk-based target action levels (after SPAWAR and ENVIRON 2010)**

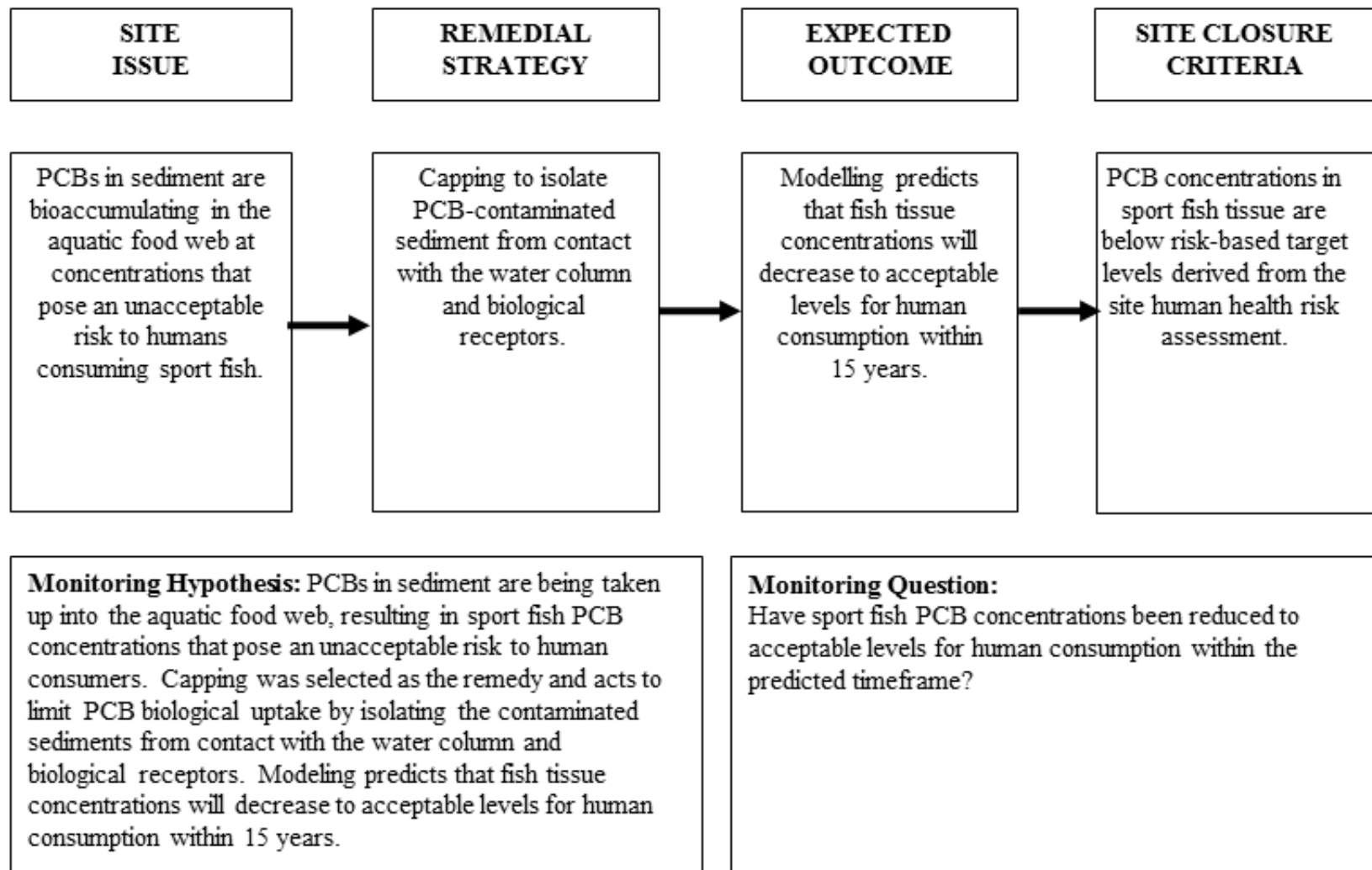
<b>Monitoring objective</b>	<b>Monitoring tool</b>	<b>Timing</b>	<b>Frequency</b>	<b>Exit criteria</b>	<b>References</b>
Assessment of bioaccumulation potential to aquatic organisms	Contaminant concentrations in fish tissue	Before remedial activity and days to years after remedial activity	Every 1–2 years if possible	The 95% UCL of fish tissue concentrations is below the risk-based threshold for upper trophic level consumers for three consecutive sampling periods.	US EPA (2008)
Assessment of human health risks via dermal contact with sediments	Contaminant concentrations in sediment samples	Before remedial activity and days to years after remedial activity	Possibly more than once	The 95% UCL of sediment sample concentrations is below the risk-based threshold for the protection of human health.	
Assessment of human health risks via consumption of aquatic biota	Contaminant concentrations in fish, seal or shellfish tissue	Before remedial activity and days to years after remedial activity	Every 1–2 years if possible	The 95% UCL of fish tissue concentrations is below the risk-based threshold for upper trophic level consumers for three consecutive sampling periods. A spatial component may also be included (e.g., harvested within a 5 km radius of the site).	US EPA (2008); ESG (2008)
Assessment of ecological health risks via ingestion of sediments	Mortality of bioindicator species	During remedial activities and years after remedial activity	Every year for the first eight years, then years 10, 15 and 20	1% mortality rate for the bioindicator species.	CH2M HILL (1998)

Table V-1: Examples of exit criteria used for various monitoring objectives related to ecosystem recovery using regulatory or risk-based target action levels (after SPAWAR and ENVIRON 2010) (cont'd)

<b>Monitoring objective</b>	<b>Monitoring tool</b>	<b>Timing</b>	<b>Frequency</b>	<b>Exit criteria</b>	<b>References</b>
Assessment of monitored natural recovery through physical processes (dispersion and transport to deep basins)	Contaminant concentrations in sediment samples	Before remedial activity and days to years after remedial activity	Possibly more than once; after extreme events	The 95% UCL of surface sediment sample concentrations is below the risk-based threshold for the protection of the most sensitive ecological receptor.	ESG (2008)
Assessment of ecological health risks via exposure to surface water	Contaminant concentrations in surface water	Before and after remedial activities	Quarterly sampling for at least 10 years. If parameters meet the exit criteria before 10 years, monitoring will be reduced to once per year during low flow	Ten years after remedial activities are complete, the primary parameters must meet the more restrictive of the aquatic life or human health guidelines. Secondary parameters must be at or near background levels and show no change or a declining trend for three consecutive years.	PBS&J (2010)
Assessment of human and ecological health risks via ingestion of sediment	Contaminant concentrations in sediment samples	Before and after remedial activities	Quarterly sampling for at least 10 years, if parameters meet the exit criteria before 10 years, monitoring will be reduced to once per year during low flow	Ten years after remedial activities are complete, the primary parameters must be below the threshold effect concentrations for at least three consecutive years. Secondary parameters must be at or near background levels and show no change or a declining trend for three consecutive years.	PBS&J (2010)

Table V-1: Examples of exit criteria used for various monitoring objectives related to ecosystem recovery using regulatory or risk-based target action levels (after SPAWAR and ENVIRON 2010) (cont'd)

<b>Monitoring objective</b>	<b>Monitoring tool</b>	<b>Timing</b>	<b>Frequency</b>	<b>Exit criteria</b>	<b>References</b>
Assessment of benthic ecological recovery over time	Macroinvertebrate and periphyton community composition	Before and after remedial activities	Annually until monitoring objectives are reached	Macroinvertebrate community must attain a total metrics score of 75 percent of the total possible score in the “Good” category for two consecutive years.  Periphyton community must attain a total score within “Excellent” to “Good” biological integrity for all metrics for two consecutive years.	PBS&J (2010)
Assessment of re-establishment of trout populations	Fish community survey (species composition, abundance and population structure)	Before and after remedial activities	Annually; however, will not begin until trout species are known to be surviving in the creek.	Considered successful if stream is able to support a trout population.	PBS&J (2010)



**Figure V-1: Example of a conceptual model for monitoring reduced human health risks through sport fish consumption (after USEPA, 2004).**

In other cases, target action levels for site closure can be determined through measuring equivalence to pre-disturbance or reference site conditions. Ideally, ecological recovery would be assessed by comparing measurement endpoints with those representing pre-disturbance conditions from the site. However, in the absence of these data (which is often the case), comparison to measurement endpoints from analogous reference sites can be used to assess ecological recovery. Reference sites may be defined as areas that have similar physical, chemical and ecological characteristics to the site of interest, but with minimal human disturbance and contaminant concentrations typical of background levels (Stoddard et al., 2006). Reference condition generally implies a range of measured values for the variable of interest that captures the natural variability associated with the measure (EC, 2010). Significant differences between monitoring data for a particular measurement endpoint compared with the reference condition therefore suggests that site conditions are outside the range of natural variability. The selection of appropriate reference sites for the measure in question is crucial for accurate detection of differences. Detailed guidance regarding the selection of appropriate reference sites for aquatic monitoring is found in Bailey et al. (2004) and Stoddard et al. (2006). Examples of monitoring objectives with exit criteria associated with equivalence to reference site conditions are listed in Table V-2. Figure V-2 provides an example of a monitoring conceptual model using action levels that are compared to reference site conditions.

Decision criteria for some monitoring objectives may require that several action levels are met for successful attainment of the desired conditions. For example, restoration of aquatic habitat productivity to levels similar to pre-disturbance or reference conditions following capping may require several steps: restoration of benthic physical habitat (i.e., similar substrate characteristics and distribution); recolonization of benthic communities (i.e., similar density, coverage, and species composition of macroinvertebrate and algal communities); and finally, similar overall aquatic productivity, species composition, and habitat use (including upper trophic level consumers such as fish). An example of a monitoring conceptual model for this objective is found in Figure V-3.

**Table V-2: Examples of exit criteria used for various monitoring objectives related to ecosystem recovery using equivalence to pre-remediation or reference conditions (after SPAWAR and ENVIRON 2010)**

<b>Monitoring objective</b>	<b>Monitoring tools</b>	<b>Timing</b>	<b>Frequency</b>	<b>Exit criteria</b>	<b>References</b>
Assessment of benthic ecological recovery over time	Macro-invertebrate community analyses	Before remedial activity and months to years after remedial activity	Annually or more frequently to determine long-term trend	No significant differences in benthic community structure between test and reference sites; or stabilization of benthic community assemblage at an alternative state defined by effects of inherent ecological processes.	Grapentine (2009), Exponent (2001), EC (2010)
Assessment of benthic ecological recovery over time	Fish liver neoplasm analysis	Before remedial activity and days to years after remedial activity	Possibly more than once	No significant differences in fish liver neoplasm prevalence between test and reference sites.	Baumann (2010a; 2010b)
Assessment of toxicity to benthic species over time	Laboratory toxicity tests with benthic organisms	Before remedial activity and days to years after remedial activity	Possibly more than once	Test site toxicity < 20% different from mean/median reference site toxicity.	Grapentine (2009)
Assessment of recovery of aquatic habitat productivity	Macro-invertebrate density, periphyton biomass, fish biomass and riparian vegetation	Before remedial activity and days to years after remedial activity	Annually or more frequently to determine long-term trend	No significant differences in mean monitoring tool measures between test and reference sites.	Quigley and Harper (2006)

Table V-2: Examples of exit criteria used for various monitoring objectives related to ecosystem recovery using equivalence to pre-remediation or reference conditions (after SPAWAR and ENVIRON 2010) (cont'd)

<b>Monitoring objective</b>	<b>Monitoring tools</b>	<b>Timing</b>	<b>Frequency</b>	<b>Exit criteria</b>	<b>References</b>
Assessment of sediment concentrations to assess natural recovery through physical processes	Contaminant concentrations in sediment samples	Before and after remedial activities	More than once	Surface sediments must meet the reference area concentration which represents the 90 <sup>th</sup> percentile concentration from approved surrounding areas.	US EPA (2000d), Exponent (2001)
Assessment of bioaccumulation potential to aquatic organisms	Contaminant concentrations in tissue samples	Before and after remedial activities	Every few years	Fish tissue concentrations must meet the 90 <sup>th</sup> percentile of fish tissue concentrations from the reference area.	US EPA (2000d)

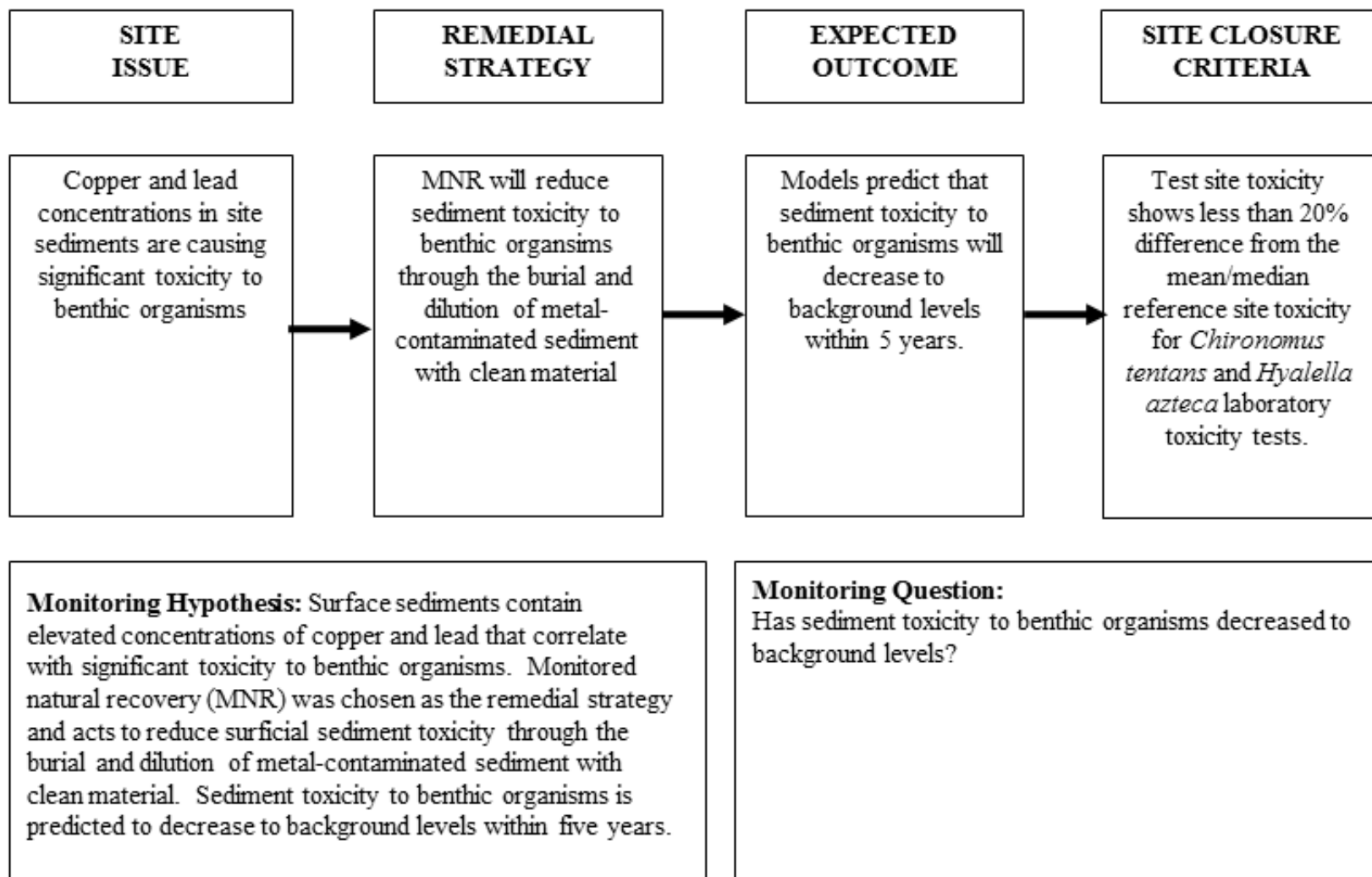
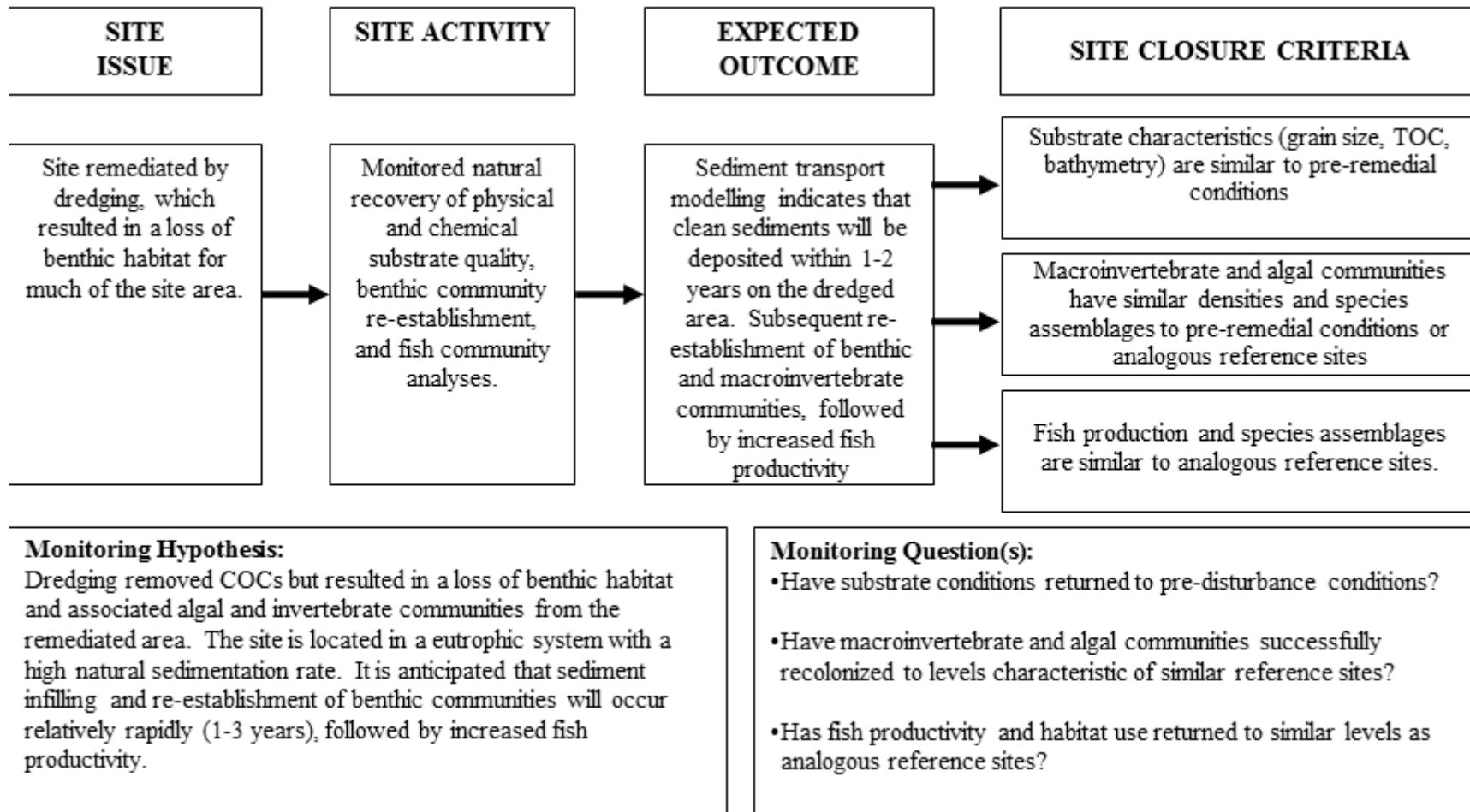


Figure V-2: Example of a conceptual model for monitoring decreases in sediment toxicity to benthic organisms (after USEPA, 2004)





**Figure V-3: Example of a conceptual model for monitoring recovery of aquatic habitat productivity (after USEPA, 2004)**

Exit criteria may also combine a temporal component with the specified action level as a basis for evaluating attainment of the desired condition (NAVFAC 2007). For example, measurement of fish tissue concentrations below the specified action level may be required for multiple and consecutive sampling periods (e.g., the action level must be attained for three consecutive sampling periods) before a management decision and response are prompted. This aids in ensuring reproducibility of the monitoring results and reducing uncertainty in decision-making. Trend analysis, where monitoring data are plotted over time, can also be included in decision-making criteria to evaluate the likelihood of attaining the exit criteria in the desired timeframe and allow for adaptive management of the monitoring plan. Trend analysis can be very useful for monitoring objectives that are anticipated to take relatively long periods of time for completion, such as the decrease in fish tissue contaminant concentrations or the restoration of aquatic habitat productivity.

Monitoring decision criteria should be revisited periodically as part of an adaptive site management process to ensure that the exit criteria are appropriate and achievable (USEPA, 2004). New information that alters the risk assessment for a site may also impact risk-based target action levels for some monitoring objectives. Alternatively, monitoring results may indicate that the attainment of a target action level may not be feasible in the anticipated timeframe. For example, a target fish tissue concentration may have been selected as an action level to monitor reduced risk to human health. However, monitoring results indicate that fish tissue contaminant concentrations are not decreasing and likely reflect exposure to off-site contaminant sources associated with elevated background concentrations or general urban runoff. In this case, it may be decided that the exit criterion for this monitoring objective cannot be achieved and continued administrative controls (e.g., fish consumption advisories) are necessary. The monitoring program may be scaled down in level of effort and monitoring frequency to accommodate this new information.

**Section V Summary**  
**(Establishing decision rules and exit criteria)**

- Quantitative decision-making rules for interpreting monitoring data are important to provide a basis for concluding that a desired condition has been or is being met; to facilitate adaptive management for the monitoring program and site activities; and to reduce the potential for unclear or incorrect decision-making.
- Definition of spatial and temporal boundaries for monitoring plan design determines the scale of inference for decision-making. Defining spatial boundaries includes defining the overall geographical area of the site and relatively homogeneous units within the site for sampling. Defining temporal boundaries includes identifying an index period for sampling to minimize natural temporal variability, as well as the anticipated timeframe to site closure.
- It is critical to establish scientifically defensible exit criteria for decision-making rules to measure progress towards site closure. Exit criteria are defined based on the remedial objectives, the risk assessment outcomes, and stakeholder input. Regulatory or risk-based targets may be used as exit criteria; alternatively, the target may be equivalence to pre-disturbance or analogous reference site conditions.

## **VI. ADDRESSING UNCERTAINTY IN MONITORING PROGRAMS FOR SITE CLOSURE**

All environmental data has associated uncertainty with measured values due to sampling and measurement errors, as well as natural variability. Since these data will be used to make management decisions, it is critical to determine performance or acceptance criteria that the collected data need to achieve to minimize the possibility of making incorrect conclusions. Step 6 of the DQO process provides guidance for the derivation of performance and acceptance criteria to address data uncertainty. The following section outlines important statistical considerations to address uncertainty in monitoring data, as well as recommending methods to reduce uncertainty in measured data.

### **A. Statistical approaches to address uncertainty**

Decision-making problems, such as comparisons of monitoring data with a defined action level to make a decision, are evaluated by performing statistical hypothesis tests. The most commonly used null hypothesis is that there is no difference between the measured data and the action level (Mapstone, 1995). For example, for measures of sediment contamination, the null hypothesis (also called the baseline condition) may be that there are no differences between the measured sediment contaminant levels for a monitoring area and the exit criterion. The alternative condition would be that the measured contaminant concentrations for the monitored area are higher than the exit criterion.

There are four possible outcomes from statistical hypothesis testing (Table VI-I; USEPA, 2006). Two of these outcomes (accepting the null hypothesis if it is true, rejecting the hypothesis if it is false) lead to the correct decisions being made regarding the monitoring data. The other two outcomes represent decision errors. A false rejection decision error (also called a Type I error) occurs when the null hypothesis is true, but is rejected. The probability of this error occurring is called the *level of significance* ( $\alpha$ ). A false acceptance decision error (also called a Type II error) occurs when the null hypothesis is false, but is accepted; the probability that this error will occur is called beta ( $\beta$ ). The *statistical power* of the hypothesis test is defined as the probability of rejecting the null hypothesis when it is truly false (Zar, 1984; USEPA, 2006); it is equal to  $1 - \beta$ . Power is a measure of the likelihood that the collected data will lead to the correct conclusion that the alternative condition is true rather than the null hypothesis. For a given sample size, the values of  $\alpha$  and  $\beta$  are inversely related (i.e., lower probabilities of committing a false rejection decision error are associated with higher probabilities of committing a false acceptance decision error).

**Table VI-I: Possible outcomes from statistical hypothesis testing (from USEPA, 2006)**

Decision made by applying the statistical hypothesis test to the monitoring data	True condition (reality)	
	Baseline condition (null hypothesis) is true	Alternative condition is true
Decide that the baseline condition (null hypothesis) is true	Correct decision	False acceptance (Type II) decision error
Decide that the alternative condition is true	False rejection (Type I) decision error	Correct decision

Setting appropriate limits on the likelihood of making decision errors is an important part of the DQO process for monitoring programs. Biological studies typically use a significance level of 0.05 and a statistical power of 0.80, but these arbitrary criteria may not be sufficient to protect from the risks of making incorrect decisions in some cases. Alternatively, the increased sampling effort and costs required to meet these criteria may not be justified if the risks associated with potential incorrect decisions are low. Accordingly, Mapstone (1995) and the USEPA (2006) recommend that the consequences of making wrong decisions be taken into account when deciding on a level of significance and statistical power for decision rules. Using the null hypothesis example described above, a false acceptance decision error would assume that the exit criteria for the monitoring objective had been achieved, when in reality sediment concentrations for the monitoring area exceed the target level. The consequences may be continued human health and ecological risks that are not addressed. In contrast, a false rejection decision error would assume that the exit criteria had not been achieved, when in fact sediment concentrations for the monitoring area have reached the target level. The consequences for this scenario are unnecessary costs associated with additional monitoring. More stringent controls may be placed on the probability of making false acceptance decision errors in this case if the potential human health and ecological risks could be appreciable. Detailed guidance on setting tolerable limits for hypotheses tests when comparing data with an action level is provided in USEPA (2006).

In most cases, there is also uncertainty associated with the target action levels that are used as decision criteria. Exit criteria for ecosystem recovery that are based on risk assessment contain uncertainty as a result of sampling and measurement error as well as the assumptions and models used in the risk assessment. Sources of uncertainty and the potential magnitude of impacts on risk assessment outcomes should have been documented as part of the risk assessment. Residual risk analyses are also generally completed during evaluation of the potential remedial options for the site, and documented in the remedial action plan. These analyses may be completed using point estimates or with probabilistic methods that provide quantitative estimates regarding the

uncertainty distribution of residual risk (e.g., Katsumata and Kastenberg, 1998). There is little information in the scientific literature regarding what levels of residual risk are acceptable for aquatic ecosystems. Using an adaptive management approach for monitoring programs allows for the adjustment of monitoring programs and, if necessary, remedial strategies if risk-based ecosystem recovery rates do not meet with expectations.

For exit criteria based on an estimated value, such as benthic invertebrate diversity or fish biomass, uncertainty associated with the value should be reported (Clarke et al., 2003; Clarke and Hering, 2006; Carstensen, 2007). This is typically expressed either as a standard error or as an interval of possible values (e.g., a confidence interval). A detailed description of these parameters and possible acceptance criteria for use in environmental studies is found in USEPA (2006).

## **B. Reducing uncertainty in monitoring data**

Uncertainty in monitoring data can be reduced in several ways. Measurement error includes random and systematic errors introduced during sample collection, handling, preparation, analysis, data reduction, transmission, and storage (USEPA, 2006). The use of a detailed Quality Assurance Project Plan (QAPP), including protocols for sample collection, analysis, and storage as well as acceptable DQO criteria for analytical programs, is important for minimizing measurement error (Batley, 1999; USEPA, 2002b; Clarke and Hering, 2006). The use of more precise analytical measurement techniques may also reduce measurement uncertainty.

Sampling error is generally much larger than measurement error and requires greater resources to control (USEPA, 2006). Sampling error is influenced by the inherent levels of spatial and temporal variability for the area to be sampled, the monitoring program design, and the number of samples collected. Reducing sampling error involves minimizing inherent variability where possible. For example, contaminant tissue concentrations in fish show seasonal variability due to changes in tissue lipid content; the fish species type, age and sex also influence contaminant uptake (USEPA, 2008). To minimize variability, monitoring programs should target collection of similar numbers of males and females from the same age class for a single species of fish; sampling should always be conducted at the same time of year under similar stream flow conditions (USEPA, 2008). It is also common to analyze composite samples of five to 10 fish to reduce statistical variability. Important considerations for minimizing variability in monitoring programs are summarized in Section IV above for each indicator. Examples of sources of variability and strategies for minimizing uncertainty in sampling programs are provided for water quality monitoring programs (e.g., Carstensen 2007; MacDonald et al., 2009), sediments (USEPA, 2001c), benthic invertebrates (Clarke et al., 2003; Clarke and Hering, 2006; Hering et al., 2010), and fish (USEPA, 2008).

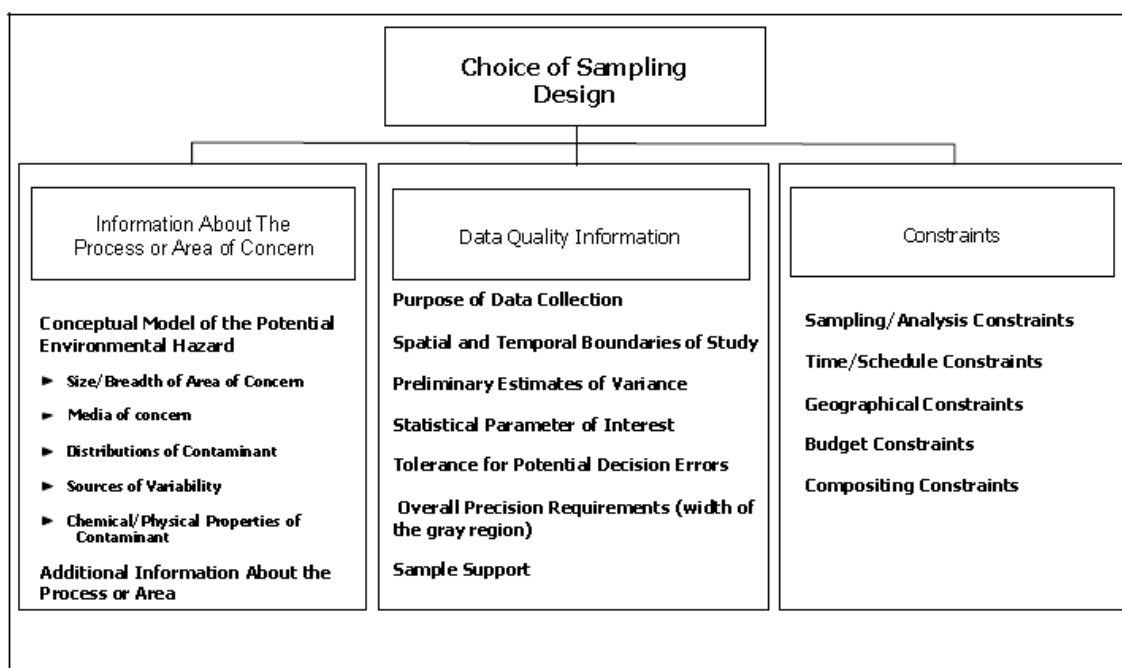
Development of an appropriate monitoring program design is also important for minimizing sampling error. This type of error occurs when the data collection design does not represent the spatial and temporal variability for the measurement of interest to the extent needed for making conclusions (USEPA, 2006). General guidance for developing environmental sampling designs is provided in USEPA (2002b) and through the USEPA DQO process (USEPA, 2006). Specific guidance is also available for developing sediment sampling programs (USEPA, 2001c) and water quality monitoring programs, including biomonitoring (BCMOE, 1998). Expert peer review of the monitoring program design can also aid in ensuring that the most appropriate design has been selected (Clark et al., 2010). Level of effort considerations for developing monitoring plans are discussed in the following section.

**Section VI Summary**  
**(Addressing uncertainty in monitoring programs for site closure)**

- Statistical approaches to address uncertainty in monitoring data include defining a desired level of significance and statistical power for the monitoring plan design. These should be selected based on evaluation of the consequences of incorrect decision-making.
- Measurement errors can be minimized through the use of a quality assurance project plan (QAPP) that includes definition of the data quality objectives for analytical methods. Sampling error can be reduced through minimizing inherent variability where possible, and the use of an appropriate monitoring plan design.

## VII. LEVEL OF EFFORT CONSIDERATIONS FOR MONITORING PLANS

Once the monitoring objectives, indicators, metrics, target action criteria and DQOs have been identified for a site, the next step is to design the monitoring plan (Step 7 of the DQO process; USEPA, 2006). Determining the level of effort required for the monitoring plan is dependent on a number of factors, as summarized in Figure VII-1. These include site-specific information such as the nature and impact of past human activities and the ecological setting; data quality information, such as preliminary estimates of variance and the tolerance for potential decision errors; and resource constraints such as budget and time/scheduling constraints (USEPA, 2002b; Clark et al., 2010). The following discussion focuses on determining the level of effort needed for monitoring programs that can achieve site closure.



**Figure VII-1: Factors in selecting a sampling design (Figure 3.2 in USEPA, 2002b)**

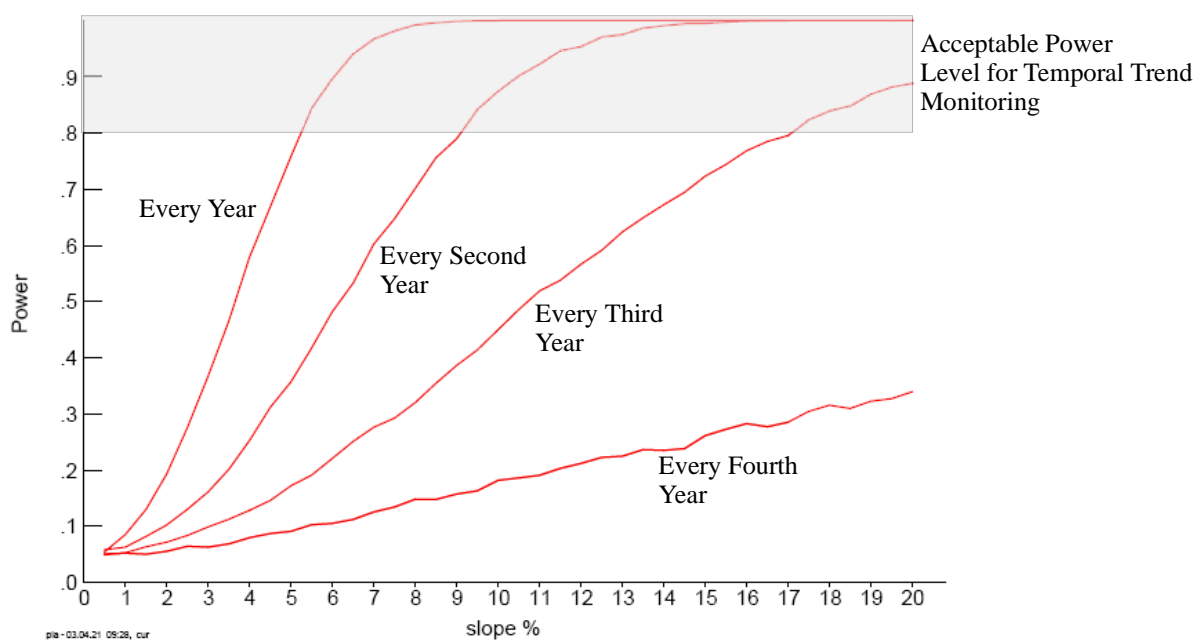
An important aspect of designing a monitoring program is determining the number of samples that needs to be collected for each indicator to meet the monitoring objectives and DQOs. A variety of statistical techniques may be used to calculate the number of samples required to meet the defined DQOs. In general, these methods require input of the acceptable limits for decision errors (i.e., level of significance), the desired statistical power, the variability around the mean, and either a minimum detectable spatial or temporal difference, or a pre-specified margin of error (BCMOE, 1998; NEC, 2004). Data that characterize the variability in the metric of interest for the site are therefore important, and may require a pilot monitoring study to be completed if this information is not available. An example of a method for deriving sample sizes needed for testing the



mean of a normal distribution versus an action level is provided in the Appendix of USEPA (2006).

Power analysis is a valuable statistical technique that can be used to test the suitability of data sets to meet monitoring requirements (Green, 1989; Nicholson and Fryer, 1992; Nicholson et al., 1997). Detailed guidance for completing power analysis may be found in Cohen (1988). This statistical technique enables calculation of the minimum sample size and sampling frequency required to be able to detect spatial or temporal changes for a particular effect size (i.e., minimum detectable spatial or temporal difference); knowledge of the variability around the mean is also necessary and may require a pilot monitoring study to acquire. Power analysis has been applied, for example, in guidance for fish and benthic invertebrate monitoring programs to assess environmental effects from metal mining in Canada (EC, 2011), the number of composite samples required for fish tissue monitoring (USEPA, 2008), the number of replicates required for lab toxicity and bioaccumulation testing (Appendix L of USACE 2003), and the number of replicates and sampling frequency required to detect temporal trends in fish tissue contaminant concentrations (NEC, 2004). Estimating the power of the sampling design before completion of the monitoring program is critical to ensure credibility of non-significant results (i.e., whether the sampling design is sufficient to detect differences if they are present). This is particularly important for sites with severe constraints on monitoring program design, such as remote sites where monitoring may only be feasible every few years.

Power analysis can also be applied to assess whether or not the sample numbers and sampling frequency are adequate to detect if exit criteria for site closure can be achieved in the desired monitoring timeframe. It is particularly useful for assessing the sampling design for monitoring metrics that are anticipated to require long time periods to meet exit criteria, such as reductions in fish tissue contaminant concentrations. For these indicators, trend analysis is important to assess whether ecosystem recovery is occurring and the achievement of exit criteria is feasible so that monitoring programs and remedial strategies can be altered if necessary. Application of power analysis to several monitoring programs for tissue contaminant concentrations indicated that the ability to detect temporal trends is strongly tied with sampling frequency: as the sampling frequency decreased from annual sampling to sampling every three years, the statistical power of the monitoring programs to detect temporal trends decreased greatly (Fryer and Nicholson, 1993; Bignert et al., 2004; NEC, 2004; see Figure VII-2). Annual or biennial sampling may therefore be important for temporal trend monitoring programs, particularly when the monitoring data begin to approach the target criteria and the annual change in contaminant concentrations is small.



**Figure VII-2: The effect of sampling frequency on the power of a trend monitoring program for biota tissue contaminant concentrations. The slope (x-axis) is the percent change in contaminant concentration per year. The illustrated model is for a 12 year sampling program with a  $p=0.05$  level of significance (from NEC, 2004).**

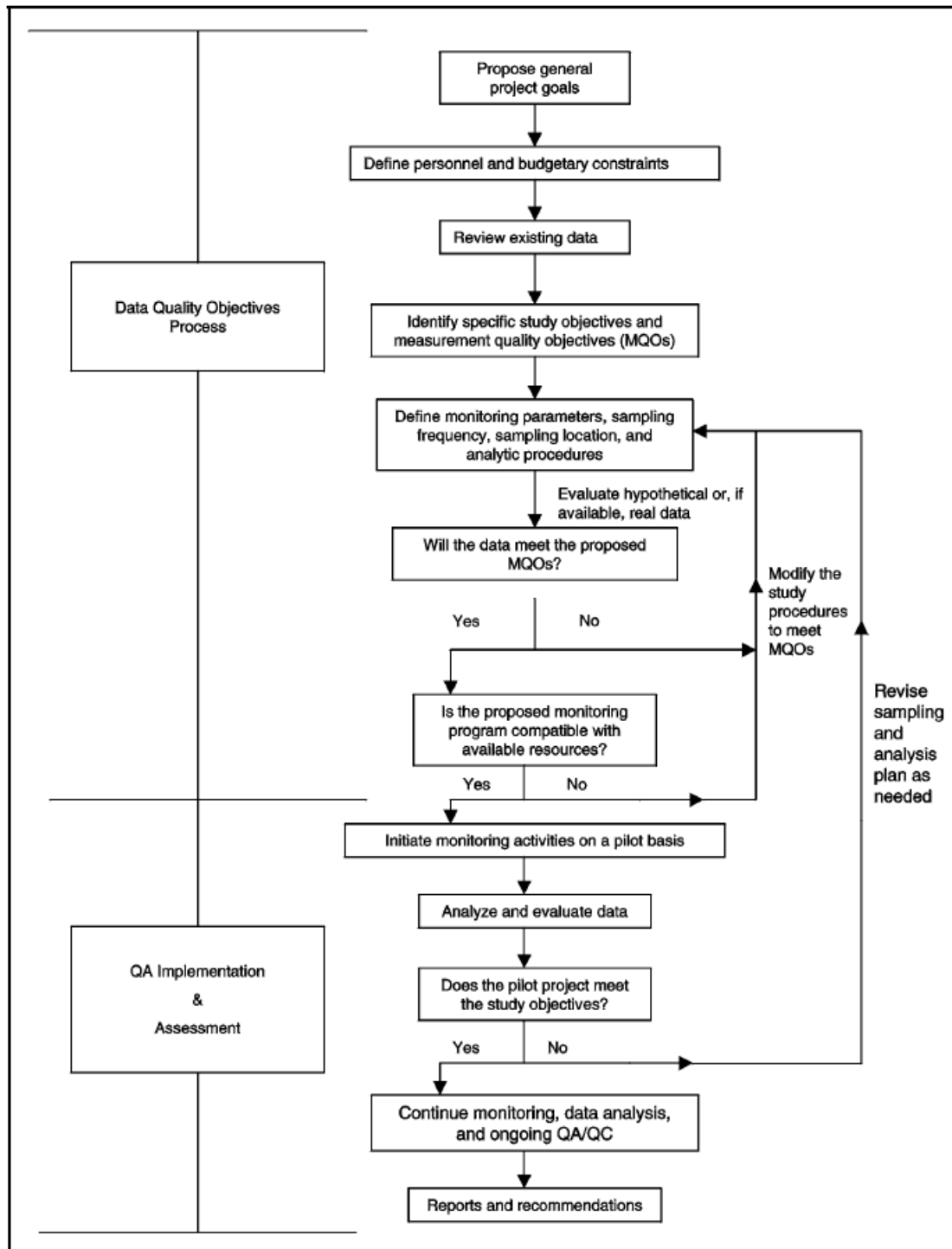
Resources for monitoring plans are usually limited and need to be taken into account when optimizing the monitoring plan design. Sampling costs and the probability of making incorrect decisions are inversely correlated: as less money is spent on sampling, making decision errors becomes more likely (Clark et al., 2010). For each monitoring objective, therefore, determining the consequences of incorrect decisions and setting tolerable limits for making decision errors (as discussed in Section VI.A) becomes critical in deciding the minimum level of effort necessary for the monitoring program to achieve its overall goals. Comparison of these limits for the different monitoring objectives can also aid in prioritizing which areas of the monitoring program require the greatest allocation of resources. A flow chart summarizing the iterative process for balancing resource constraints and data quality objectives for monitoring programs is shown in Figure VII-3. If there is no feasible way to achieve the DQOs for the monitoring program with the proposed budget, then either the decision error tolerable limits must become less stringent or the funds for monitoring must increase. USEPA (2006) identifies software tools that may be used to assist in finding a balance between budget limitations and statistical precision for monitoring programs.

Optimization of the sampling program design should include review of potential alternate approaches for data collection that would achieve the DQOs for the list of monitoring

objectives (Clark et al., 2010). Existing environmental data for the site should be examined to assess the data quality, sources of variability, and the cost-effectiveness of conducting pilot sampling to attain estimates of variability. Alternate designs for data collection and analytical measurement should be explored to identify the most cost-effective balance of level of sampling effort and measurement performance, taking into consideration the site-specific constraints on spatial and temporal sample designs and measurement methods. Assumptions used to develop the monitoring program should be documented and critically examined for their adequacy and relevance (Clark et al., 2010). The final choice of monitoring program design, as well as the main assumptions and rationale for its selection, should also be documented at this stage.

**Section VII Summary**  
**(Level of effort considerations for monitoring plans)**

- The level of effort required for site closure monitoring plans is defined based on site-specific information (e.g., nature and impact of past human activities), data quality information (e.g., tolerance for potential decision errors), and resource constraints such as budget. Statistical power analysis can be used to define the sampling frequency and number of samples required to meet data quality objectives for decision-making.



**Figure VII-3: Flow chart summarizing the process that should be implemented in designing and performing a monitoring study (Figure 2-1 in USEPA, 2001c)**

## **VIII. EVALUATING MONITORING DATA FOR MANAGEMENT DECISIONS**

Once the monitoring plan has been developed, actions include data collection and analysis, evaluation of the results, addressing deviations from the DQOs, communication of the findings to stakeholders, and establishing management decisions based on the results (SPAWAR and ENVIRON 2010). Specific guidance for the completion of these activities is provided in Steps 5 and 6 of the USEPA (2004) monitoring framework. The following section highlights aspects of these activities that are important for achieving site closure.

An *adaptive site management* approach (Linkov et al., 2006) should be used to adjust the monitoring program design, the level of effort for sampling, and the remedial strategy throughout the post-remediation monitoring period as the monitoring data is collected (SPAWAR and ENVIRON, 2010). The predicted outcomes of remedial actions and monitoring activities are not always realized due to uncertainty regarding the assumptions about remedial strategy performance and efficacy; the monitoring conceptual models; or inherent natural variability in the metrics used for monitoring ecosystem recovery that may mask short-term data trends (USEPA, 2004; SPAWAR and ENVIRON, 2010). The adaptive site management approach allows for continual modification of the remedial strategy and monitoring plan if necessary, maximising the chances of achieving successful completion of the monitoring objectives in the shortest possible time period.

As the monitoring data are collected, the first stage in data review is to evaluate if the data meet the DQOs for the monitoring plan design. These include the spatial and temporal boundaries defined for monitoring each objective, as well as the data collection and data analysis methods and QAQC criteria defined in the monitoring QAPP. If the data do not meet the DQOs, the underlying reasons for the deviations should be assessed. In general, these will either be due to errors in the monitoring plan implementation or uncertainties in the assumptions about the remedial strategy outcomes or the monitoring conceptual model (USEPA, 2004). Once the cause of the deviations is identified, either the remedial strategy or the monitoring plan may be revised.

If the monitoring data meet the DQOs, the data are evaluated using the decision rules to identify further actions for the monitoring objective. Examples of generic management decisions are summarized in Table VIII-I. A framework for evaluating monitoring data is provided in Figure VIII-1. When exit criteria are achieved for a particular monitoring objective, related monitoring activities can be concluded. Further guidance for evaluating decision rules is provided in USEPA (2004).

Site closure is achieved when the exit criteria have been met for all of the monitoring objectives. At this point, the remedial strategy and the monitoring program for the site may be concluded. The monitoring program outcomes and the scientific rationale used to

determine that the site no longer poses unacceptable human health and ecological risks should be documented as part of the site closure process and reporting framework currently being developed by PWGSC.

Final site closure may not be attainable for those sites where contaminants remain in place (e.g., capped sites, engineered containment facilities) and ongoing maintenance and performance monitoring are required. However, as confidence in the remedy performance following disruptive events increases, the scale and frequency of performance monitoring can be greatly reduced.

**Section VIII Summary**  
**(Evaluating monitoring data for management decisions)**

- An adaptive management approach should be used to evaluate monitoring data as they are collected and revise the monitoring program and remedial strategy if needed. The first step in evaluating data is to assess if the data meet the desired data quality objectives and address any deviations. The data are then compared with the monitoring decision rules as outlined in Figure VIII-1.
- Site closure is achieved when all of the exit criteria for the monitoring objectives have been attained. At this point, site activities and the monitoring program may be concluded, and the reporting and regulatory process for site closure completed.

**Table VIII-I: Examples of generic management decisions based on monitoring decision criteria (after USEPA, 2004 and SPAWAR and ENVIRON, 2010)**

Condition	Decision
The exit criteria for the monitoring decision rules have been met.	Monitoring for ecosystem recovery is no longer required. Low-intensity and low-frequency performance monitoring may be required in some cases, such as to verify cap or MNR stability after severe storm events.
<p>The monitoring data are trending toward meeting the decision rules</p> <ul style="list-style-type: none"> <li>• Performance monitoring data affirm hypotheses regarding remedy effectiveness.</li> <li>• Attainment of the exit criteria for ecosystem recovery appears likely.</li> </ul>	Continuation of the current monitoring program and remedial strategy.
The monitoring data are inconclusive	More monitoring or alternative monitoring strategies or tools are required to evaluate remedy performance and ecosystem recovery.
<p>The monitoring data show mixed success</p> <ul style="list-style-type: none"> <li>• Performance monitoring data affirm hypotheses regarding remedy effectiveness.</li> <li>• Attainment of the exit criteria for ecosystem recovery does not appear likely.</li> </ul>	The current monitoring program and remedial strategy may require modification.
The monitoring decision rules have not been met.	Determine causation for the inability of the remedy to meet its objectives and modify the remedial strategy and monitoring plan accordingly.

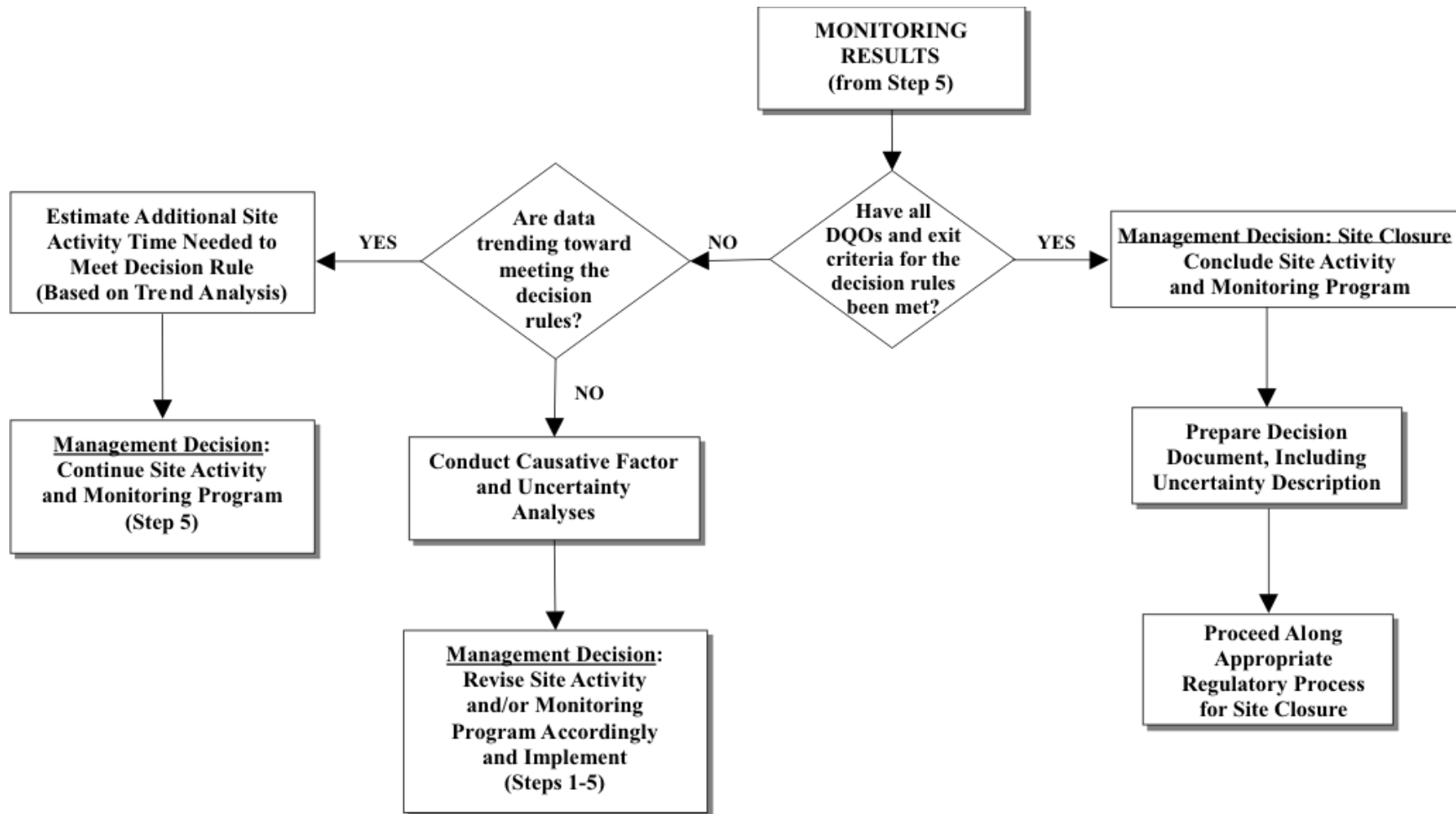


Figure VIII-1: Framework for evaluating monitoring data for progress toward site closure (modified from USEPA, 2004)



## IX. CONCLUSIONS

This document reviews the relevant scientific literature, guidance frameworks, and international policy documents concerning monitoring plan development and site closure for aquatic contaminated sites. The conclusions are as follows:

- General frameworks for monitoring plan development related to aquatic contaminated sites are available, as well as procedural documents outlining a reporting and regulatory framework for site closure of contaminated sites. However, the review did not identify any existing scientific guidance or policy documents specific to site closure of aquatic contaminated sites.
- Information needed to develop monitoring plans for site closure of aquatic contaminated sites is integrated in this document with the USEPA (2004) six-step process for monitoring plan development, as well as the Data Quality Objectives process (USEPA, 2006) for monitoring plan design. A consistent approach to developing monitoring plans is facilitated through identifying common monitoring objectives and associated monitoring tools and exit criteria for performance and ecosystem recovery monitoring.
- Measuring progress towards site closure requires the development of strong decision rules for interpreting monitoring data, including quantitative scientifically defensible exit criteria that represent the attainment of the desired condition for a monitoring objective. Site closure is attained when all exit criteria for the monitoring objectives have been met.
- Addressing uncertainty in monitoring data involves determining the tolerable limits on decision errors through evaluating the consequences of wrong decision-making, a detailed Quality Assurance Project Plan, and minimizing inherent variability when designing the monitoring plan where possible. The level of effort required for monitoring plans for site closure should be determined based on the balance between resource constraints and the desired level of statistical precision regarding uncertainty in decision-making.
- An adaptive management approach should be used to evaluate monitoring data as they are collected and the monitoring program and remedial strategy should be revised accordingly. A framework for evaluating monitoring data to assess if site closure has been attained is provided in Figure VIII-1.

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## **XI. CASE STUDIES OF AQUATIC LONG-TERM MONITORING PROGRAMS**

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## LIST OF ABBREVIATIONS

Abbreviation	Full name
AWQC	ambient water quality criteria
CAD	confined aquatic disposal
CoC	contaminant of concern
DEQ	(Oregon) Department of Environmental Quality
DFO	Department of Fisheries and Oceans
EPA	United States Environmental Protection Agency
ERA	ecological risk assessment
ERF	Eagle River Flats
ERZ	ecological risk zone
FWQC	Federal Water Quality Criterion
GE	General Electric Company
HBI	Hilsenhoff Biotic Index
LEL	lowest effect level
KPC	Ketchikan Pulp Company
LOAEL	lowest observed adverse effect level
MCUL	minimum cleanup level
MDEQ	Montana Department of Environmental Quality
NAPL	non-aqueous phase liquid
NMFS	National Marine Fisheries Service
NOAEL	no observed adverse effect level
NWP	Northern Wood Preservers Inc.
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
OC	organochlorine
OU	Operation Unit
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyl
PCDD/F	dioxin /furan
PCP	pentachlorophenol
ppb, ppm	parts per billion, parts per million
PWQO	Provincial Water Quality Objectives
RAO	remedial action objective
RG	remediation goal
ROD	record of decision
SBC	Silver Bow Creek
SEL	severe effect level
U.S. EPA	United States Environmental Protection Agency



## I. INTRODUCTION

Long-term monitoring is designated as Step 10 in the Federal Contaminated Sites Action Plan (FCSAP) Aquatic Contaminated Sites Framework. The overall goals of a long-term monitoring plan are evaluation of remedy effectiveness and documentation of ecosystem recovery (i.e., the on-going reduction of human health and environmental risks to acceptable levels, as well as the effectiveness of habitat mitigation). The types of monitoring employed and the level of effort undertaken will differ depending on the nature, size and complexity of the contaminated site and on the remedy chosen.

This appendix provides detailed examples of long-term monitoring case studies for aquatic contaminated sites. The case study review was used to ground-truth the approach to developing long-term monitoring plans outlined in the main document, as well as to provide specific examples of exit criteria and lessons learned in current and past aquatic long-term monitoring programs. Ten case studies of aquatic contaminated sites are summarized in the following pages. The case studies are from sites in Canada and the United States, include both freshwater and marine environments, and were selected to be representative of a range of aquatic remedial strategies and contaminant types. The review focused on the following components for each case study.

- **Primary sediment contaminants:** The primary contaminants on which the remedial activities and goals for site cleanup were based.
- **Sediment remedial strategies applied:** The technologies or approaches applied for the remedial cleanup of the site.
- **Site summary:** A brief overview of historical land use, contaminants present at the site and project timelines, and a summary of remedial activities implemented.
- **Remediation triggers and objectives:** A short summary of the issues that prompted the decision to remediate and the goals of the cleanup.
- **Receptors considered and protection level afforded:** An overview of human health and ecological risk assessments completed, focusing on which receptors were selected for inclusion in the risk assessment and the protection level afforded.
- **Monitoring plan summary:**

*Monitoring plan objectives:* Overall goals that the long-term monitoring program aims to accomplish.

*Monitoring approach and frequency:* A summary of where sampling will occur, how often locations will be monitored, monitoring methods, etc.

*Indicators and metrics chosen to evaluate each objective:* A summary of the indicators and metrics selected to evaluate each monitoring objective, along with the rationale for their selection. An indicator is a measurable variable that can be

used to provide information related to a specific monitoring objective. Metrics are the quantifiable measurement units used for the indicators.

***Exit criteria:*** Target action levels that represent the successful completion of a particular monitoring objective. Exit criteria are used to evaluate progress towards site closure.

- **Data quality objectives:** A description of the process used to determine sampling locations, sample numbers, sampling frequency, analytical methods and associated performance criteria, methods for interpreting results relative to the monitoring objectives and the level of uncertainty acceptable with respect to monitoring decision outcomes.
- **Monitoring habitat replacement and reconstruction:** A discussion of habitat replacement and any reconstruction efforts carried out after remediation.
- **Project performance, modifications and lessons learned:** A review of the success or failure of the long-term monitoring program, adjustments made to the program, and lessons learned.

## II. CASE STUDIES

### A. Hudson River

***Site custodian:***

General Electric Company (GE)

***Site location:***

Hudson River, New York

***Primary sediment contaminant:***

Polychlorinated biphenyls (PCBs)

***Sediment remedial strategies applied:***

Dredging, capping, monitored natural recovery



**Figure 1: Dredging the river during Phase 1 remediation.**

**Source:** <http://www.hudsondredging.com/>.

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#### ***1. Site Summary***

The Upper Hudson River Site incorporates a stretch of river approximately 64 km long along the Hudson River in eastern New York State, from Hudson Falls to the Federal Dam at Troy. From approximately 1947 to 1977, the General Electric Company (GE) discharged polychlorinated biphenyls (PCBs) from its capacitor manufacturing plants at the Hudson Falls and Fort Edward facilities into the Hudson River.

This project is currently in progress. The cleanup of the Upper Hudson River has been divided into two phases. Phase 1 of the project, which was completed in 2009, involved dredging 9.6 km of the river. Phase 2 of the project, to remove the remainder of the contaminated river sediment, commenced in 2011 and is expected to take between five and seven years to complete.

#### ***2. Remediation Triggers and Objectives***

In 1984, the site was listed on the National Priorities List and the United States Environmental Protection Agency (EPA) completed a feasibility study and issued a record of decision (ROD) for the site. The EPA chose an interim No Action remedy for the site. They recognized that PCB-contaminated sediment was a problem as the New York State Department of Environmental Conservation (NYSDEC) had issued a ban on

all fishing in the Upper Hudson River from Hudson Falls to the Federal Dam at Troy. However, the reliability and effectiveness of remedial technologies available at that time were uncertain and PCB concentrations in fish, sediment and water appeared to be declining over time.

In 1989, the EPA decided to initiate a detailed reassessment of the interim No Action decision. This was prompted by the Comprehensive Environmental Response, Compensation, and Liability Act requirement for a five-year review, technical advances in sediment dredging and treatment/destruction technologies, and a request by NYSDEC for a re-examination of the 1984 decision. Included in the reassessment was the completion of a human health and ecological risk assessment.

The EPA issued a Superfund ROD in 2002 calling for the removal and disposal of approximately 2.65 million cubic yards (2.03 cubic metres) of PCB-contaminated sediments from the Upper Hudson River. Dredging was chosen as the main remedial strategy because of sediment redistribution by erosion and river flows. The major components of the remedy selected by the EPA for the PCB-impacted sediments of the Upper Hudson River included the following:

- removal of sediments, primarily on a mass-per-unit area of 3 grams per metre squared ( $\text{g/m}^2$ ) Tri+ PCBs or greater (approximately 1.19 million cubic metres of sediments) from River Section 1
- removal of sediments, primarily on a mass-per-unit area of 10  $\text{g/m}^2$  Tri+ PCBs or greater (approximately 0.44 million cubic metres of sediments) from River Section 2
- removal of selected sediments with high concentrations of PCBs and high erosional potential (approximately 0.39 million cubic metres) from River Section 3
- removal of all PCB-contaminated sediments within areas targeted for remediation, with an anticipated residual of approximately 1 milligram per kilogram ( $\text{mg/kg}$ ) Tri+ PCBs (prior to backfilling)

The following remedial action objectives (RAO) were developed by the EPA for protection of human health and the environment:

- Reduce the cancer risks and non-cancer health hazards for people eating fish from the Hudson River by reducing the concentration of PCBs in fish.
- Reduce the risks to ecological receptors by reducing the concentration of PCBs in fish.

- Reduce PCB levels in sediments in order to reduce PCB concentrations in river (surface) water that are above surface water Applicable or Relevant and Appropriate Requirements.
- Reduce the mass of PCBs in sediments that are or may be bioavailable.
- Minimize the long-term downstream transport of PCBs in the river.

### ***3. Receptors Considered and Protection Level Afforded***

Human health and ecological risk assessments were carried out for the site. The reports found that there were increased cancer risks and non-cancer health hazards associated with human ingestion of fish. Ecological risks were associated with ingestion of fish by birds, fish and mammals (including largemouth bass, striped bass, belted kingfisher, great blue heron, bald eagle, mink and river otters).

For more information regarding specific protection level goals, refer to the individual monitoring plan objectives below.

### ***4. Summary of Monitoring Plan***

#### **a. Water column monitoring**

##### **1) Objectives**

- Provide water column PCB concentration data over time to assess whether the RAOs and remediation goals (RGs) (see below) are being achieved.
  - 0.5 ug/L federal maximum contaminant levels
  - 0.09 ug/L New York State standard for protection of human health and drinking water sources
  - 0.03 ug/L criteria continuous concentration Federal Water Quality Criterion (FWQC) for saltwater
  - 0.014 ug/L criteria continuous concentration FWQC for freshwater
- Determine whether the chosen remedy has been effective in minimizing long-term downstream transport of PCB load.
- Determine the level of PCB concentrations entering the river from upstream of the project area and from the Mohawk River.

##### **2) Monitoring approach and sampling frequency**

- Nine monitoring stations selected to monitor conditions.
- Sampling frequency at each monitoring station varies depending on the location, seasonal variations in PCB concentrations and the downstream transport of PCBs during high flow events. In most cases, sampling frequency is weekly or monthly.
- Three-year monitoring as per the consent decree. At this time the data will be reviewed and a possible reduction in monitoring stations may be agreed

upon. At the end of 20 years of monitoring or at any time thereafter, if GE concludes that further reductions or other modifications to the monitoring program are warranted, a written proposal may be submitted for further modifications or for termination of the program, as appropriate.

3) Indicators and metrics chosen to evaluate each objective

- PCB concentrations and total suspended solids; surface water samples will be tested for temperature, specific conductivity, pH, turbidity, and dissolved oxygen (DO). Metals may be monitored once a month, depending on agreement between EPA and GE (to be monitored once a month for first year only, then to be re-assessed after the first year).

4) Exit criteria

- Monitoring will be carried out for three years. After that three-year period, the data will be reviewed and GE may submit a plan for reduced monitoring to EPA for approval. Monitoring will continue for 20 years, after which GE may submit another plan to EPA for reduced or terminated monitoring. The decision to stop monitoring will be made by EPA when it determines that the relevant RAOs and RGs (see list above) have been achieved.

**b. Fish monitoring**

1) Objectives

- Provide data on PCB concentrations in fish over time to assess whether the RAOs, RGs and target levels set forth in the ROD (see below) are being achieved.
  - Human health goals:
    - 0.05 mg/kg PCBs in fish fillet, based on non-cancer hazard indices for the reasonable maximum exposure adult fish consumption rate of one half-pound meal per week (this level is protective of cancer risks as well)
    - 0.2 mg/kg PCBs in fish fillet, which is protective at a fish consumption rate of one half-pound meal per month, and 0.4 mg/kg PCBs in fish fillet, which is protective of the average angler who consumes one half-pound meal every two months
  - Ecological goals:
    - 0.3 to 0.03 mg/kg PCBs in fish (largemouth bass, whole body), based on the lowest observed adverse effect level (LOAEL) and the no observed adverse effect level (NOAEL) for consumption of fish by the river otter

- 0.7 to 0.07 mg/kg PCBs in spottail shiner (whole fish), based on the NOAEL and LOAEL for the mink, which is a species known to be sensitive to PCBs
  - Provide data on PCB concentrations in Hudson River fish to the New York State Department of Health for evaluation of fish consumption advisories.
- 2) Monitoring approach and sampling frequency
- Four stations will be monitored in the Upper Hudson River; stations represent reference conditions, River Section 1, River Section 2 and River Section 3.
  - Three stations will be monitored in the Lower Hudson River; one station will coincide with the Baseline Monitoring Program and the Remedial Action Monitoring Program fish sampling locations.
  - Standard sampling methods, including netting, electroshocking and angling, will be used to collect target species.
  - Monitoring will be conducted annually, with the exception of two locations which will be sampled every two years. The program will be reviewed after three years and possibly decreased in scope subsequently.
- 3) Indicators and metrics chosen to evaluate each objective
- Species to be analyzed vary depending on location. Species groups include striped bass, black bass (largemouth and/or smallmouth bass), ictalurids (bullhead and/or channel catfish), yellow perch, yearling pumpkinseed, and forage fish (spottail shiner and/or alternative).
  - Standard fillets are analysed for bass, bullhead, catfish, and perch; individual whole body samples for yearling pumpkinseeds; and whole body composites for spottail shiners or other forage fish.
  - The required sample size varies by species and location. For locations where individual fish are submitted for analysis, between 20 and 30 fish are targeted. Where forage fish will be sampled, two composites per location will be collected.
  - PCBs and percent lipid shall be measured to monitor PCB concentrations in fish. Supplementary information to be collected includes the weight and length of collected fish, external abnormalities, sex of fish, and scale samples for age determination in pumpkinseeds to ensure that they are yearling fish.
  - Supplementary sampling to provide information for fish consumption advisory assessment will be conducted. The species for collection vary by location and include white perch, walleye, carp, catfish, herring, American eel, bluefish, striped bass and black bass. Sample sizes of 20 individuals of

striped bass and 10 individuals of the remaining species are required. Standard fillets are analyzed for PCBs and % lipids.

4) Exit criteria

- Monitoring will be carried out for three years. After that three-year period, the data will be reviewed and GE may submit a plan for reduced monitoring to EPA for approval. Monitoring will continue for 20 years, after which GE may submit another plan to EPA for reduced or terminated monitoring. The decision to stop monitoring will be made by EPA when it determines that the relevant RAOs and RGs (see list above) have been achieved.

5) Supplemental fish sampling program for fish consumption advisory

- GE will conduct a supplemental fish sampling program to provide PCB data to the New York State Department of Health (NYSDOH) for evaluating whether existing fish advisories should be modified. This program will involve sampling four other locations not listed above and the collection of the following (in addition to those outlined above in the fish monitoring section):
- Location 1: 10 individual samples each of walleye, carp and herring (alewife and/or blueback).
- Location 2: 10 individual samples each of white perch, walleye, carp, catfish (white and/or channel) (not required if collected as part of fish monitoring) and herring (alewife and/or blueback).
- Location 3: 20 individual samples of striped bass and 10 individual samples each of white perch, carp, catfish (white and/or channel), American eel, black bass (largemouth and/or smallmouth) and herring (alewife and/or blueback).
- Location 4: 10 individual samples each of white perch, catfish (white and/or channel), carp, American eel and bluefish.

This sampling will be completed in the first, second and third years of the fish monitoring program. The samples will be processed for analysis as standard fillets and will be analyzed for PCBs and percent lipids. After the initial three years of sampling is complete, the NYSDOH will inform GE if additional sampling is required to further evaluate fish consumption advisories.

**c. Sediment monitoring**

1) Objectives

- Determine post-remediation PCB levels in sediments in non-dredge areas of the Upper Hudson River.



- Provide data on areas of sediments that exceeded the mass-per-unit-area removal criteria but were not targeted for removal because they were buried by cleaner sediments, to assess whether erosion of the deposits has occurred.
  - Determine sediment recovery rates in non-dredged areas of the Upper Hudson River.
  - Examine the changes to surface PCB concentrations in backfilled areas.
- 2) Monitoring approach and sampling frequency
- Will sample non-dredged areas and backfilled areas.
  - Non-dredged areas: Will sample surface sediments in each area upon completion of dredging (approximately 350 sampling locations per sampling event). Each area will be sampled every three years following the initial sample collection until data satisfy the approved recovery criteria. (As there are no federal or state cleanup standards for PCBs in sediment, the goal is to reduce the mass of PCBs in sediment that are or may be bioavailable, thus ultimately reducing PCB levels in fish and the associated risks to human health and the environment.) These samples will provide a record of the recovery of surface sediments in non-dredged areas.
  - Backfilled areas: Collect a minimum of 50 samples from backfilled areas in each river section. Also to be sampled every three years.
- 3) Indicators and metrics chosen to evaluate each objective
- Surface sediments (0–2 inch; 0–5 cm).
  - Analytes are PCBs (total Aroclors) and TOC, with a subset of the samples analyzed for the radioisotope Beryllium-7 to identify recent deposition.
  - Bathymetric surveys (multibeam or single-beam survey techniques) to produce a riverbed elevation map in near-shore, shallow areas.
- 4) Exit criteria
- Monitoring will be carried out for three years. After that three-year period, the data will be reviewed and GE may submit a plan for reduced monitoring to EPA for approval. Monitoring will continue for 20 years, after which GE may submit another plan to EPA for reduced or terminated monitoring. The decision to stop monitoring will be made by EPA when it determines that the relevant RAOs and RGs have been achieved.

#### **d. Capping**

##### **1) Objectives**

- Determine whether the physical integrity of individual cap layers/components has been maintained, through the use of sediment cores and other means.

- Determine whether the effectiveness of the cap component for chemical isolation has been maintained.
  - Determine whether there is a need for additional protective measures and institutional controls (e.g., additional controls for caps in the navigational channel, notifications to boaters regarding actions in capped areas, etc.).
  - Determine whether the physical integrity and chemical isolation effectiveness of cap layers/components installed in known fish spawning areas are maintained, through monitoring using response thresholds that are at a spatial scale appropriate for the extent and depth of cap placed within the spawning ground and the nature of the potential disturbance (e.g., an area less than 4,000 square feet (370 m<sup>2</sup>) or an area less than 20% of the cap).
- 2) Monitoring approach and sampling frequency
- Bathymetric surveys will be used as the primary means to evaluate the integrity of the cap. The survey will be carried out one year following the placement of the cap. This survey will be used as the baseline for subsequent cap measurements. If an area has lost more than three inches of thickness over 4,000 square feet (370 m<sup>2</sup>) or over 20% of the cap area, whichever is less, the cap will be repaired.
  - Subsequent bathymetric surveys will be performed 5 and 10 years after construction of the cap and thereafter at 10-year intervals in perpetuity.
  - Visual surveys will be conducted if a measureable loss to the cap is observed based on comparisons to the record drawings and/or the first-year bathymetric survey.
  - Six sentinel areas will be selected for chemical isolation monitoring. Twenty cores will be collected per sentinel area and monitoring will commence 10 years after the construction of the first sentinel cap.
- 3) Indicators and metrics chosen to evaluate each objective
- Bathymetric surveys will be conducted to investigate cap thickness.
  - Sediment cores will be analyzed for PCBs.
- 4) Exit criteria
- Bathymetric surveys will be performed 5 and 10 years after construction of the cap and will be continued at 10-year intervals in perpetuity.
  - Monitoring of the sentinel areas may be terminated after 30 years or at EPA's discretion.

## ***5. Data Quality Objectives***

Data quality objectives were not discussed in the documentation reviewed.

## **6. Monitoring Habitat Replacement/Reconstruction**

### **a. Shoreline stabilization and other stabilization measures**

Natural shorelines shall be maintained where practicable (i.e., the “default” shoreline stabilization measure is installation of near-shore backfill). Shoreline stabilization and other stabilization measures used within Phase 2 dredge areas include the use of planted material, biologs, coir fabric, backfill or riprap to stabilize riverbanks, shorelines and habitat replacement and reconstruction areas as needed. For Phase 2, it is proposed that these measures be installed in the year of dredging/backfilling. If specific response actions are necessary to prevent or stop problems such as bank slope failure where structural integrity is needed to support the permanence of the stabilization measure, GE shall implement such response actions.

### **a. Monitoring objectives**

The monitoring objective for the post-construction monitoring of habitat replacement/ reconstruction measures is to:

- evaluate whether, and to what extent, the replacement/reconstruction of habitat in a given river reach is achieving the goal of replacing the habitat functions to within the range found in similar physical settings in the Upper Hudson River, given changes in river hydrology, bathymetry and geomorphology resulting from the remedy as well as from other factors.

### **b. Monitoring approach and frequency**

- Monitoring of the installed stabilization measures will be conducted once a month (or more frequently if conditions indicate) within the year of installation and annually (or more frequently if conditions indicate) thereafter.
- Sampling of the replaced and reconstructed unconsolidated river bottom, aquatic vegetation bed and riverine fringing wetland habitats shall be conducted annually between June 1 and September 30 and will focus on peak growth times for aquatic vegetation and wetlands.
- Data shall be collected from both target (dredged) and unimpacted (non-dredged area) stations for each habitat.
- Collected data should be evaluated on an ongoing basis (at a minimum, annually) to determine whether modifications to the sampling design are warranted.
- In addition, fish and wildlife observational and other data may be collected in any of the habitat replacement/reconstruction areas as direct measurements of habitat functions. Areas within the Upper Hudson River that are not directly impacted by the dredging shall be used as post-remediation reference sites. In addition, at least one off-site reference station within each of the upstream

Upper Hudson River and the Lower Mohawk River will be included as reference sites.

- The off-site reference areas will be used to evaluate the impacts (if any) of potential broad, watershed-wide or regional changes unrelated to the remediation project that may extend beyond the 40-mile (64 km) project area, and to determine whether these changes have had an effect on habitat replacement/ reconstruction.
- Monitoring stations shall be identified within each habitat replacement/ reconstruction area located within the certification unit. Parameters to be monitored in each habitat area are summarized Table A-1 below.

**Table A-1: Parameters to be monitored in each habitat type of the Hudson River**

<b>Unconsolidated river bottom</b>	<b>Submerged aquatic vegetation beds</b>	<b>Riverine fringing wetlands</b>
<ul style="list-style-type: none"> <li>- substrate type</li> <li>- epifaunal substrate and cover</li> <li>- total organic carbon</li> <li>- temperature</li> <li>- DO</li> <li>- specific conductivity</li> <li>- pH</li> <li>- turbidity</li> <li>- percent fines</li> <li>- embeddedness</li> <li>- downfall</li> </ul>	<ul style="list-style-type: none"> <li>- total organic carbon</li> <li>- shoot density</li> <li>- percent cover</li> <li>- shoot biomass</li> <li>- plant species composition (including percent nuisance species)</li> <li>- sediment nutrient availability</li> <li>- light availability</li> <li>- water depth</li> <li>- current velocity</li> <li>- temperature</li> <li>- DO</li> <li>- specific conductivity</li> <li>- pH</li> <li>- turbidity</li> <li>- percent fines</li> <li>- downfall</li> </ul>	<ul style="list-style-type: none"> <li>- stem density</li> <li>- stem length</li> <li>- stem thickness</li> <li>- soil properties</li> <li>- percent cover</li> <li>- shoot biomass</li> <li>- plant species composition (including percent nuisance species)</li> <li>- slope</li> <li>- water depth/inundation</li> <li>- water temperature</li> <li>- DO</li> <li>- specific conductivity</li> <li>- pH</li> <li>- turbidity</li> <li>- area</li> <li>- wetland edge</li> <li>- area of buffer</li> <li>- percent contiguous with other habitats</li> </ul>

**c. Success criteria**

EPA and GE will discuss and further develop success criteria for Phase 2, subject to EPA approval, based on the results of Phase 1 success criteria

derivations for each habitat type. If GE and EPA cannot reach agreement, the success criteria shall be determined by EPA.

**d. Design**

Parameters for habitat replacement and reconstruction design include

- backfill placement;
- analyses for submerged aquatic vegetation design;
- plant stock;
- post-initial planting monitoring and maintenance.

***7. Project Performance, Modifications and Lessons Learned***

Project performance and modifications were not discussed in the documentation reviewed.

***8. Further Site Information***

<http://www.epa.gov/udson>

<http://hudsondredgingdata.com/content/pdf/phase2/2010-12-16%20Attachment%20E.pdf>

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## B. McCormick and Baxter Creosoting Co.

### *Site custodian:*

Oregon Department of  
Environmental Quality (DEQ)

### *Site location:*

Willamette River, Portland, Oregon

### *Primary sediment contaminant:*

Polycyclic aromatic hydrocarbons (PAHs), pentachlorophenol (PCP), non-aqueous phase liquid (creosote), dioxins/furans, arsenic, chromium, copper and zinc

### *Sediment remedial strategy applied:*

Sediment cap



**Figure 2: Site overview with the cap outlined in blue.**

Source: <http://www.mandbsuperfund.com/SitePages/Home.aspx>.

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### *1. Site Summary*

The McCormick and Baxter Creosoting Company, Portland Plant, is situated on the Willamette River, in Portland, Oregon. The plant operated from 1944 until 1991. During a preliminary site investigation in 1983, environmental problems were identified. In 1987, Oregon Department of Environmental Quality (DEQ) entered into a Stipulated Order with McCormick and Baxter which required a series of corrective actions. McCormick and Baxter filed for bankruptcy in 1988 and in 1990 DEQ assumed responsibility for completing the investigation and cleanup activities at the site. The site was added to the National Priorities List in 1994.

Site investigations noted releases of contaminants to soils, groundwater and sediments. Remedial investigations identified two non-aqueous phase liquid (NAPL) plumes migrating towards the river and impacting surface water and sediments and an additional NAPL plume migrating toward Willamette Cove.

Remedial construction activities were completed in 2005. Remedial activities included soil excavation and disposal, upland soil capping, installation of a subsurface barrier wall, NAPL recovery, construction of a multi-layer sediment cap in the Willamette River, monitoring, and engineering and institutional controls such as deed notices and restrictions on future land use.

## ***2. Remediation Triggers and Objectives***

### ***Remedial Action Objectives:***

- Prevent human exposure through direct contact (ingestion, inhalation or dermal contact) to contaminated surface and near-surface soil that would result in an excess lifetime cancer risk above  $1 \times 10^{-6}$  for individual compounds, above  $1 \times 10^{-5}$  for additive carcinogenic compounds, or above a hazard index of 1 for non-carcinogenic compounds in an industrial land use scenario.
- Prevent storm water runoff containing contaminated soil from reaching the Willamette River.
- Prevent human exposure to or ingestion of groundwater with contaminant concentrations in excess of federal and state drinking water standards or protective levels.
- Minimize further vertical migration of NAPL to the deep aquifer.
- Prevent discharges to the Willamette River of groundwater that contains dissolved contaminants that would result in contaminant concentrations within the river in excess of background concentrations or in excess of water quality criteria for aquatic organisms.
- Minimize NAPL discharges to the Willamette River beach and adjacent sediment to protect human health and the environment.
- Remove mobile NAPL to the extent practicable to reduce the continuing source of groundwater contamination and potential for discharge to Willamette River sediment.
- Prevent direct contact with contaminated sediment by humans and aquatic organisms.
- Minimize releases of contaminants from sediment that might result in contamination of the Willamette River in excess of federal and state ambient water quality criteria.

## ***3. Receptors Considered and Protection Level Afforded***

Human health and ecological risk assessments were completed for the site.

### **a. Human health risk assessment**

Polycyclic aromatic hydrocarbons (PAHs) and dioxins/furans were compared to background concentrations and local reference concentrations as they are abundant in urban environments. Contaminants of concern included carcinogenic and non-carcinogenic PAHs, chlorinated phenols including PCP, tetrachlorophenol and trichlorophenol, dioxins/furans, hexachlorobenzene, arsenic and chromium.

Recreational scenarios including beach visitors and recreational fishing had a hazard index of 2 related to dermal exposure to contaminated sediment. The risks associated with living near the site and eating fish or shellfish collected near the site were no greater than those normally present in any urban environment.

**b. Ecological risk assessment**

Bioassay results of the river sediment indicated that the sediment is likely to be toxic to benthic organisms. The toxicity of soil and sediment at the site to other types of wildlife was not quantified. Based on bioaccumulation and histopathological studies of the site, it was determined that risks to fish and shellfish near the site were low, although seeps of oily material may present acute risks to individual organisms.

**4. *Summary of Monitoring Plan***

**a. Sediment monitoring**

1) Objectives

- Maintain contaminant concentrations in surface sediments below the following risk-based cleanup goals, as specified in the record of decision (ROD). As no state or federal sediment quality criteria exist, risk-based cleanup goals were developed.
  - arsenic: 12 mg/kg, dry weight, based on background concentrations
  - pentachlorophenol: 100 mg/kg, dry weight, based on an acceptable risk of  $1 \times 10^{-6}$  for recreational exposure scenario
  - total carcinogenic PAHs: 2 mg/kg, dry weight, based on an acceptable risk of  $1 \times 10^{-6}$  for recreational exposure scenario
  - dioxins/furans:  $8 \times 10^{-5}$  mg/kg, dry weight, based on an acceptable risk of  $1 \times 10^{-6}$  for recreational exposure scenario
- Protect benthic organisms, based on sediment bioassay tests resulting in impaired survival and growth (i.e., weight).
- Minimize releases of contaminants from sediment that might result in contamination of the Willamette River in excess of the following federal and state ambient water quality criteria:
  - arsenic (III): 190 micrograms per litre ( $\mu\text{g/L}$ )
  - chromium (III): 210  $\mu\text{g/L}$
  - copper: 12  $\mu\text{g/L}$
  - zinc: 110  $\mu\text{g/L}$
  - PCP: 13  $\mu\text{g/L}$
  - acenaphthene: 520  $\mu\text{g/L}$
  - fluoranthene: 54  $\mu\text{g/L}$



- naphthalene: 620 µg/L
  - total carcinogenic PAHs: 0.031 µg/L
  - dioxins/furans: 1x10<sup>-5</sup> nanograms per litre (ng/L)
  - Prevent visible discharge of creosote to the Willamette River.
  - Maintain the armouring layer to within 50% of the design specification.
  - Maintain uniformity and continuity of articulated concrete block armouring.
  - Maintain at least 20% excess sorption capacity of the organoclay cap.
- 2) Monitoring approach and sampling frequency
- The cap will be monitored regularly after the first five years of installation and after any major flood event to verify its integrity. After five years, the inspection frequency will be reassessed.
- 3) Indicators and metrics chosen to evaluate each objective
- Monitoring activities for the sediment cap include:
    - visual inspections of near-shore areas
    - aerial photography of the shoreline during extreme low river stages (late September or early October)
    - multi-beam bathymetric surveys and side-scan sonar surveys of deeper areas
    - diver inspections of areas of concern identified from the bathymetry and sonar surveys
  - Monitoring activities also include collection of samples from:
    - surface water
    - inter-armouring water
    - sub-armouring water
    - granular organophyllic clay cores
    - crayfish
- 4) Exit criteria
- Not discussed.

### ***5. Data Quality Objectives***

Data quality objectives were not discussed in the documentation reviewed.

### ***6. Monitoring Habitat Replacement/Reconstruction***

Descriptions and monitoring of habitat replacement and reconstruction activities were not discussed in the documentation reviewed.

## ***7. Project Performance, Modifications and Lessons Learned***

The project has been found to be functioning as intended by the ROD. The exposure assumptions and toxicity data used at the time of remedy selection were found to be no longer valid when the second five-year review was completed in 2006. In this report, the United States Environmental Protection Agency (EPA) determined that alternative concentration limits were not valid as substitutes for maximum contaminant levels in groundwater at the site. New cleanup levels for groundwater have not yet been selected formally. DEQ has revised and adopted new water quality criteria for human consumption of fish based on a fish consumption rate that is 10 times higher than the rate used by EPA to develop national AWQC. EPA has not yet approved DEQ's proposed new water quality criteria. The remedial action objectives and cleanup goals for soil and sediment are still valid and protective of current and expected future land use.

## ***8. Further Site Information***

<http://www.mandbsuperfund.com/SitePages/Home.aspx>

Hart Crowser, Inc. and GSI Water Solutions Inc., 2010. Operational and Maintenance Report, January 2009 to December 2009 —McCormick and Baxter Superfund Site, Portland, Oregon. Oregon Department of Environmental Quality.

Oregon Department of Environmental Quality and U.S. Environmental Protection Agency, 2011. Third Five-year Review Report for McCormick & Baxter Creosoting Company Superfund Site.

United States Environmental Protection Agency, 1996. Record of Decision, McCormick and Baxter Creosoting Company, Portland Plant.

## C. Lower Fox River and Green Bay

### *Site custodian:*

Brown County, East Bay, U.S.  
Environmental Protection Agency, Georgia-Pacific Consumer Products LP

### *Site location:*

Green Bay, Wisconsin

### *Primary sediment contaminant:*

Polychlorinated biphenyls (PCBs)

### *Sediment remedial strategies applied:*

Dredging, capping, monitored natural recovery



**Figure 3: Site overview showing the breakdown of each OU. Source: U.S. EPA, 2007.**

### *1. Site Summary*

The Lower Fox River has the highest concentration of pulp and paper mills in the world. During the 1950s and 1960s, these mills used polychlorinated biphenyls (PCBs) in their operations, and the PCBs eventually contaminated the river. It has been estimated that the 14 million cubic yards of contaminated sediments in Lower Fox River contain over 65,000 pounds of PCBs, and at least several hundred million cubic yards of sediments in Green Bay are contaminated with as much as 150,000 pounds of PCBs.

Little Lake Butte des Morts Operation Unit (OU) 1 was the first of five portions of the Lower Fox River site to be cleaned up. This section was completed in 2009 with the removal of approximately 370,000 cubic yards of contaminated sediment. Dredging and capping of contaminated sediment below the De Pere Dam was completed in 2008; 130,000 cubic yards of contaminated sediment was removed under a federal agreement that the United States Environmental Protection Agency (EPA) and Wisconsin Department of Natural Resources reached with two paper companies in April 2006. This case study will focus on OU1.

## ***2. Remediation Triggers and Objectives***

Fish and wildlife in the area are contaminated with PCBs and people who eat contaminated fish or waterfowl may suffer adverse health effects. Fish consumption advisories for the site were first issued in 1976 and are still in effect.

The remedial action level for the project calls for remediation of sediments with PCB concentrations above 1 ppm. If post-dredged residual PCB sediment concentrations remain above 1 ppm in OU 1 following the remedial action, the contingent cleanup level is to attain a surface-weighted average concentration in sediment of 0.25 ppm.

The remedial objectives are to:

- Achieve, to the extent practicable, surface water quality criteria throughout the site. The current water quality criteria for PCBs are 0.003 nanograms per litre (ng/L) for the protection of human health and 0.012 ng/L for the protection of wild and domestic animals.
- Protect humans who consume fish from exposure to contaminants of concern (CoCs) that exceed protective levels. The short-term goal is to protect human health by removing the fish consumption advisories as quickly as possible. The long-term goal for protecting human health is for fish consumers to be able to eat unlimited amounts of fish safely, within 10 years of completion of remediation for occasional consumers and within 30 years for high-intake consumers.
- Protect ecological receptors such as invertebrates, birds, fish and mammals from exposure to CoCs above protective levels. The expected timeframe to achieve safe ecological thresholds for fish-eating birds and mammals is 30 years following remedy completion.
- Reduce transport of PCBs from the Lower Fox River into Green Bay and Lake Michigan as quickly as possible. The expectation is to decrease sediment loading into Green Bay and Lake Michigan to levels comparable to the loading from other Lake Michigan tributaries.

## ***3. Receptors Considered and Protection Level Afforded***

Conclusions from the human health and ecological risk assessments conclude that fish consumption represents the greatest level of risk for human and ecological receptors, aside from the direct risks posed to benthic invertebrates via direct exposure to contaminated sediments. Potential risks from total PCBs are indicated for water column invertebrates, benthic and pelagic fish, and insectivorous, piscivorous and carnivorous birds. Risk based on weight of evidence was used to determine that predatory birds have actual risk — specifically, the bald eagle, which is listed as threatened by the federal government.

The human health remedial action objective is to remove fish consumption advisories for recreational and high-intake fish consumers. Numerical target tissue concentrations were not provided for the protection of human health.

The ecological remedial action objective is the achievement of safe ecological thresholds for fish-eating birds and mammals (cormorants, terns and mink), as they are among the most sensitive ecological receptors to PCB contamination. Numerical target tissue concentrations were not provided for the protection of ecological resources.

#### ***4. Summary of Monitoring Plan***

The overall objective of the long-term monitoring plan is to characterize long-term post-remediation water quality and fish tissue quality in the Lower Fox River and Green Bay. The combined baseline and long-term monitoring data will provide the response agencies with information to determine whether the implemented remedy meets remedial action objectives (RAOs) and risk reduction success criteria.

The long-term monitoring objectives include:

- monitoring reductions in water and fish tissue concentrations
- monitoring progress toward achieving human health risk goals
- monitoring progress toward achieving ecological risk goals
- monitoring reductions in PCB loadings to Green Bay

##### **a. Water monitoring**

###### **1) Objective**

- Monitor the net PCB contribution from each OU and the effectiveness of the remedy in each OU.

###### **2) Monitoring approach and sampling frequency**

- Monthly sampling of 10 stations during the eight-month non-winter season between April and November.
- 80 water samples, plus QC samples, during a given monitoring year.
- The water quality monitoring locations are the same as those used in the Baseline Monitoring Program.
- Area-weighted composite samples will be collected on specified transects to obtain representative water concentrations averaged over the cross-section of flow.
- Transects will be sampled in general accordance with USGS “quarter-point” sampling procedures. The channel cross-sections are divided into three equal areas based on bathymetric data. In the Lower Fox River and

Lake Winnebago, discrete water samples will be collected at 0.2 and 0.8 times the depth of the water column. In Green Bay, the sampling depths will be adjusted based on the observed temperature profiles and, specifically, the depth of the thermocline at the time of sampling.

- Discrete water subsamples will be collected at each of the six quarter-point locations and depths (i.e., 2 depths x 3 stations = 6 subsamples for each transect).
- Sampling will be carried out in five-year intervals, with sampling activities to be scheduled one year before the five-year review. The review will then reassess the frequency of sampling and assess whether the RAOs have been achieved.

3) Indicators and metrics chosen to evaluate each objective

- PCB concentrations in water samples.

4) Exit criteria

- Not discussed.

**b. Fish tissue**

1) Objective

- Monitor fish tissue PCB concentrations to determine whether they are declining in response to sediment remedial actions.

2) Monitoring approach and Frequency

- Sample four different types of species: walleye (human health index species), carp and drum (ecological index species), and gizzard shad (young forage fish species).
- The fish will be sampled at nine different stations. The locations will be the same as those for water monitoring with one exception.
- Each walleye station will be comprised of 15 individual fish; each carp or drum station will be comprised of five composite samples of five fish each; and each gizzard shad station will be comprised of seven composite samples of 25 fish in each composite.
- It is expected that different fish species will be collected from different parts of the OUs because of varying habitat preferences, feeding and migration patterns. Exact locations may be adjusted in response to the local field conditions at the time of sampling.
- Sampling will occur between August 15 and September 15. Collection activities may be extended for another month if necessary to fill data gaps.

- Sampling will be carried out in five-year intervals, with sampling activities to be scheduled one year before the five-year review. The review will then reassess the frequency of sampling and determine whether RAOs have been achieved.
- If the walleye catch is found to be deficient, bass may be substituted for the human health index species. Bass fishing in certain OUs (Lake Winnebago, OU 4 and OU 5) should be conducted in the month of June to be consistent with the bass collection schedule used in the Baseline Monitoring Program.

### 3) Indicators and metrics chosen to evaluate each objective

- Target fish species (walleye, carp, drum and gizzard shad) were selected based on the following criteria:
  - presence of fish consumption advisories (human health index species)
  - popular in recreational fishery (human health index species)
  - key species evaluated in human health or ecological risk assessments
  - common food source for upper-level animals, i.e., fish-eating mammals and birds (ecological index species)
  - available in the Lower Fox River and Green Bay (according to recommendations from State fish biologists)
- In OU 1, walleye fillets were analyzed for PCB concentrations.
  - Length and weight were also recorded to ensure that scientifically valid comparisons are made.

### 4) Exit criteria

- Not discussed.

## c. **Surficial sediment monitoring**

### 1) Objectives

- Collect sediment samples to demonstrate compliance with the ROD's remedial design.

### 2) Monitoring approach and frequency

- 63 composite surface sediment samples were collected from OU 1.

### 3) Indicators and metrics chosen to evaluate each objective

- Samples were analyzed for PCB concentrations.
- Stratified sampling and analysis was used in order to combine data from dredging areas, sand-covered areas and no-action areas.

#### 4) Exit criteria

- Not discussed.

### ***5. Data Quality Objectives***

The collection of water and fish tissue data is targeted to achieve a 90% confidence level and 80% power level.

Location control: Water quality monitoring stations will be located to within a target accuracy of two metres using a differential global positioning system. The beginning, end, and turning points of fishing transects will be located to a target accuracy of within 10 metres using a global positioning system as well as references to shoreline landmarks.

Precision: Checks for field and analytical precision will include the analysis of field replicates for water and fish, as well as for matrix spike/matrix spike duplicate.

Accuracy: Both field accuracy (temperature and turbidity measurements) and analytical accuracy will be monitored through initial and continuing calibration of instruments. In addition, internal standards, matrix spike, blank samples, laboratory control sample, and surrogate standards will be used to assess the accuracy of the analytical data. Accuracy will be calculated in terms of percent recovery.

Sampling programs have been chosen to ensure the samples are representative.

### ***6. Monitoring Habitat Replacement/Reconstruction***

Descriptions and monitoring of habitat replacement and reconstruction activities were not discussed in the documentation reviewed.

### ***7. Project Performance, Modifications and Lessons Learned***

#### **a. Results**

For OU1 (Little Lake Buttes des Morts), at which remedial activities occurred from 2004 through 2009, 2010 results indicated a reduction in PCB concentrations for fish, sediment, and water samples.

##### 1) Fish

PCB concentrations in walleye fillets decreased an average of 73% as a result of the sediment remediation. This is approximately 15 to 20 years faster than the projected rate for natural recovery without remediation (based on full-time data set records from 1990 to 2003).



It was noted that, during dredging activities, fish-tissue PCB concentrations increased above background levels. However, they decreased rapidly to substantially lower than expected levels after the remediation activity was complete.

## 2) Sediment

The PCB concentration in the sediment was reduced an average of 94%, from an average of 3.7 ppm pre-remediation to 0.23 ppm after remediation.

## 3) Water

For OU 1's water column PCB concentrations, the post-remediation (2010) results are significantly lower than pre-remediation (1998) results and show even more of a reduction when compared to the baseline monitoring (2006/2007) results. However, due to various changes in field sampling and analytical methods between 1998 and 2010, the percentage change effected by the remediation cannot be reliably estimated.

It was noted that water column PCB concentrations increased above background levels during dredging but that they decreased rapidly to substantially lower than expected levels after remediation.

# **b. Lessons learned**

The statistical characteristics of the data collected in the baseline monitoring program were used to validate the sample sizes for the long-term monitoring program.

## 1) Fish

Statistical confidence goals were not always met in the gizzard shad data, the young-of-year species. Four of the OUs showed only modest statistical power, with 80 to 90% confidence. Therefore, the gizzard shad sample size will be increased from five to seven composite samples to improve statistical power.

## 2) Water

It was found that an eight-month warm-weather data set exhibited better statistical power for detecting long-term reductions in PCB concentrations than a year-round data set, hence the selection of water column sampling on a monthly basis from April through November. It was suggested that additional sampling in the winter months would be unlikely to improve statistical performance and may in fact degrade it.

## ***8. Further Site Information***

<http://www.epa.gov/region5/sites/foxriver/index.html>

Anchor Environmental, L.L.C., Tetra Tech EC, Inc., J. F. Brennan Co., Inc., Boskalis Dolman, 2008. Lower Fox River Remedial Design 60 Percent Design Report for 2010 and Beyond Remedial Actions, Appendix I: Long-term Monitoring Plan. Prepared for Appleton Papers Inc., Georgia-Pacific Consumer Products LP NCR Corporation.

BOLDT, 2011. Lower Fox River Operable Unit 1 Post-remediation Executive Summary. Prepared for the Wisconsin Department of Natural Resources, Madison, WI.

United States Environmental Protection Agency (U.S. EPA), 2007. EPA Proposes Revisions to Cleanup Plan for Little Lake Butte des Morts.

Wisconsin Department of Natural Resources and United States Environmental Protection Agency, 2002. Record of Decision, Operable Unit 1 and Operable Unit 2, Lower Fox River and Green Bay, Wisconsin.

## **D. Saglek, Labrador**

### ***Site custodian:***

Department of National Defence

### ***Site location:***

Saglek, Labrador

### ***Primary sediment contaminant:***

Polychlorinated biphenyls (PCBs)

### ***Sediment remedial strategy applied:***

Monitored natural recovery



**Figure 4: Soil excavation during the site cleanup.**

Source: <http://www.rmc.ca/aca/cce-cgc/gsr-esr/esg-gse/saglek-eng.asp>.

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## ***1. Site Summary***

Marine sediments in Saglek Bay were contaminated with polychlorinated biphenyls (PCBs) as a result of soil contamination associated with a former military radar facility located on the shore of the bay. The terrestrial remediation removed the source of PCBs to the marine ecosystem. It was predicted that after the remediation was completed, sediment burial and transport would reduce the risks to ecological and human health over a ten-year period.

## ***2. Remediation Triggers and Objectives***

A preliminary site investigation completed in 1996 found evidence that PCBs had entered the marine ecosystem of Saglek Bay. During that investigation, concentrations of PCBs in marine sediments, invertebrates, fish and diving seabirds were found to be elevated above background levels. Approximately 10 km<sup>2</sup> of surface sediment was found to contain PCB concentrations above the interim sediment quality guideline (21.5 ng/g dry weight) established by the Canadian Council of Ministers of the Environment (CCME).

The Environmental Sciences Group, Nunatsiavut Government, Geological Survey of Canada—Atlantic and Canadian Wildlife Service conducted additional marine investigations from 1999–2003, and found that PCB contamination in marine sediments

was associated with ecological risks and could lead to potential human health risks if wild foods from the area were consumed. As a result of a human health risk assessment, Labrador Inuit were advised by their local health commission to avoid harvesting the most affected wildlife within this 5 km zone.

Study predictions suggested that natural processes would cause a decrease in PCB concentrations within 5 to 10 years in the shallowest environment close to the former source of PCBs, redistribution of PCBs within the near-shore Saglek anchorage area over 10 to 50 years, and gradual export of PCBs to deeper portions of Saglek Bay over decades.

### ***3. Receptors Considered and Protection Level Afforded***

In 2002, a human health risk assessment was conducted to provide information on the potential health risks associated with harvesting and consumption of wild foods in the Saglek Bay area. The human health risk assessment found that harvesting inside the ecological risk zone (ERZ), and over a wider area extending approximately 5 km from the site, would result in higher long-term PCB exposures than harvesting elsewhere in Labrador, Nunavik, or Nunavut.

The results of the ecological risk assessment (ERA) indicated that both shorthorn sculpin and black guillemots were potentially at risk from the contaminated sediments in Saglek Bay. The ERA suggested that average sediment PCB concentrations in the foraging areas of shorthorn sculpin would need to be reduced to less than 750 ng/g (dry weight) to protect the local sculpin population. For black guillemots, the ERA identified a lower risk threshold, somewhere in the order of 77–355 ng/g sediment (dry weight). Since black guillemots were the most sensitive receptor examined in the ERA, a sediment concentration of 77 ng/g was suggested to be protective of the whole ecosystem.

### ***4. Summary of Monitoring Plan***

#### **a. Surface sediment**

##### **1) Objectives**

- Monitor sediment concentrations to assess whether sediment PCB concentrations are decreasing as predicted.

##### **2) Monitoring approach and sampling frequency**

- Surface sediment samples were collected because they are the primary source of PCBs to the food chain and are therefore most relevant to assessing ecological and human health risks.
- Sampling covered a 26 km<sup>2</sup> area of Saglek Bay.

- At water depths of less than 20 m, sediment samples were collected by scuba divers.
- Where the water depth exceeded 20 m, surface sediment samples (surface 1–2 cm) were collected with a standard Ponar sediment grab sampler.
- Three samples were collected at each location and combined to form a composite sample for analysis.

### 3) Indicators and metrics chosen to evaluate each objective

- PCB concentrations in surface sediments.

### 4) Exit criteria

- When PCB concentrations in surface sediments at depths of less than 40 m are at or below 77 ng/g (protective of black guillemot).

A box core sediment sample was also collected to enable the quantification of contaminants in the sediments over a time series. The sample was collected in the deep basin (depth=139 m) of the Saglek anchorage area. The core was sub-sampled for PCB analysis at 0.01 m intervals for the top 0.05 m and at 0.05 m intervals for the remainder of the core. Eleven sediment samples were taken for PCB contaminant analysis.

## **b. Biological monitoring**

### 1) Objectives:

- Shorthorn sculpin and black guillemots were collected to evaluate marine ecosystem recovery and Arctic char and ringed seal were assessed to monitor potential human health risks

### 2) Monitoring approach and frequency:

- Nineteen sculpins were collected within the ERZ and five were collected outside of the ERZ, six km from the former source.
- Thirty-five black guillemot chicks were collected from six locations within Saglek Bay. Twelve chicks were collected within the Saglek anchorage area, 10 chicks from two islands around the Saglek anchorage area and 13 chicks from reference areas.
  - Chicks were collected for detailed tissue analysis of PCB contamination when they reached 21–30 days of age.
- Five Arctic char were collected from the headwaters of Torr Bay, located nine km west of the former beach source.
- Nine ringed seals were collected within Saglek Bay.

3) Indicators and metrics chosen to evaluate each objective

- The black guillemot and shorthorn sculpin were selected as indicator species for the ERA at Saglek Bay because of their vulnerability to PCB accumulation and their prominent roles in the food chain.
- Arctic char and ringed seals were selected as indicators of human health risks because they are the most important traditional foods harvested from the marine environment in Saglek Bay.
- The liver was removed from all chicks for PCB analysis.
- Liver samples from char and sculpin, char muscle tissue and seal liver and blubber samples were analyzed for PCB concentrations.
- Sex, stomach contents, fork lengths and whole body weights were recorded for Arctic char samples. Otoliths were removed for age determination.
- Lower canines were removed from seals to determine age.

4) Exit criteria

- Evidence that trends in PCB concentrations in biota tissue are decreasing and biomarker effects are decreasing.
- Acceptable risk level associated with the consumption of foods harvested within five km of the site.

***5. Data Quality Objectives***

A significance level ( $\alpha$ ) of 0.05 and a power level of 0.8 were used to determine the number of biota samples required for monitoring.

***6. Monitoring Habitat Replacement/Reconstruction***

Habitat replacement and reconstruction activities were not carried out at this site, and therefore there is no monitoring.

***7. Project Performance, Modifications and Lessons Learned***

**a. Surface sediments**

Results show sediment PCB concentrations in the ERA are decreasing and are approaching the site-specific level established for probable ecological effects (77 ppb). Since the removal of the land-based source in 1998 and 1999, PCB concentrations within 500 m of the beach have decreased significantly because of the high degree of sediment mixing. Significant decreases were observed one km east and one km west of the source. Sediments sampled in areas more than 500 m north of the former source (0.5–1.5 km, >1.5 km) showed no significant decreases

from 1998–99 to 2006. The lack of change for the more distant regions supports the hypothesis of PCB redistribution in the intermediate regions followed by export to deeper regions over longer time periods.

**b. Shorthorn sculpin**

Overall, average sculpin liver PCB concentrations in the beach area have decreased significantly between 1999 and 2006 ( $P < 0.001$ , 2006  $n=17$ , 1999  $n=6$ ). The result is consistent with the significant decrease in sediment concentrations for this area. Average sculpin liver PCB concentrations from Big Island, which is located approximately 5 km from the site, decreased slightly; however, no significant difference was found between years ( $P=0.542$ , 2006  $n=5$ , 1999  $n=2$ ). This corresponds with sediment data from 2006 which suggested no significant changes in sediment PCB concentrations around Big Island.

**c. Black guillemot**

Black guillemot chicks collected from the beach area had an average PCB concentration 16 times greater than guillemot chicks collected from the island group and 40 times greater than guillemot chicks collected from the reference group. The average liver PCB concentrations from the beach group showed the greatest decrease between years ( $P=0.043$ ; 2007  $n=11$ , 1999  $n=11$ ), with an average five-fold PCB concentration decrease. This result is consistent with the significant decrease in sediment concentrations observed throughout the near-shore area of the beach ( $>1.0$  km from the beach).

**d. Arctic char**

The total Aroclor concentrations in Arctic char liver ( $P=0.019$ ; 2006  $n=5$ , 1999  $n=4$ ) and muscle tissue collected in 2006 ( $P=0.000$ ; 2006  $n=5$ , 1999  $n=4$ ) indicated significant decreases from total Aroclor concentrations in Arctic char collected in 1999. Previous studies concluded that Arctic char have not been significantly affected by the presence of local PCB contamination in Saglek Bay. The 2006 results for Arctic char support these conclusions.

**e. Ringed seals**

The average total blubber Aroclor concentrations in ringed seals collected in 2006–07 from Saglek (1,530 ppb) were above average total Aroclor concentrations in ringed seals collected from Nain in 1999 (508 ppb) and Anaktalak in 2006 (313 ppb). However, no significant differences were found among the three locations.

Two seals were found to have very high PCB concentrations. To determine the reason for such high concentrations, it was suggested that stable isotope and fatty-acid analysis would help to determine whether these seals had been feeding at higher trophic levels or consuming more benthic-based organisms, and a tagging study would allow monitoring of seal movements and home range.

**f. Overall results**

The results generally support previous predictions that natural processes would cause decreases in sediment PCB concentrations in the area. The results also demonstrate that decreases in sediment PCB concentrations are being reflected by the biological indicator species (shorthorn sculpin and black guillemots). Because of these decreases, it is evident that there is a decrease in the ecological risk associated with the contaminated sediments. Significant decreases in average concentrations at the majority of sites sampled suggest that there is a general temporal trend of decreasing contamination affecting the ecosystem at Saglek Bay.

The study indicates that ecosystem recovery has occurred over the past 9 or 10 years and is continuing. However, additional long-term monitoring of Saglek Bay is required to monitor ecological recovery.

**g. Suggested future program focuses and modifications**

- As human and ecological health is linked with status of the terrestrial environment, the long-term monitoring plan should be linked with terrestrial monitoring.
- Monitoring must be conducted with sufficient power (frequent-enough intervals and adequate sample sizes) to permit differentiation between long-term trends and year-to-year variability.
  - PCB concentrations were found to vary from one year to the next in previous studies (e.g., in the sand patches), so that long-term trends only became evident over a period of several years.
- The biological monitoring should consider the level of certainty required for making changes to ecological and human health risk communications.
  - Continuing to monitor shorthorn sculpin, black guillemots and ringed seal will provide enough confidence in assessing ecological and human health risk around Saglek Bay to achieve the overall objective of removing the food harvest caution sign currently posted at the Saglek Bay beach.



### ***8. Further Site Information***

Environmental Sciences Group (ESG), 2002. Ecological Risk Assessment of PCB-contaminated Sediments at Saglek, Labrador. Royal Military College, Kingston, ON.

Environmental Sciences Group (ESG), 2008. Assessing Marine Ecosystem Recovery from a Local Historical PCB Source in Saglek, Labrador. Royal Military College, Kingston, ON.

Environmental Sciences Group (ESG), 2012. Saglek (LAB-2), Newfoundland and Labrador Summary of Remediation, Risk Management and Monitoring of Historic PCB Contamination (1997–2011). Draft. Royal Military College, Kingston, ON.

## E. Grasse River

***Site custodian:***

Alcoa Inc.

***Site location:***

Massena, New York

***Primary sediment contaminant:***

Polychlorinated biphenyls (PCBs)

***Sediment remedial strategies applied:***

Dredging, capping (pilot study), proposed *in situ* treatment using activated carbon



**Figure 5: Overview of the Grasse River. Source: <http://www.thegrasseriver.com/>.**

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### ***1. Site Summary***

Since 1903, Alcoa has operated a 2,700-acre aluminum smelting and fabricating facility situated at the confluence of the Massena Power Canal and the Grasse River. Historic disposal of production waste by-products into onsite landfills and lagoons resulted in the release of polychlorinated biphenyls (PCBs) into the lower Grasse River.

The site is being addressed in two stages: a non-time-critical removal action, which focused on removing the highly contaminated sediments upstream, and a long-term remedial action focusing on cleanup of the remaining river system sediments. The non-time-critical removal, which consisted of dredging approximately 3,000 cubic yards of contaminated sediments from an area adjacent to the outfall area, was completed in 1995. The removal decreased the average PCB concentrations in the top foot of the sediment bed by approximately 86%.

A capping pilot study was conducted in 2001 for the long-term stage of the project. Monitoring completed in 2003 indicated that a loss in cap material had occurred and that, in some areas, underlying sediment had also eroded since the previous monitoring conducted in the fall of 2002. Investigation indicated that an ice jam had caused the erosion. This event prompted Alcoa to reevaluate other remedial alternatives. Alcoa has since proposed a pilot study involving the *in situ* treatment of contaminated sediment through the addition of granulated activated carbon.

Alcoa, under a consent decree with the New York State Department of Environmental Conservation, initiated a series of land-based remediation activities at the site in 1991.

These activities were completed in 2001 and have greatly reduced this source of PCBs in the river.

## ***2. Remediation Triggers and Objectives***

Consent orders between the New York State Department of Environmental Conservation and Alcoa prompted investigations and remedial actions to be initiated.

As fish were found to pose the greatest risk to human and ecological health (discussed below), reducing PCB concentrations in fish is the primary goal of the remediation project.

## ***3. Receptors Considered and Protection Level Afforded***

A human health risk assessment completed in 2002 found that fish consumption at the site posed an elevated human health risk. Currently, the New York State Department of Health has an advisory in place recommending that no fish be consumed from the lower Grasse River.

A baseline risk assessment for the site completed in 1993 identified potential ecological risks to sediment-dwelling organisms, birds foraging in the Grasse River, bats foraging above the Grasse River, and mink living along the Grasse River. The main concern regarding ecological risk involves consumption of fish containing PCBs.

## ***4. Summary of Monitoring Plan***

The current ongoing monitoring plan involves the collection of water column and resident fish samples to examine how PCB levels in the lower Grasse River have changed over time and to identify the impacts that naturally occurring events (e.g., high flow events and ice jams) and major in-river pilot studies have had on the recovery of the lower Grasse River.

### **a. Water column monitoring**

#### **1) Objectives**

- Continue the ongoing monitoring of PCB concentrations in the water column.
- Document variations associated with location, season, flow, temperature, biological activity, and other variables.

#### **2) Monitoring approach and sampling frequency**

- Water column samples were collected biweekly from seven locations between April and October (for a total of 15 sampling rounds).

- During each event, two samples were collected mid-channel at each location using a stainless steel Kemmerer water sampler. Samples were collected at 0.2 and 0.8 times the total water column depth.
  - Total water column depth was recorded and specific conductivity and water temperature measurements were obtained every two feet in the water column at mid-channel.
  - Field water quality measurements of specific conductivity, water temperature, pH, turbidity, and dissolved oxygen were also collected at 0.2 and 0.8 times the total water column depth at mid-channel.
- 3) Indicators and metrics chosen to evaluate each objective
- Water column samples were analyzed for PCB congeners and total suspended solids.
- 4) Exit criteria
- Not discussed.

**b. Resident fish monitoring**

- 1) Objectives
- Continue observation of annual trends in fish PCB concentrations.
- 2) Monitoring approach and sampling frequency
- The resident fish species targeted during this program included adult ( $\geq 25$  centimetres (cm)) smallmouth bass (*Micropterus dolomieu*), adult ( $\geq 25$  cm) brown bullhead (*Ameiurus nebulosus*), and young-of-year ( $< 6.5$  cm) spottail shiner (*Notropis hudsonius*).
  - Sampling was carried out in the Massena Power Canal and at four locations in Grasse River (background, upper, middle and lower).
  - Seventeen adult smallmouth bass were collected from Massena Power Canal, 17 adult smallmouth bass and 18 adult brown bullhead were collected from the upper, middle and lower stretches of the river, and five adult smallmouth bass and five brown bullhead were collected from the background stretch.
  - Spottail shiners were collected from four areas within the study area (one area being the background location). Composite samples were collected; target sample size was 20 fish.
- 3) Indicators and metrics chosen to evaluate each objective
- PCB Aroclors and lipid content were analyzed.

- Smallmouth bass fillets were prepared with skin on (scales removed), brown bullheads fillets were prepared with skin off, and young-of-year spottail shiners were whole-body composite samples.

4) Exit criteria

- Not discussed.

**c. Benthic monitoring**

1) Objective

- Assess the potential effects of the Post-remedial Options Pilot Study construction activities (dredging and capping) on the sediment-based benthic community and aquatic habitat.

2) Monitoring approach and sampling frequency

- Both spring and fall post-construction monitoring were performed in the northern and southern shores near-shore capped areas.
- Two control locations upstream were selected to have similar habitat and substrate characteristics.
- Sampling of sediments for benthic community analysis was conducted using a Petite Ponar grab sampler. A total of six Petite Ponar grab samples were collected within each of the northern and southern near-shore areas.
- Grab samples were sieved using a 0.6 mm sieve and then preserved in 91% isopropyl alcohol.
- In total, 18 benthic samples per sampling event were submitted for identification and measurement of wet weight biomass.

3) Indicators and metrics chosen to evaluate each objective

- Spring and fall datasets are not compared to each other because of seasonal effects.
- Indicator: Benthic invertebrates.
- Metrics: Total organisms, biomass, number of taxa, diversity index, tolerance index, feeding guild and organism habit.

4) Exit criteria

- Not discussed.

**5. *Data Quality Objectives***

Data quality objectives were not discussed in the documents reviewed.

**6. *Monitoring Habitat Replacement/Reconstruction***

Descriptions and monitoring of habitat replacement and reconstruction activities were not discussed in the documentation reviewed.

## ***7. Project Performance, Modifications and Lessons Learned***

### **a. Water column monitoring**

Total suspended solids levels measured throughout the river were generally low. PCB levels were generally low in the spring, increased in the summer and declined in the fall. Excluding the data obtained during the 2005 monitoring events when sediment removal activities in 2005 caused significant increases in water column PCBs, water column PCB levels have exhibited an overall decline over the period of record. Seasonal and year-to-year variations in river flow affect the water column PCB concentration. However, the same patterns are evident in PCB mass flux, indicating that PCB sources to the river vary seasonally and have declined over the period of record.

### **b. Resident fish monitoring**

Overall, results indicate decreases in average lipid based PCBs between 1993 and 2006. Similar patterns were observed in PCB concentrations on a wet-weight basis.

### **c. Benthic monitoring**

The results of the ecological monitoring studies generally indicate that recolonization by similar benthic communities into similar benthic habitats is occurring in the northern and southern near-shore areas, and that areas are being revegetated by similar plant species. The data are variable, however, suggesting both seasonal and temporal effects (i.e., natural variation), as well as possible treatment effects. It appears that the southern near-shore area is recovering more quickly and is close to or at pre-construction conditions. While the northern near-shore area is showing signs of recovery, benthic organisms and native plant species may take longer to return because it is sheltered in a cove.

## ***8. Further Site Information***

<http://www.thegrasseriver.com/>

Alcoa Inc., 2007. 2006 Data Summary Report, Grasse River Study Area, Massena, New York.

## F. Silver Bow Creek/Butte Area Superfund Site

### *Site custodian:*

U.S. EPA and Montana  
Department of Environmental  
Quality (MDEQ)

### *Site location:*

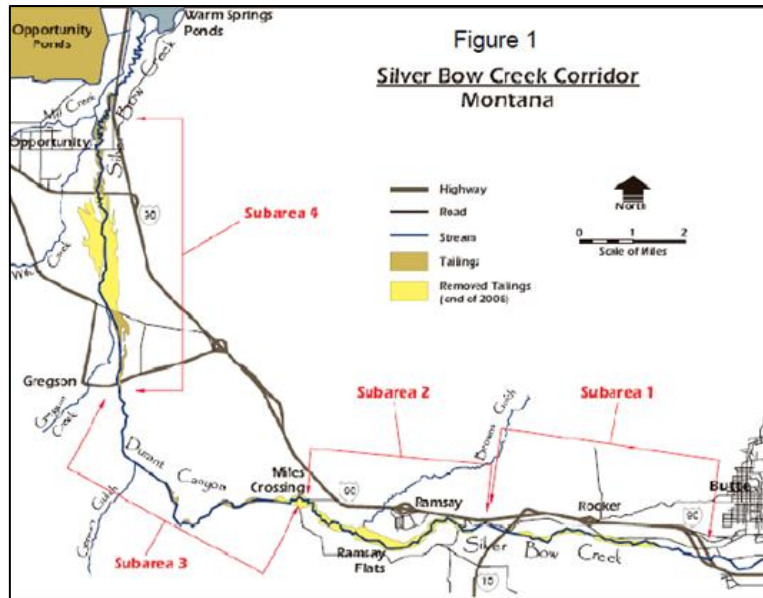
Silver Bow Creek

### *Primary sediment contaminants:*

Arsenic, cadmium, copper,  
lead, mercury and zinc

### *Sediment remedial strategy applied:*

Monitored natural recovery



**Figure 6: Silver Bow Creek map. Source: PBS&J, 2010.**

### **1. Site Summary**

Tailings and other mining wastes were deposited in and along the Silver Bow Creek (SBC) through historic mining and milling operations carried out along the river since the late 1800s. Since mining and milling commenced in the area, these wastes have been redistributed in the floodplain by occasional flooding, precipitation, snow melt and ice jam events. Metal loads present in groundwater and surface water contributed further to contamination of in-stream sediments. Sections of the railroads, within the site, were constructed with mine wastes and other contaminated materials which have impacted the stream and the floodplain. Remedial actions involved excavating impacted soils from the flood plain and reconstructing the stream channel and flood plain.

### **2. Remediation Triggers and Objectives**

#### **a. Soil triggers**

The wastes at the site (mostly tailings) are characterized as acidic, with median pH values ranging from 3.5 to 5.1 standard units, and contain high levels of arsenic (median concentrations of 145 to 649 milligrams per kilogram [mg/kg]) and metals, including cadmium (median concentrations of 0.1 to 17 mg/kg), copper (median concentrations of 760 to 4,395 mg/kg), lead (median

concentrations of 218 to 2,265 mg/kg), mercury (median concentrations of 0.4 to 37.5 mg/kg) and zinc (median concentrations of 1,032 to 7,210 mg/kg). In 1995, it was estimated that 2.5 to 2.8 million cubic yards of tailings and contaminated soils covered about 1,300 acres.

**b. Surface water triggers**

Water quality analysis indicated elevated concentrations of dissolved and total arsenic, cadmium, copper, lead, mercury, and zinc, some above state and federal water quality criteria. The Silver Bow Creek also contains tailings and is devoid of most aquatic life.

**c. Groundwater triggers**

Scattered areas of the shallow alluvium contain detectable concentrations of arsenic, copper, cadmium and zinc throughout the site. Concentrations of arsenic, copper and cadmium were elevated above state and federal drinking water maximum contaminant levels.

**d. Sediment triggers**

The highest arsenic and metals concentrations were associated with silt and clay fractions in the stream; these were elevated between 10- and 65-fold over background concentrations for arsenic, cadmium, lead, and zinc. Copper was elevated 40- to 70-fold over background, and total metals and arsenic concentrations were approximately one-half to one-third of the concentrations found in tailings/impacted soils.

The remedial action objectives are as follows:

1. Meet the more restrictive of the aquatic life or human health standards for surface water identified in MDEQ-7 Circular through application of I-classification requirements.
2. Prevent exposure of humans and aquatic species to sediments with concentrations of inorganic elements exceeding the risk-based standards.
3. Achieve the remedial action objective to improve the quality of SBC's surface water and in-stream sediments to the point that the SBC could support the growth and propagation of fishes and associated aquatic life, including a self-sustaining population of trout.

The remedial action goal to guide soil excavations was to remove 90% of the floodplain tailings/impacted soils with 95% confidence. Remedial excavation was considered a success if four of the six constituents of concern were at less than the following concentrations:



- arsenic—200 mg/kg
- cadmium—20 mg/kg
- copper—1,000 mg/kg
- mercury—10 mg/kg
- lead—1,000 mg/kg
- zinc—1,000 mg/kg

A remedy was not applied to surface water or groundwater because their cleanup is directly dependent on the successful remediation of the floodplain soils.

### ***3. Receptors Considered and Protection Level Afforded***

Human health and ecological risk assessments were completed.

#### **a. Human health risk assessment**

Three exposure scenarios — residential, occupational and recreational — were evaluated. The primary carcinogenic risk to people living in the area comes from potential exposure to arsenic in soil and groundwater. The calculated reasonable maximum exposure values were  $2.5 \times 10^{-4}$  for ingesting soil or sediment and  $3.11 \times 10^{-4}$  for ingestion of near-stream groundwater.

Non-carcinogenic risks exceeded acceptable levels for arsenic in soils under the residential scenario (hazard index = 1.1 for ingestion of soil/sediment and hazard index = 1.2 for near-stream ground water). Non-carcinogenic risks related to arsenic, cadmium, copper and zinc in groundwater were found only in upper alluvial, near-stream groundwater within and directly adjacent to the floodplain. The risks posed by lead contamination in soils were generally within the acceptable range.

Human health risk-based concentrations were not defined for the site.

#### **b. Ecological risk assessment**

A weight-of-evidence approach, using measures of potential adverse effects, was then used to define risk potentials to receptors (fish and benthic macroinvertebrates) in/on a media and chemical basis. Risk potential (classified as low, medium or high) was estimated by evaluating the difference between average and upper 95% confidence limit concentrations to relevant effects concentrations. Risk potentials were rated as high when average or upper 95% values greatly exceeded the relevant effects concentration.

Risk potential for surface water copper and zinc was assessed as high, cadmium and lead was moderate, mercury was low to moderate, and arsenic was low. Risk potential for sediment was high for all six metals. Risk potential for surface soil

was high for arsenic, copper, lead and zinc, moderate for cadmium, and low to moderate for mercury.

Other chemical stressors identified for surface water included ammonia (moderate to high), dissolved oxygen (DO) (low to high, depending on location and time), and nitrogen (moderate to high).

#### ***4. Summary of Monitoring Plan***

##### **a. Surface water monitoring**

###### **1) Objectives**

- All primary parameters listed below must meet the more restrictive of the aquatic life or human health standards for surface water.
- The secondary parameters listed must be at or near background conditions for at least three consecutive years.

###### **2) Monitoring approach and sampling frequency**

- Fourteen surface water sites have been chosen.
- Sampling will take place quarterly, including during approximate high and low flow conditions. Fall sampling must coincide with sediment sampling and biological monitoring.
- Sampling will occur for at least 10 years.

###### **3) Indicators and metrics chosen to evaluate each objective**

- Primary parameters:
  - Metals: total recoverable and dissolved As, Cd, Cu, Pb, Hg, Zn
  - Common ions: Ca, Mg, Na, K, Cl<sup>-</sup>, K, SO<sub>4</sub><sup>2-</sup>, HCO<sub>3</sub><sup>3-</sup>
  - Nutrients: nitrate + nitrite nitrogen, ammonia, total phosphorus, total persulfate nitrogen
  - Field parameters: temperature, pH, conductivity, DO, turbidity
- Secondary parameters: Ag, Al, B, Ba, Be, Co, Cr, Fe, Mo, Ni, Sb, Se, U, V, Mn

###### **4) Exit criteria**

- After 10 years of monitoring, the primary metrics must meet the more restrictive of the aquatic life or human health standards for surface water.
- The secondary metrics must decrease to near background levels and show no change or must show a declining trend for three consecutive years with no significant spikes. If these levels are reached before 10 years of monitoring, monitoring will be reduced to once per year during low flow conditions.

## **b. Sediment monitoring**

### 1) Objectives

- Reduce sediment concentrations to the following (based on threshold effect concentrations):
  - arsenic—9.79 mg/kg
  - cadmium—0.99 mg/kg
  - copper—43.4 mg/kg
  - lead—35.8 mg/kg
  - mercury—0.18 mg/kg
  - zinc—no value listed
- Improve the quality of sediments in order to support the growth and propagation of fisheries and associated aquatic life

### 2) Monitoring approach and frequency

- Fourteen sediment sampling sites have been chosen (same locations as surface water sites).
- Sampling will take place in the fall and must coincide with surface water sampling and biological monitoring.
- Sampling will occur for at least 10 years.
- Sediments are analyzed in three different size fractions: less than 63  $\mu\text{m}$ , 63  $\mu\text{m}$  to 1 mm, 1 mm and greater.

### 3) Indicators and metrics chosen to evaluate each objective

- Primary parameters: As, Cd, Cu, Pb, Hg, Zn
- Secondary parameters: Ag, Al, B, Ba, Be, Co, Cr, Fe, Mo, Ni, Sb, Se, U, V, Mn

### 4) Exit criteria

- The primary parameters must be below the concentrations listed in the objectives for at least three consecutive years. If they are reached before the mandatory ten-year sampling period, analytes will only be monitored once per year and the number of monitoring sites will be re-evaluated.
- The secondary parameters must be near background levels and show no change or show a declining trend for three consecutive years with no significant spikes.

## **c. Revegetation monitoring**

### 1) Objectives

- Main goal is to speed up the return of the stream and floodplain vegetation to a baseline condition.
- Restoration aims to increase the structural diversity and establish a mix of physiognomic types.

The following table outlines the minimum desired canopy coverage approximately 10 years after seeding.

**Table F-1: Minimum canopy coverage approximately 10 years after seeding**

<b>Hydrologic Zone</b>	<b>Average Canopy Coverage*</b>	<b>Transects Meeting Cover</b>
Uplands, sub-irrigated	60%	65%
Stream banks, transition zone	80%	95%
Wetlands (not open water)	95%	65%

\*Noxious weeds and non-native annual species are not factored into total canopy cover.

## 2) Monitoring approach and frequency

- Monitoring measurements will be taken at 3, 6 and 10 years. The final measurement (year 10) will not be taken if there has been abnormal precipitation. As the site is in a semi-arid climatic zone, the most accurate way to evaluate revegetation performance is to measure recovery in years of relatively normal precipitation.
- Three transects per vegetation type and soil material will be established in a reach in order to make conclusions regarding a treatment.
- The revegetation sampling methods combine monitoring canopy coverage from plots along transects and shrub density from one-metre-wide belts along the same transects in established revegetation.

## 3) Indicators and metrics chosen to evaluate each objective

- Parameters:
  - Cover: Total plant cover and cover by species.
  - Woody plant density: Measured as the number of stems per linear foot of streambank. Stems rather than individual plants are counted because one species of willow that propagates from rootstocks is planted along the banks.
  - Diversity: Richness and proportional species abundance.

- Photomonitoring: Landscape scale and micro scale.

#### 4) Exit criteria

- The remediation goals are fulfilled if the canopy coverage equals or exceeds the goals listed in Table F-1 10 years after the germination of the last seeding.
- If goals are met before year ten, measurement of the parameters exceeding the goals may be discontinued. However, photomonitoring will continue until year ten. Monitoring will be resumed if declining trends are noted in the photomonitoring.
- In addition to meeting the objectives, analysis of long-term monitoring should answer these questions:
  - How has species composition shifted through time, and what lessons does this hold for future revegetation?
  - Are weeds controlled effectively?
  - What special measures can be employed on sites where revegetation efforts have proven ineffective or unsatisfactory?

#### **d. Macroinvertebrates and periphyton monitoring**

##### 1) Objectives

- The goal is for community composition to reflect a balanced, integrated and adaptive community of organisms having a species composition, diversity and functional organization comparable to that of the natural habitat of the region.
- Specific goals for the macroinvertebrate community include the attainment of a total metric score of 75% of the total possible score in the “Good” category for two consecutive years.
- Specific goals for the periphyton community include the attainment of a score within “Excellent” to “Good” biological integrity for all metrics for two consecutive years.

##### 2) Monitoring approach and frequency

- Monitoring of both macroinvertebrates and periphyton will occur annually at 14 locations during low water.
- Sampling should coincide with the in-stream sediment and surface water sampling.

##### 3) Indicators and metrics chosen to evaluate each objective

- Macroinvertebrate parameters: Ephemeroptera, Plecoptera, Trichoptera taxa (EPT richness), Hilsenhoff Biotic Index (HBI), sensitive taxa
- Periphyton metrics: diatom algae, soft-bodied algae
  - Cladophora or other soft-bodied algal taxa associated with sewage inputs cannot rank as the dominant soft-bodied algae.

#### 4) Exit criteria

- Once monitoring goals are attained, monitoring will no longer be required as part of the restoration and remediation activities. However, the Montana Department of Environmental Quality (MDEQ) will continue to monitor the creek every five years as part of another program.

### e. **Fish monitoring**

#### 1) Objectives

- Improve SBC over time to a condition that supports a self-reproducing fishery for trout species.
- Determine the presence or absence of a fish species.

#### 2) Monitoring approach and frequency

- Monitoring will occur in remediated portions and unremediated reaches.
- Fish sampling will occur at six locations. Locations near Rocker and Ramsey will be sampled annually in the fall and locations near German Gulch will be sampled in the spring and fall.

#### 3) Indicators and metrics chosen to evaluate each objective

- Fish community survey
- Parameters: species composition, abundance, population structure

#### 4) Exit criteria

- Remediation is considered successful when surface water and in-stream sediment quality is sufficient to support fish.
- Once monitoring goals are attained, monitoring will no longer be required as part of the restoration and remediation activities. However, MDEQ will continue to monitor the creek every five years as part of another program.

A caged fish study was completed. Five locations were chosen, one of which was used as a background site. Water samples were collected during the study and analyzed for ammonia, copper, cadmium, arsenic, lead and zinc as well as temperature, conductivity, pH, DO, oxygen reduction potential and turbidity. The water sample results indicated spikes in copper and zinc concentrations

following a rain event in the watershed. Concentrations on these days exceeded both chronic and acute standards for copper and zinc. An increase in the ammonia level in water was also recorded at a concentration above the acute water quality standard after the rain event. Mortality was also monitored during this time. Conclusions from the study indicate that the remediated areas of Silver Bow Creek are being recontaminated with metals from a location near the sewage treatment outfall. This was marked as a concern requiring further investigation.

**f. Fish habitat and fluvial geomorphology monitoring**

1) Objective

- Provide suitable habitat to support a healthy fishery.

2) Monitoring approach and frequency

- Monitoring will occur at 5 and 10 years after construction.

3) Indicators and metrics chosen to evaluate each objective

- Parameters:
  - Ten sample cross sections, to be assessed for:
    - average width to depth ratio
    - average areal cover from overhanging banks
    - average areal cover from overhanging vegetation
    - average percent overstory canopy cover
    - average percent cover provided by woody debris
  - One 1000-ft channel profile to assess:
    - run/riffle/pool ratio
    - gross sediment deposition pattern
    - channel platform and gradient
  - Two stream flow measurements, one each at the most upstream and downstream cross sections
  - Two pebble counts on riffles to assess bed material gradation

4) Exit criteria

- Not discussed.

***5. Data Quality Objectives***

Normally distributed sample means will be compared to performance standards using a  $p < 0.1$  significance level and 0.9 statistical power.

## **6. Monitoring Habitat Replacement/Reconstruction**

Descriptions and monitoring of habitat replacement and reconstruction activities were not discussed in the documentation reviewed.

## **7. Project Performance, Modifications and Lessons Learned**

### **a. Surface water**

Surface water quality monitoring results show a significant post-remedial improvement in primary contaminant concentrations in two subareas when compared to pre-remedial action baseline concentrations.

Arsenic, lead and mercury are consistently below human health standards until a certain stretch of stream, at which point concentrations begin to rise and exceed the standards. However, the latter stretch of stream is downstream of the site and coincides with the unremediated portion of the operation unit. Cadmium, copper, and zinc are well below the human health standard for the entire operation unit.

### **b. Sediment**

According to the 2008 monitoring report, current remediation goals for stream sediments are equivalent to the cleanup standards for tailings and impacted soils throughout the floodplain. The United States Environmental Protection Agency (EPA) has recommended that the State consider using the threshold effects concentration and the probable effects concentrations for sediment quality guidelines as restoration goals. These values are lower than the values presented above in the monitoring section.

### **c. Revegetation monitoring**

Remedial success is visually apparent in most areas as the previously barren riparian habitat is now densely vegetated. Success in some areas has been inhibited by coarse *in situ* soils, near-surface salinity, and residual contamination.

### **d. Macroinvertebrates and periphyton monitoring**

Analysis of macro-invertebrate metrics for samples collected in September 2008 indicated continued impairment in the reach of stream sampled. Impairment ranged from moderate to severe, and depended on both the bioassessment method employed and the station location within the study area.

All stations, with the exception of one, displayed an improvement (decrease) in the Hilsenhoff Biotic Index (HBI) in 2008. The HBI revealed an increase in the



abundance of less tolerant species and a notable decrease in percent tolerant taxa throughout the study reach when compared to the 2007 data, suggesting improved health and rehabilitation of the aquatic habitat. EPT richness values showed a general increase in the number of mayflies and caddisflies, further indicating improvement of stream health.

A sustained reduction in metals-tolerant taxa corresponded with the removal of metals sources. However, the number of nutrient-tolerant invertebrates has risen and indicates impairment due to nutrient loading. It appears unlikely that restoration and remediation goals can be met without reductions in all pollutant loading, including nutrients, throughout the SBC watershed.

A more rigorous monitoring approach has been suggested — for example, using the quantitative (Hess) sampling and completing four replicates. The replicates would improve the reliability of the macroinvertebrate assessments.

Other suggested improvements to the current sampling program include standardizing sampling and analysis with existing MDEQ and EPA monitoring programs for downstream reaches of the Clark Fork River Basin; using longitudinal and trend assessments for the preremediation data (over 20 years of data) as a baseline for assessing restoration success; and choosing a monitoring location to use as a reference site.

**e. Fish population monitoring**

Prior to 2002, the SBC was considered to be void of fish, except for occasional observations of suckers during the late 1990s when remediation of the stream channel began. Results from monitoring studies have been used primarily to assess the presence or absence of fish species, an estimate of the number of fish per 100 seconds of electrofishing effort, and average size of fish captured.

It was recommended that small fluctuations in fish abundance or species composition at specific sampling locations not be considered significant unless a multi-year trend is observed.

## ***8. Further Site Information***

<http://www.epa.gov/region8/superfund/mt/sbcbutte/>

PBS&J, 2010. Interim Comprehensive Long-term Monitoring Plan for Silver Bow Creek Streamside Tailings Operable Unit. Prepared for the Montana Department of Environmental Quality, Mine Waste Cleanup Bureau, Helena, MT.

United States Environmental Protection Agency (U.S. EPA), 1998. EPA Superfund Explanation of Significant Differences: Silver Bow Creek/Butte Area.

United States Environmental Protection Agency (U.S. EPA), 2011. Third Five-year Review Report for Silver Bow Creek/Butte Area Superfund Site, Helena, Montana.

## G. Puget Sound Naval Shipyard Complex (Bremerton Naval Complex)

***Site custodian:***

U.S. Navy

***Site location:***

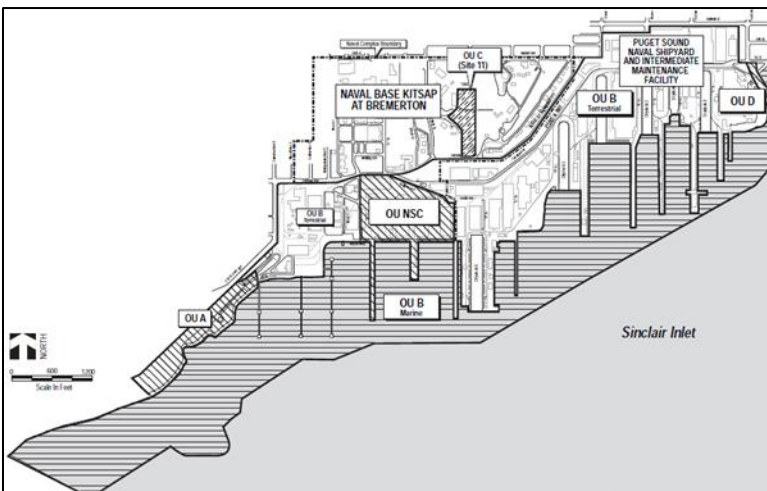
Bremerton Naval Complex,  
Bremerton, Washington

***Primary sediment  
contaminants:***

Polychlorinated biphenyls  
(PCBs) and mercury

***Sediment remedial  
strategies applied:***

Dredging to confined aquatic  
disposal (CAD) cells,  
sediment capping and  
monitored natural recovery



**Figure 7: Overview of the Puget Sound Naval Shipyard Complex. Source: NAVFAC, 2007.**

### ***1. Site Summary***

The Bremerton Naval Complex was completed in 1891. Industrial activities at the complex since the early 1900s have contributed to environmental contamination. Wastes include plating wastes, metal filings and shavings associated with metal work, petroleum products, transformers containing polychlorinated biphenyls (PCBs), electrical components, batteries, acids, oxidizing materials, paints and paint chips, degreasing and cleaning solvents, and wood and miscellaneous materials from shipbuilding and ship demolition.

The marine remedy for the Complex included dredging of contaminated sediments with on-site disposal into confined aquatic disposal (CAD) cells, thick- and thin-layer capping and natural recovery. The remedial construction activities were completed in 2001. Additional thin-layer capping was required in 2004 after discovering additional contamination near the CAD cells.

## ***2. Remediation Triggers and Objectives***

The Bremerton Naval Complex was added to the National Priorities List in 1994. Remedial action was necessary to protect the public health and the environment from actual or threatened releases of hazardous substances. A release would have presented an imminent and substantial danger to the environment.

The remedial action objectives (RAOs) for the project were the following:

- Reduce the concentration of PCBs in sediments to less than the minimum cleanup level (MCUL) in the biologically active zone (0 to 10-cm depth), as a measure expected to reduce polychlorinated biphenyl (PCB) concentrations in fish tissue.
- Control shoreline erosion of contaminated fill material (at Site 1).
- Selectively remove sediment with high concentrations of mercury co-located with PCBs.

The following list summarizes action levels for the marine sediment. Mercury was added to the list for practicability, as the higher concentrations of mercury coincide with areas where PCBs exceed the remedial action levels.

- Dredging or capping was selected for areas where PCB-contaminated sediment was >12 mg/kg organochlorine (OC) PCBs, based on relative risk reduction and sediment quality standards.
- Enhanced natural recovery was selected for areas where PCB-contaminated sediment was >6 mg/kg OC, based on resource agency concern and relative risk reduction.
- Dredging or capping was selected for areas where mercury-contaminated sediment was >6 mg/kg OC PCBs and >3 mg/kg mercury, based on resource agency concern and practicability.

The following were listed as minimum cleanup levels and long-term cleanup goals.

- Sediment
  - MCUL is 3 mg/kg OC PCBs (based on the area-weighted average).
  - Cleanup goal is the reference area PCB concentration of 1.2 mg/kg (based on the area-weighted average), represented by the 90<sup>th</sup> percentile of reference area concentrations.
- Fish tissue

- Cleanup goal is the reference area PCB concentration of 0.023 mg/kg wet weight, represented by the 90<sup>th</sup> percentile of reference area concentrations in English sole from Sinclair Inlet.

### ***3. Receptors Considered and Protection Level Afforded***

The Navy requested that National Marine Fisheries Service and the U.S. Fish and Wildlife Service identify any threatened and endangered species that could potentially be affected by a proposed dredging project in and near the marine portion of Operation Unit (OU) B. The agencies identified the following endangered or threatened species:

- bull trout: threatened
- chinook salmon: threatened
- bald eagle: threatened
- Steller sea lion: threatened
- humpback whale: endangered
- leatherback sea turtle: endangered
- marbled murrelet: threatened

The agencies also identified the following species of concern and species that are candidates for protection:

- Puget Sound coho salmon: candidate for protection under ESA
- long-eared myotis: species of concern
- long-legged myotis: species of concern
- Pacific lamprey: species of concern
- Pacific Townsend's big-eared bat: species of concern
- river lamprey: species of concern

Of these species, only chinook salmon, coho salmon, and bald eagles are likely to be found in the area of the Naval Complex.

#### **a. Human health risk assessment**

Five separate data groups were screened for chemicals of potential concern: marine sediment within the Complex boundary, marine sediment within Sinclair Inlet but outside the Complex boundary, sea cucumber tissue, English sole fillet tissue and mussel tissue.

The hazard index computed for the subsistence finfisher is 12, almost entirely because of the presence of PCBs in fish tissue. The hazard index for the (future) subsistence shellfishing scenario is 2, primarily because of PCBs and chromium in shellfish tissue.

The excess cancer risk for the subsistence finfish harvester is  $5 \times 10^{-4}$ , almost entirely because of PCBs in fish tissue. In contrast, the cancer risk for the recreational finfish harvester is  $2 \times 10^{-5}$ , which is below the United States Environmental Protection Agency (EPA) guideline ( $10^{-4}$ ) but slightly above the Washington State Department of Ecology ( $10^{-5}$ ) guideline.

The cancer risk for the future subsistence shellfish harvester is  $1 \times 10^{-4}$ . Most of the risk is from arsenic and PCBs in shellfish tissue.

The risk for the subsistence sea cucumber harvesting scenario is  $2 \times 10^{-5}$ , which is below both agencies' guidelines.

The conclusion of the risk assessment was that there are unacceptable risks posed to subsistence seafood harvesters relying on seafood collected in Sinclair Inlet as a principal component of their diet. The risks are primarily related to the presence of PCBs in the tissue of bottom-dwelling fish.

**b. Ecological risk assessment**

The primary component of the ecological risk assessment (ERA) was evaluation of the potential effects of exposure to site conditions on four categories of indicator organisms:

Benthic invertebrates: At OU-B, while chemical contamination is found, direct biological testing shows relatively little evidence of impact. The overall conclusion of the evaluation of benthic invertebrates is that conditions at OU-B pose at most a relatively minor threat to these marine species.

Shellfish: The overall conclusion is that, while mussels were prone to accumulate more chemicals in their tissues in Sinclair Inlet than in the reference location, inlet conditions overall posed only minimal risk.

Bottom-dwelling fish: Overall, the conclusion of the English sole evaluation is that there is very little evidence of the types of stress that trigger the development of liver lesions, but there is some indication of limited risk to bottom-dwelling fish from antimony, chromium, and lead.

Marine birds: The results for the surf scoter and pigeon guillemot suggest some potential for risk, although comparison of model parameters with conditions at background areas suggest the actual risks are minor.

The results from the ERA concluded that remedial action was not necessary. Areas that had inorganic and organic contaminant concentrations exceeding the

SQS and that were co-located or adjacent to areas with minor bioassay results could be remediated as part of the human health-based cleanup program.

#### ***4. Summary of Monitoring Plan***

The objectives of the long-term monitoring program are summarized below:

- Verify attainment of the cleanup objectives.
- Confirm the physical integrity of the CAD cell and shoreline stabilization measures.
- Confirm predicted natural recovery of sediments in marine OU B.
- Evaluate the success of the remediation in reducing contaminant of concern (CoC) concentrations in fish tissue, as represented by English sole.

##### **a. Marine tissue monitoring**

###### **1) Objectives**

- Assess reductions in CoC concentrations in edible seafood and allow determination of the need for seafood harvest restrictions.

###### **2) Monitoring approach and sampling frequency**

- Not discussed.

###### **3) Indicators and metrics chosen to evaluate each objective**

- English sole tissue samples will be collected periodically and analyzed for PCBs and mercury.
- Because of concerns of the Suquamish Tribe, a single round of sea cucumber samples were collected once, and were analyzed for PCBs.

###### **4) Exit criteria**

- For PCBs in fish tissue (as represented by English sole), the cleanup goal is the reference-area concentration of 0.023 mg/kg wet weight. This reference-area concentration represents the 90<sup>th</sup> percentile concentration of PCBs in English sole collected from non-urban embayments.
- Monitoring of sediments and fish tissue will continue even if the RAOs are achieved, until either of the cleanup goals are met or until the U.S. Navy, Washington State Department of Ecology and the EPA agree that the monitoring program is no longer providing useful information.

##### **b. Sediment monitoring**

###### **1) Objective**

- Monitor surface sediments in Sinclair Inlet to verify long-term protection of the environment and to assess the natural recovery of sediment.

2) Monitoring approach and sampling frequency

- The monitoring program consisted of sediment sampling and chemical analysis combined with natural recovery modeling.
- A 500-foot square grid was used to guide the primary marine sediment sampling within OU B Marine, and a 1,500-foot grid was used to guide sampling in the remainder of Sinclair Inlet.

3) Indicators and metrics chosen to evaluate each objective

- Sediment samples will be collected periodically and analyzed for PCBs, mercury, TOC and particle size parameters.

4) Exit criteria

- For PCBs in Sinclair Inlet sediments, the cleanup goal is the reference-area concentration of 1.2 mg/kg OC, based on an area-weighted average (in the top 10 cm). The reference-area concentration represents the 90<sup>th</sup> percentile concentration of PCBs in sediments collected from approved Puget Sound reference areas.
- Monitoring of sediments and fish tissue will continue even if the RAOs are achieved, until either of the cleanup goals are met or until the U.S. Navy, Washington State Department of Ecology and the EPA agree that the monitoring program is no longer providing useful information.

**c. CAD and shoreline stabilization monitoring**

1) Objective

- Verify the long-term integrity of the CAD cap system and the shoreline stabilization measures.

2) Monitoring approach and sampling frequency

- Sediment core sampling through the CAD cap and into the unsuitable dredge material will be conducted to demonstrate the continued integrity of the cap and confinement of contaminants.
- Physical observations of the structural integrity of the CAD cap and shoreline stabilization measures will occur periodically.
- The types and quantities of these monitoring events will be greater in early years than in later years.

3) Indicators and metrics chosen to evaluate each objective

- Biological assessments of the CAD area, to document re-establishment of the benthic community.
- Water quality measurements of the CAD area, to confirm that contaminant leaching is not resulting in exceedances of marine water quality criteria.



- Precision hydrographic surveys of the CAD cap and shoreline stabilization measures, to detect any physical movement.

#### 4) Exit criteria

- Not discussed.

### ***5. Data Quality Objectives***

Data quality objectives were not discussed in the documents reviewed.

### ***6. Monitoring Habitat Replacement/Reconstruction***

It was proposed that the OU A shoreline receive placement of sediments and/or other imported materials to create a more gently sloping shoreline, with the intent to improve habitat quality in this area.

Habitat replacement and reconstruction of OU B included the following components:

- Habitat restoration in the area offshore from OU A by placement of sediment to create a shallower slope.
  - Approximately 5,000 tons of a special mixture of rock and gravel were used to enhance near-shore habitat in the vicinity of OU A.
- Shoreline stabilization at Site 1.
  - Riprap was placed to improve armouring and limit erosion, and gravel mix was placed to enhance near-shore habitat quality.

The first five-year review found the coarse gravel to be moving through tidal action. Monitoring and maintenance of the implemented habitat enhancements were excluded specifically from the record of decision (ROD) requirements.

Recommendations from the 2002 annual habitat enhancement inspection at OU A included removal of dead plants and noxious weeds that were choking off native plants along the vegetated berm area, addressing stressed trees along the Charleston Beach enhancement area, and extension of the irrigation line to the south end of the Charleston Beach area to ensure all plants were receiving adequate water.

### ***7. Project Performance, Modifications and Lessons Learned***

The first five-year review reported the discovery of contaminated sediment adjacent to the CAD cell. Additional investigation was recommended. The CAD cell did appear to be functioning as intended.

In the second five-year review, changes were made to the monitoring program, including:

- Modification of the standard EPA guidance for interpreting dual-column chromatographic PCB data to treat the lower reading column value as the default

for reporting. This approach is consistent with historical site data and was expected to improve comparisons between pre-remedy and post-remedy data.

- The use of geometric means rather than arithmetically derived averages (means) to report site-wide sediment PCB and mercury concentrations. While arithmetic means were used in earlier stages of the monitoring program, geometric means were determined based on statistical analysis of the data to provide a better estimate of the central tendency.

**a. Sediment**

Results from within the 500-foot grid from 2003 to 2005 indicated decreases in the carbon-normalized PCB concentration from 6.7 to 6.1 mg/kg OC and a slight decrease in the geometric mean mercury concentration from 0.81 mg/kg to 0.76 mg/kg.

The ROD predicted that the MCUL for marine sediments of 3 mg/kg OC would be achieved within 10 years after the completion of the remediation (2014). As 2005 PCB levels were considerably higher than the target value, statistical analysis results indicated that the MCUL would probably not be reached until 2020.

Results for the 1,500-foot grid from 2003 to 2005 indicated a decline in the carbon-normalized PCB concentration from 2.6 to 2.4 mg/kg OC, while sediment mercury concentrations have remained almost unchanged, from 0.36 mg/kg in 2003 to 0.37 mg/kg in 2005.

Estimated PCB geometric mean for all of Sinclair Inlet, calculated from the geometric mean for the 500-foot and 1,500-foot grid sampling, declined from approximately 3.1 mg/kg OC in 2003 to 2.9 mg/kg OC in 2005. Both values exceed the ultimate cleanup goal of 1.2 mg/kg OC for the inlet as a whole.

**b. Tissue sampling**

The average reported PCB concentration in English sole tissue in 2003 was 0.11 mg/kg, which was identical to the average of the results from the 1991–1997 pre-remediation sampling. Overall, the results indicated that there had been no change in PCB levels in English sole.

The reported PCB concentrations for the Sinclair Inlet samples ranged from 0.020 to 0.075 mg/kg on a wet weight basis, with an average concentration of 0.042 mg/kg. The reported PCB concentration for the reference sample was 0.0079 mg/kg.

Additional information regarding mercury concentrations in rockfish has become available. Older fish, and rockfish in particular, tend to have higher mercury concentrations than the levels measured in English sole. A study of rockfish tissue by Washington State Fish and Wildlife found some mercury concentrations greater than 1 mg/kg. U.S. Food and Drug Administration guidelines require that action be taken to prevent human consumption of fish with mercury concentrations above 1 mg/kg. The report recommended the collection of additional information that would be required to perform a risk evaluation and reach conclusions regarding the protectiveness of the remediation with respect to mercury concentrations in Sinclair Inlet sediment and fish tissue.

**c. CAD monitoring**

The hydrographic survey, sub-bottom profiling and sediment coring at the CAD cell have demonstrated that the cap is functioning as planned. Sediment profile imaging in 2003 showed that benthic community recovery was proceeding rapidly, with plentiful evidence of recolonization.

***8. Further Site Information***

Naval Facilities Engineering Command (NAVFAC), 2007. Second Five-year Review. Department of the Navy, Naval Facilities Engineering Command Northwest, Silverdale, WA.

United States Environmental Protection Agency (U.S. EPA), 2000. EPA Superfund Record of Decision: Puget Sound Naval Shipyard Complex.

URS Group, Inc., 2002. Final Five-year Review of Record of Decision, Bremerton Naval Complex, Bremerton Washington. Prepared for Engineering Field Activity Northwest.

## H. Ketchikan Pulp Company

***Site custodian:***

U.S. Environmental  
Protection Agency  
(EPA)

***Site location:***

Ward Cove, Ketchikan,  
Alaska

***Primary sediment  
contaminants:***

Ammonia and 4-  
methylphenol; organic  
material

***Sediment remedial  
strategies applied:***

Capping, dredging,  
monitored natural  
recovery



**Figure 8: Overview of the Ketchikan Pulp Company Site with the Marine OU outlined in blue. Source: U.S. Army Corps of Engineers, 2010.**

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### 1. Site Summary

The Ketchikan Pulp Company (KPC) began operations in 1954 as a dissolving sulfite pulp mill, and discharged the pulp mill effluent into Ward Cove until pulping operations ended in 1997. The site was split into an Uplands Operation Unit (OU) and a Marine OU. The Marine OU, consisting of approximately 80 acres, has been designated an Area of Concern.

Large quantities of organic material released to Ward Cove have altered the physical structure of the sediments and the type and number of benthic organisms. Degradation of the organic-rich pulping by-product has led to anaerobic conditions in the sediment and production of ammonia, sulfide, and 4-methylphenol in quantities that are potentially toxic to benthic organisms. The selected remedy was a combination of thin-layer capping, mounding, navigational dredging and natural recovery.

## ***2. Remediation Triggers and Objectives***

It was determined that remedial action in Ward Cove may be necessary because of the risk to benthic organisms posed by sediments impacted by historical releases from the KPC. A release could present an imminent and substantial danger to the environment. In order to eliminate or minimize the ecological risk associated with the toxicity of Ward Cove sediments to benthic organisms, the response action was intended to:

- reduce toxicity of surface sediments, and
- enhance recolonization of surface sediments to support a healthy marine benthic infauna community with multiple taxonomic groups.

Chemical-specific bulk sediment chemistry values were not established as cleanup levels for the contaminants of concern (CoCs) at this site. Rather, it was believed that the success of the remedy would be best measured by biological indicators that are most directly representative of the remedial action objectives (RAOs), i.e., sediment toxicity and benthic community structure. Site-specific biological criteria for sediment toxicity and benthic community analyses will be established in a Monitoring and Reporting Plan to evaluate the protectiveness of the remedial action and assess whether the RAOs were being achieved.

## ***3. Receptors Considered and Protection Level Afforded***

### **a. Human health risk assessment**

The human health risk assessment focused on potential risks associated with contacting sediment or eating seafood from the study area. Results of the study did not identify any CoCs for human health. As a result, risks to humans were considered to be within levels considered acceptable by regulatory agencies.

### **b. Ecological risk assessment**

Ecological evaluations focused on the effects of sediment toxicity throughout Ward Cove and a food-web bioaccumulative assessment to estimate risks of chemicals in sediments to representative birds and mammals at the top of the Ward Cove food web. Results from standard and specialized sediment toxicity tests identified ammonia, sulfide and 4-methylphenol as CoCs. Results from the food-web bioaccumulative assessment indicate that no risks of adverse effects resulted from exposure to chemicals of potential concern through the food web for avian or mammalian receptors at Ward Cove. In addition, Ward Cove sediments do not pose a risk to fish inhabiting the Cove.

Threatened and endangered species potentially occurring within the local area include the American peregrine falcon, which is listed by the U. S. Fish and Wildlife Service as an endangered species, the humpback whale, which is listed by

the National Marine Fisheries Service (NMFS) as a threatened species, and the Steller sea lion, which is listed by NMFS as a threatened species.

#### ***4. Summary of Monitoring Plan***

The long-term effectiveness of sediment remediation in Ward Cove will be demonstrated by a reduction in sediment toxicity and the existence of a healthy benthic community.

##### **a. Sediment sampling**

###### **1) Objectives**

- Compare thin-capped and natural recovery areas to reference areas.
- Evaluate temporal trends in thin-capped and natural recovery areas.
- Evaluate chemical concentrations and their relationship to sediment toxicity and benthic community structure.

###### **2) Monitoring approach and sampling frequency**

- Sampling occurred every third year.
- The top 10 cm of sediment in one or more grab samples was homogenized for analysis for chemical and toxicity analysis at each station.

###### **3) Indicators and metrics chosen to evaluate each objective**

- Sediment chemistry and toxicity was monitored at each sampling location.
- Each surface sediment sample (0–10 cm) was analyzed for ammonia and 4-methylphenol. Sediment samples were also analyzed for grain size distribution, organic content and total solids.
- The potential toxicity of each surface sediment sample (0–10 cm) was evaluated using a ten-day amphipod test based on *Rhepoxynius abronius*. Because *R. abronius* has been documented to be sensitive to chemical toxicity and because it is a free-burrowing organism that is directly exposed to sediment contaminants, it will provide an environmentally conservative assessment of the changes in sediment toxicity that will occur following remedial activities in Ward Cove.

###### **4) Exit criteria**

- Sampling will occur in July every third year after completion of the remedial activities, until RAOs are achieved.
- If RAOs are not achieved by year 10, United States Environmental Protection Agency (EPA) proposes that those localized areas that have not recovered continue to be monitored through to year 20, at reduced frequency.

## **b. Benthic community**

### 1) Objectives

- Compare the characteristics of benthic communities in thin-capped and natural recovery areas in the remediated area with the characteristics of communities in reference areas located elsewhere in the Cove.
- Evaluate temporal trends in the characteristics of benthic macroinvertebrate communities found in the thin-capped and natural recovery areas of the remediated areas.

### 2) Monitoring approach and sampling frequency

- Sampling locations for benthic macroinvertebrates were organized as follows:
  - very shallow (<20 feet) , thin-capped: five monitoring stations
  - shallow (20–70 feet), thin-capped: four monitoring stations
  - shallow (20–70 feet), natural recovery (thick organic deposits): seven monitoring stations
  - shallow (20–70 feet), natural recovery (thin organic deposits): five monitoring stations
  - moderate (70–120 feet), thin-capped: six monitoring stations
  - moderate (70–120 feet), natural recovery: five monitoring stations
  - deep (>120 feet), natural recovery: five monitoring stations
  - shallow (20–70 feet), reference: one monitoring station (five field replicates)
  - moderate (70–120 feet), reference: one monitoring station (five field replicates)
- Sampling locations for bioassay samples were the same as above.
- Reference stations were chosen to have sediment characteristics and water depths similar to those of the remediated areas.
- Since the characteristics of benthic communities can be influenced by water depth and sediment character, the monitoring program focused on four different water depths and two remedial actions (thin-capped areas and natural recovery areas). Monitoring locations were not located in the area that was dredged or in the areas with a high density of sunken logs.
- Sediments collected for benthic community analysis were sieved sequentially using mesh sizes of 1.0 mm and 0.5 mm. However, initial laboratory taxonomic analyses were conducted only on the organisms retained on the 1.0 mm screen; organisms retained on the 0.5 mm screen were archived for potential future analysis.

- A three-year gap between remedy implementation and initiation of sampling for monitoring was selected to allow initial recolonization of the benthos following thin capping. Increments of three years allow progress to be assessed over the time scale during which recolonization usually occurs.

### 3) Indicators and metrics chosen to evaluate each objective

- Characteristics of benthic communities in various parts of Ward Cove were evaluated directly by collecting and enumerating the organisms found in surface sediment samples (0–10 cm) collected from the site.
- Because low oxygen conditions may be found in some deeper waters of Ward Cove during late summer, July was chosen as the preferred time to sample benthic communities so that the characteristics of the communities would not be affected by low oxygen levels.
- Reference area comparisons and temporal analyses were carried out using both benthic infauna and bioassay data. Benthic infauna abundances will be given the greatest weight with regard to conclusions reached, because *in situ* conditions are a better reflection of sediment quality.
- The benthic evaluations included comparisons between the remediated areas and reference areas with respect to the following metrics:
  - total abundance, total richness, Swartz’s dominance index, major taxa abundance and major taxa richness
- Qualitative observations of benthic community characteristics were also made to determine whether the communities are recovering. The following were patterns used:
  - initial colonization by “pioneering” species, subsequent modification of physical/chemical characteristics, and final colonization by deeper-dwelling “equilibrium” species
- To help determine the degree of recovery between sampling events, the identities and relative abundances of the benthic species found in the sediments were compared with literature accounts of life history characteristics to determine the stages of recovery of the various benthic communities and the degrees of similarity with communities in the reference areas. Both numerically dominant and non-numerically dominant taxa will be considered.
- Monitoring data from the different strata of thin-capped and natural recovery areas will be analyzed separately. Any observed variability between stations within a stratum will be used to assess the statistical significance of differences from reference areas—or differences over



time—for the entire stratum rather than to evaluate differences in the progress of recovery at individual points.

- Individual benthic infauna and toxicity samples will be distributed spatially throughout each stratum to allow an overall assessment to be conducted. All individual samples from within a stratum will be treated as replicates for the purpose of data analysis.

4) Exit criteria

- Sampling will occur in July every third year after completion of the remedial activities, until RAOs are achieved.
- If RAOs are not achieved by year 10, EPA recommends that those localized areas that have not recovered continue to be monitored through year 20, at reduced frequency.

### ***5. Data Quality Objectives***

Relevant statistical tests for comparison of the benthic communities used a significance level of  $p=0.05$ . The minimum detectable difference for each statistical comparison was calculated for a range of power (e.g., 0.6, 0.7, 0.8) for each non-significant result.

### ***6. Monitoring Habitat Replacement/Reconstruction***

Descriptions and monitoring of habitat replacement and reconstruction activities were not discussed in the documentation reviewed.

### ***7. Project Performance, Modifications and Lessons Learned***

The RAOs were achieved after a ten-year period. The results of the 2004 and 2007 monitoring events revealed that environmental conditions in Ward Cove had improved substantially since the Remedial Investigation/Feasibility Study was conducted in 1996–1999. As well, most conditions showed continual improvement between 2004 and 2007. Both of the two Five-year Review Reports completed for this site found the remedy to be functioning as intended.

Remediation of the thin-capped areas was successful in eliminating sediment toxicity and stimulating colonization of benthic macroinvertebrate species, to the degree that diverse communities comprising multiple taxa now inhabit most parts of the thin-capped areas and exhibit enhanced characteristics beyond those of the reference areas.

Recovery was also found to be proceeding in the natural recovery areas, such that all four areas surpassed sediment toxicity screening levels and three of the four areas have achieved healthy benthic communities with multiple taxonomic groups. The last area is expected to continue to recover, as sediment toxicity in that area has achieved the RAO,

concentrations of total organic carbon, ammonia and 4-methylphenol declined by 20 to 50% between 2004 and 2007, and the major source of contaminants of concern to the Area of Concern has been removed.

#### ***8. Further Site Information***

Exponent, 2001. Long-term Monitoring and Reporting Plan for Sediment Remediation in Ward Cove. Prepared for Ketchikan Pulp Company, Ketchikan, AK.

United States Environmental Protection Agency (U.S. EPA), 2000. EPA Superfund Record of Decision: Ketchikan Pulp Company.

United States Environmental Protection Agency (U.S. EPA), 2005. First Five-year Review Report for Ketchikan Pulp Company Site, Ketchikan, Alaska. Prepared for United States Environmental Protection Agency, Region 10 Environmental Cleanup Office, Seattle, WA.

U.S. Army Corps of Engineers, Alaska District, 2010. Second Five-year Review Report for Ketchikan Pulp Company Site, Ketchikan, Alaska. Prepared for United States Environmental Protection Agency, Region 10 Environmental Cleanup Office, Seattle, WA.

## I. Fort Richardson, Alaska

***Site custodian:***

U.S. Environmental Protection  
Agency (EPA)

***Site location:***

Fort Richardson — Operation  
Unit C, Anchorage, Alaska

***Primary sediment contaminant:***

White phosphorus

***Sediment remedial strategies  
applied:***

De-watering, capping



**Figure 9: Pumping water from the marsh.**

**Source: U.S. EPA, 2008.**

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### ***1. Site Summary***

Munitions use at the Fort Richardson U.S. military base resulted in a buildup of white phosphorus particles in the sediments of Eagle River Flats (ERF). ERF is an 865-hectare estuarine salt marsh along the upper Cook Inlet in Anchorage Borough, Alaska. It was used as the primary munitions impact area from the 1940s to 1989. The environmental conditions at ERF, including the soft, anoxic sediments and frequent deposition of sediment by flooding, contributed to the long-term stability of the white phosphorus as granules. Ingestion of just a few milligrams of white phosphorus by waterfowl is lethal.

Between 1998 and 2007, the U.S. Army implemented numerous water quality restoration projects, including draining the marsh and applying AquaBlok to cap the sediment and prevent contaminants from entering the water column. During each field season, the Army placed six pumping systems into the contaminated ponds and drained them. This helped to reduce the saturation of the soil and increase the soil temperature, thus facilitating sublimation of the white phosphorus and rendering it harmless to the local waterfowl populations.

### ***2. Remediation Triggers and Objectives***

A pattern of high waterfowl mortalities at ERF were first noted in the early 1980s. Fort Richardson was placed on the Comprehensive Environmental Response, Compensation,

and Liability Act National Priorities List in 1994. The Alaska Department of Environmental Conservation (ADEC) placed the ERF on Alaska's 1996 and 1998 Clean Water Act section 303(d) lists of impaired waters because it violated the Alaska Water Quality Criteria for Toxic and Other Deleterious Organic and Inorganic Substances.

The remedial action objectives (RAOs) were as follows:

- Within five years of the record of decision (ROD) being signed, reduce the dabbling duck mortality rate attributable to white phosphorus to 50% of the 1996 mortality rate attributable to white phosphorus. Radio tracking and aerial surveys suggest that about 1,000 birds died from white phosphorus at ERF in 1996, so the allowable number of duck deaths from white phosphorus would be approximately 500.
- Within 20 years of the ROD being signed, reduce the mortality attributable to white phosphorus to no more than 1% of the total annual fall population of dabbling ducks at ERF. Currently, that population is about 5,000, so the allowable number of duck deaths from white phosphorus would be approximately 50. This long-term goal could be adjusted based on future population studies conducted during the monitoring program.

It was assumed that implementation of the remedy would begin in 1999 and be completed by 2018 (duration of 20 years). Treatment would occur between 1999 and 2003, and would be followed by long-term monitoring from 2004 to 2018.

### ***3. Receptors Considered and Protection Level Afforded***

The human health risk assessment considered hunters consuming ducks that may have been contaminated with white phosphorus at ERF. It was concluded that there is a very low human health risk.

The ecological risk assessment considered the three species of dabbling ducks observed at ERF (mallard, northern pintail and green-winged teal) that have accounted for almost 97% of all bird mortality. Swans (trumpeter and tundra) were also considered, as they feed in deeper water habitats. The risk assessment concluded that the effects of white phosphorus exposure to ducks and swans were lethal. No other direct effects to wildlife (benthic invertebrates, fish, predatory birds, mammals) or plants were identified.

Dabbling ducks, the waterfowl group most affected by the contamination, served as the bioindicator for water quality impairment. The long-term goal of 1% mortality represents the mortality rate from natural conditions and the measure of successful remediation for this cleanup.

#### ***4. Summary of Monitoring Plan***

##### **a. Waterfowl Monitoring**

###### **1) Objectives**

Monitoring at ERF will be conducted to verify that RAOs are achieved. The following are the monitoring goals:

- Verify that an exposure pathway does not exist between waterfowl and white phosphorus-contaminated sediment.
- Determine the number of waterfowl using ERF.
- Determine the number of waterfowl dying as a result of feeding in white phosphorus-contaminated sediment.
- Determine whether remedial action is effective or needs modification.

###### **2) Monitoring approach, sampling frequency, indicators and metrics**

- Waterfowl telemetry and mortality study and aerial waterfowl surveys were used to determine bird populations, usage and mortality in ERF.
  - Annual monitoring was scheduled to occur during the first five years of treatment and was planned to continue for three additional years to verify that short-term goals were being maintained. Monitoring would also be conducted at year 10, year 15 and year 20 to ensure that remedial action objectives continue to be maintained.
- Pond survey, ground-truthing and limited aerial surveys were used to evaluate waterfowl mortality, physical habitat changes, and vegetation rebound.
  - Monitoring was scheduled to begin in year 1 and continue every year from year 9 to year 20 (13 events).
- Aerial photography and interpretation were used to monitor habitat changes resulting from remedial actions. From the data collected, changes in drainage, topography and vegetation were evaluated.
  - Monitoring was scheduled every other year for 10 years (five events).
- Mapping of physical habitat changes and vegetation rebound was performed to evaluate impacts to habitat as a result of remedial actions, as well as to observe physical habitat changes and vegetation rebound after pumping was discontinued
  - Monitoring was scheduled once every four years for 20 years (6 events).
- Cap and fill integrity were inspected to ensure the cap and fill remain in place.

- Monitoring was scheduled every year for four years after material was placed (years 5, 6, 7, 8) and in year 10, year 15 and year 20 (7 events).

3) Exit criteria

- Although the mortality rates are below the short- and long-term RAO goals, the Remedial Project Managers require that monitoring be continued to verify the short-term and long-term RAOs continue to be met.

## ***5. Data Quality Objectives***

Data quality objectives were not discussed in the documents reviewed.

## ***6. Monitoring Habitat Replacement/Reconstruction***

Activities to monitor habitat replacement/reconstruction are listed above in the summary of the monitoring plan. Additional details were not discussed in the documentation reviewed.

## ***7. Project Performance, Modifications and Lessons Learned***

### **a. Project performance**

All monitored ponds, hot spots and drainage channels showed a reduction of white phosphorous through 2006. The mean white phosphorus reduction was 69% for monitored ponds, 53% for monitored hot spots, and 29% for monitored drainage channels.

Localized areas of white phosphorous contamination remain in select hot spots and drainage channels in Area C. These areas were capped between 2008 and 2009 to create a barrier to prevent waterfowl exposure during feeding them from waterfowl feeding.

Results from 2006 and 2007 were both below the 1% mortality rate goal as outlined by the ROD (0.3 to 0.6% and 0.4 to 0.9% respectively, adjusted for potential uncertainties in total population by +50%).

Ground-truthing studies have identified changes to the vegetation at the permanently drained ponds. Ponds emptied by the installed drainage systems remain permanently drained and no longer serve as viable habitat, and original vegetation has been replaced by halophytic herb meadow or sedge meadow.

### **b. Modifications**

The practical difficulties of obtaining a helicopter for telemetry monitoring and the inaccuracy of the data prompted the adoption of the weight-of-evidence

approach. As of 2004, ground-based mortality surveys replaced telemetry monitoring.

The ROD called for capping and filling of areas that did not drain and dry. AquaBlok (a bentonite-gravel mixture) was tested as a capping material and proved ineffective. The bentonite became loose and unstable in open water and did not succeed in preventing ducks from picking up white phosphorus particles from the areas where it was applied. It was recommended that, if capping was required in the future, gravel be used as capping material.

#### ***8. Further Site Information***

[http://water.epa.gov/polwaste/nps/success319/ak\\_eagle.cfm](http://water.epa.gov/polwaste/nps/success319/ak_eagle.cfm)

CH2MHILL, 1998. EPA Superfund Record of Decision: U.S. Army Fort Richardson OU C, Fort Richardson, AK. Prepared for Department of the Army, US Army Engineer District, Alaska.

United States Army Alaska, 2003. First Five-year Review Report for Fort Richardson, Alaska. Fort Richardson, Alaska.

United States Army Alaska, 2008. Second Five-year Review Report for Fort Richardson, Alaska. Fort Richardson, Alaska.

United States Environmental Protection Agency, 2008. Section 319 Nonpoint Source Program Success Story: Alaska — Water Quality Restored at Eagle River Flats to Revive Bird Population. Washington, DC.

## J. Northern Wood Preservers Alternative Remediation Concept

### *Site custodian:*

Northern Wood Preservers Inc. (NWP), Abitibi-Consolidated Inc., Canadian National Railway Company, Environment Canada and Ontario Ministry of the Environment (OMOE)

### *Site location:*

Thunder Bay Harbour, Ontario

### *Primary sediment contaminant:*

Polycyclic aromatic hydrocarbons (PAHs)

### *Sediment remedial strategies applied:*

Dredging, capping, monitored natural recovery



**Figure 10: Aerial view of dredging operations during remediation. Source: Environment Canada, 2005.**

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### *1. Site Summary*

For over 50 years, the Northern Wood Preservers (NWP) facility has produced wood products treated with creosote and lumber treated with pentachlorophenol. Total polycyclic aromatic hydrocarbon (PAH) concentrations in the sediments of the harbour varied from <2 ppm to >16,000 ppm. Sediment chemistry results showed decreasing PAH concentrations with increasing distance from the site. A pool of liquid creosote was encountered along the north wall of the site.

A comprehensive study completed in 1996 identified four levels/zones of contamination:

- a toxic zone of severely contaminated sediment with creosote on the surface of the sediment, representing a potential source of ongoing PAH contamination to the water column and sediment
- a zone of acute biological effects (total PAH concentration in sediment greater than 150 ppm)



- a zone of chronic biological effects (total PAH concentration in sediment between 30 ppm and 150 ppm)
- a zone of no measurable biological effects (total PAH concentration in sediment less than 30 ppm)

## ***2. Remediation Triggers and Objectives***

In 1985, Thunder Bay Harbour was listed as an Area of Concern by the International Joint Commission due to degraded sediment and water quality.

The goal of the project was to clean up the contaminated sediment, isolate the contaminant source (i.e., the NWP pier) and enhance fish habitat. The activities which were undertaken to obtain these goals were as follows:

- an end-dumped rockfill berm to encompass the NWP site area
- dredging of the more highly contaminated sediment (total PAH concentration >150 ppm)
- containment of the contaminant source by means of an isolation barrier and associated groundwater collection drain
- infilling of the area between the isolation barrier and the rockfill berm to confine contaminated sediment (total PAH concentration <150 ppm)
- construction of a compensation area for replacement of aquatic and terrestrial habitat as required by the Department of Fisheries and Oceans (DFO)

## ***3. Receptors Considered and Protection Level Afforded***

The need for cleanup was based on biological effects determined through a combination of benthic community assessment and laboratory sediment bioassays. Whole-sediment toxicity tests were conducted across a gradient of PAH and dioxin/furan (PCDD/F) concentrations using the mayfly nymph, *Hexagenia limbata* (21-day exposure, survival and growth), the midge larva, *Chironomus tentans* (10-day exposure, survival and growth) and the juvenile fathead minnow, *Pimephales promelas* (21-day exposure, survival and chemical bioaccumulation).

Tests showed through regression analysis that sediment toxicity was related to sediment PAH concentrations for all three organisms. Sediment toxicity testing indicated no effects on either survival or growth at sediment PAH concentrations below 30 ppm. Between 30 ppm and 150 ppm, there was an increase in growth impairment among the mayflies, chironomids and minnows. Survival was affected as concentrations of total PAH exceeded 100 ppm.

The sediment toxicity test results were verified in the field through benthic community analysis. Reductions in the density and diversity of the chironomid community were found to correspond with laboratory toxicity results.

As a result of testing, four contaminant zones were developed:

- Zone 1: an area of heavy visible contamination of sediment by creosote (a creosote “pool”) located immediately north of the NWP pier
- Zone 2: an area defined on the basis of acute biological effects (i.e., 50% or higher mortality in the test organisms), and coinciding with the area of high PAH (>150 ppm) and high PCDD/F (> 200 ppt total toxic equivalency quotient) contamination
- Zone 3: an area defined on the basis of chronic biological effects and coinciding with the sediment area between 30 ppm and 150 ppm total PAH
- Zone 4: an area considered suitable for natural remediation because existing contaminant concentrations posed little threat to biota (total PAH below 30 ppm; no measurable effect on benthic organisms)

#### ***4. Summary of Monitoring Plan***

Samples were collected from the perimeter of the site to monitor the effectiveness of the sediment remediation project.

##### **a. Water monitoring**

###### **1) Objectives**

- Compare concentrations to Provincial Water Quality Objectives or federal guidelines (Canadian Council of Ministers of the Environment, CCME)

###### **2) Monitoring approach and sampling frequency**

- Ten locations and two reference locations were chosen.
- Samples were collected in October.

###### **3) Indicators and metrics chosen to evaluate each objective**

- Water samples were analyzed for:
  - Nutrients and general water chemistry parameters
    - Alkalinity, hardness, pH, conductivity, cations, chloride, sodium, nitrogen (total Kjeldahl), total phosphorus, dissolved solids, suspended solids and total solids
  - Inorganic elements
    - Al, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Mo, Ni, K, Sr, Ti, V and Zn

- PAHs
  - Anthracene, Benzo(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(e)pyrene, Benzo(g,h,i)perylene, Benzo(k)fluoranthene, 7,12-dimethylbenz(a)anthracene, Chrysene, Dibenzo(a,h)anthracene, Fluoranthene, Indeno(1,2,3-c,d)pyrene, Perylene, Phenanthrene and Pyrene

4) Exit criteria

- Not discussed.

**b. Sediment monitoring**

1) Objectives

- Compare concentrations to provincial (OMOE) or federal (CCME) sediment quality guidelines

2) Monitoring approach and sampling frequency

- Ten locations and two reference locations were chosen.
- Samples were collected from the top 10 cm of sediment.
- Samples were collected in October.

3) Indicators and metrics chosen to evaluate each objective

- Surface sediment samples were analyzed for:
  - Particle size
  - Inorganic elements
    - Al, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Mo, Ni, Se, Sr, Ti, V and Zn
  - PAHs
    - Acenaphthene, Acenaphthylene, Anthracene, Benzo(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(g,h,i)perylene, Benzo(k)fluoranthene, Chrysene, Dibenzo(a,h)anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-c,d)pyrene, Naphthalene, Phenanthrene and Pyrene

4) Exit criteria

- Not discussed.

**c. Caged mussels**

1) Objectives

- Compare mortality and growth in test and reference sediments

## 2) Monitoring approach and sampling frequency

- Ten locations and two reference locations were chosen.
- At each location, six mussels were placed in cages which were submerged 1 m from the bottom sediment for 21 days (study began in September).
- Three mussels from each location were analyzed

## 3) Indicators and metrics chosen to evaluate each objective

- Mussel tissue was analyzed for:
  - PAHs
    - Acenaphthene, Acenaphthylene, Anthracene, Benzo(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(g,h,i)perylene, Benzo(k)fluoranthene, Chrysene, Dibenzo(a,h)anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-c,d)pyrene, Naphthalene, Phenanthrene and Pyrene
  - Percent lipids

## 4) Exit criteria

- Not discussed.

### **d. Benthic Communities**

#### 1) Objectives

- Examine community structure at test and reference sites.
- Assess the toxicity of sediments to benthic invertebrates.

#### 2) Monitoring approach and sampling frequency

- Toxicity tests were conducted to assess the chronic toxicity of sediments to benthic organisms.
- Three replicate samples were collected from each sampling location.

#### 3) Indicators and metrics chosen to evaluate each objective

- Examined survival, growth and mortality of test organisms
  - Organisms considered represent different trophic levels
    - Chironomids (midge), amphipods, mayfly, fathead minnow (survival and bioaccumulation)
  - 14- day amphipod (*Hyaella azteca*) test, 10-day chironomus (*Chironomus tentans*) test, 21-Day mayfly (*Hexagenia* spp.) test and a 21-day fathead minnow (*Pimephales promelas*) test
- Benthic community structure

- Multivariate analyses, including clustering and ordination, were used to interpret benthic invertebrate community composition in relation to water and sediment chemistry parameters.

#### 4) Exit Criteria

- Not discussed.

### 5. *Data Quality Objectives*

Data quality objectives were not discussed in the documents reviewed.

### 6. *Monitoring Habitat Replacement/Reconstruction*

#### **a. Creation of fish habitat and naturalized buffer zone**

As the project affected approximately 150,000 m<sup>2</sup> of existing lake area and would result in the loss of fish habitat, a requirement of the project under DFO's Harmful Alteration, Disruption or Destruction program was to create fish habitat. The restoration of the site included reshaping approximately 11,000 m<sup>2</sup> of reclaimed marshland and the creation of embayments within a 20 m buffer zone along the perimeter of the rockfill berm. The plan design resulted in a net gain of 1,220 m<sup>2</sup> of overall weighted suitable habitat. The fish habitat compensation features were designed to target cold and warm water fish species, including walleye, pike, perch and shiner, and included creation of the following:

- shallow habitat along the toe and slope of the rockfill berm
- deep pools and wetland cells along the eastern side of the pier
- cobble beaches to facilitate fish spawning
- a spawning channel
- log shelters to provide cover for younger fish
- incidental wetlands to serve as nursery/feeding areas
- a linked island setting in the 0–2 m depth range for incidental wetlands and varied bottom substrata

#### **b. Vegetation plan and planting**

A primary goal of the fish habitat compensation plan was to reclaim a portion of a wetland adjacent to the marsh that had become dominated by cattail growth, which had reduced severely the value of the wetland to fish and wildlife.

A vegetation plan was implemented in accordance with the DFO application for the fish habitat compensation proposal. The vegetation plan consisted of the following four zones:

- pond littoral zone: area covered with water to be left over two years to propagate with emergent and submergent aquatic vegetation through natural processes
- pond shoreline: planted with tree species able to withstand periodic flooding, such as willow and dogwood
- berm areas: sections of the original rockfill berm access road surface covered with a layer of topsoil, seeded and planted with shallow-rooted tree species such as spruce, with incidental pine and poplar
- buffer zone: sandy soil-filled areas, close to the water table, vegetated with mixed woody vegetation such as spruce, jack pine, red pine, cedar, dogwood and poplar

Monitoring was to be carried out for two consecutive growing seasons to verify that the terrestrial and aquatic vegetation was established and surviving. The monitoring consisted of visual inspections on a monthly basis during spring, summer and fall for the following items:

- aquatic vegetation: percentage of area covered, species, general health and signs of damage/loss to previously established vegetation
- terrestrial vegetation: survival rate for each species, average growth rate, general health of the vegetation and evidence of physical damage to the vegetation

## ***7. Project Performance, Modifications and Lessons Learned***

### **a. Water monitoring**

Results from 2007 found metal concentrations, including cadmium, cobalt and chromium, to be elevated above the Provincial Water Quality Objectives (PWQO) at some locations. Cadmium exceeded the PWQO (0.2 ug/L) at 10 sites. It was suggested that the elevated concentrations represented background levels, as similar concentrations were found at both reference sites. Cobalt exceeded the PWQO (0.9 ug/L) at eight sites and chromium exceeded the PWQO (1 ug/L) at one site. Cadmium and chromium had been found to be elevated above the PWQO in 2003–2004, as had copper and lead, although the latter two were not elevated in 2007. PAHs were close to or below detection limits at all sample locations in 2007. In 2009, one sample location was above

CCME guidelines for pyrene (25 ng/L) and fluoranthene (40 ng/L). Overall, concentrations of most metals reflect ambient conditions in the harbour.

**b. Sediment monitoring**

In 2007, iron levels at 8 of 12 sites were elevated above the Provincial Sediment Quality Guidelines severe effect level (SEL) (40,000 ug/g) and exceeded the lowest effect level (LEL) (20,000 ug/g) at all but one of the remaining sites. 2003–2004 results indicated the same trends. Other metal concentrations were below the SEL at all sites. Cadmium exceeded the LEL at all sites and chromium, copper, manganese, nickel and zinc exceeded the LEL at most sites. PAHs were found to be elevated in the vicinity of the historical contamination. Results from 2007 show a considerable decline in PAHs since 2003–2004 sampling. It was suggested that PAH levels were low because of the very low total organic carbon content and the coarse particles present. Overall, metals in sediment do not appear to be an issue as concentrations of most metals are similar to reference sites.

**c. Mussel monitoring**

Concentrations of PAHs in caged mussels were generally below method detection limits, with a small number at trace levels. Mussels from the most northwest site contained the highest levels of PAH congeners. The water sample collected from this location had high suspended solids, which may indicate disturbance of the sediment or significant surface runoff, which could account for the elevated levels.

**d. Toxicity**

The sediment toxicity study carried out in 1999 found the sediments to be non-lethal to benthic organisms. In 2003 and 2009, studies noted significant mortality during sediment toxicity bioassays. From the list of test organisms noted in the monitoring summary, all organisms at two sites had significant mortality in 2003 and 2009. A third site had significant mortality for all test organisms in 2003 and 2009 with the exception of mayflies in 2009. PAH concentrations in fathead minnows were at lower levels in 2009 than in 2004.

**e. Benthic Communities**

In 1999, benthic communities were dominated by chironomids, molluscs, and oligochaetes. In 2004, all sites had similar community structure as in 1999, with the exception of one site. It was suggested that the lack of difference in benthic

community structure between stations with high PAHs and others may be due to the ability of organisms to avoid creosote, which is present as distinct globules.

**f. Future modifications to monitoring program**

In 2007, Environment Canada collected a number of sediment samples in the vicinity of the site. Arsenic was included in the analysis of these samples. Results from two sites exceeded the SEL (33 ug/L). It was recommended that subsequent sediment samples be analyzed for arsenic.

In 2009, in addition to the water, sediment and mussel monitoring discussed above, benthic community samples were collected to assess any impacts on the benthic community and fish samples were collected for analysis of PAHs, metals and dioxin/furans.

***8. Further Site Information***

Baker, S., R. Fletcher and S. Petro 2006. *Northern Wood Preservers Alternative Remediation Concept (NOWPARC) Bioassessment of Northern Wood Preservers Site Thunder Bay Harbour, Lake Superior 2003 and 2004*. Ontario Ministry of the Environment Environmental Monitoring and Reporting Branch, Thunder Bay, ON.

Environment Canada, 2005. NOWPARC — Northern Wood Preservers Alternative Remediation Concept.

Golder Associates, 2005. Project Completion Report, Northern Wood Preservers Alternative Remediation Concept (NOWPARC) Project, Northern Wood Preservers Site, Thunder Bay, Ontario. Prepared for NOWPARC Steering Committee, Montréal, Quebec.

Ontario Ministry of the Environment (OMOE), 2010. Post-remediation monitoring (2003–2009) of the Northern Wood Preservers Inc. site in Thunder Bay Harbour (PowerPoint slides). Presented to the Thunder Bay Public Advisory Committee, March 10, 2010.

Scheider, W. 2009. *Re: Northern Wood Preservers, 2007 Sample Summary* (memo). To: John Taylor, Assistant Director, Northern Region, Ministry of the Environment. April 14, 2009.



## **APPENDIX D:**

### **Long Term Monitoring Plan Template**

#### **For Federal Contaminated Site Remediation/Risk Management Projects**

The following template for the development of a LTM plan has been adapted from a guidance document, *Long-term Stewardship Planning Guidance for Closure Sites*, produced by the US Department of Energy (DOE) Office of Legacy Management. Although referenced in other US EPA publications, this document would appear to have only been completed in draft form, and was possibly only used internally by the DOE. The original application of this guidance was in the context of management of the nuclear weapons complex in the United States; however, the components and rationale for what DOE refers to as Long Term Stewardship are very closely analogous to those of a remediated contaminated site with contaminants of concern remaining on site. The sections of the guidance, with applicable instruction and intent, are presented in the following appendix.

It is expected that the full Long Term Monitoring Plan as presented here would be prepared once, following the completion of remediation/risk management activities. Subsequent reports would provide an update on monitoring results and review the LTM plan assumptions in the context of new information received.

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## **1.0 EXECUTIVE SUMMARY**

This section should contain a brief summary of the site description, background, and the LTM plan and outcomes. The monitoring objectives should be stated, as well as a summary of monitoring activities completed. The environmental conditions at the end of the monitoring activities should be summarized for each area of environmental concern on site. The main outcomes from comparisons of monitoring data with the relevant decision rules should be described along with major conclusions and recommendations. A statement should be included to indicate whether the site meets the criteria for site closure or if further monitoring is required.

## **2.0 INTRODUCTION**

This section should include a brief statement describing why LTM is required at the site and how the plan will be used to implement the LTM activities. For example there might be residual CoCs remaining at the site and there are potential receptors, therefore LTM is required to manage the residual risk.

In addition to addressing the general reasons for LTM at the site, the purpose and scope of the LTM plan itself must be stated. The intent is to clearly define the:

- Boundaries to which the plan applies
- Breadth of activities it encompasses,
- Performance objectives for the activities it specifies
- Roles and responsibilities, and
- Process for changing either the plan itself or the activities within the plan

The latter are needed so that future managers can continually compare performance with objectives and stakeholders can see how their concerns have been addressed. As necessary, clearly define key terms that will be used throughout your plan as they relate to the site.

### **2.1 Objectives of the LTM Plan**

State the objectives of the LTM plan, and of each of the individual LTM activities that will be performed at the site. The goal of LTM is to ensure protection of human health and the environment; this goal is achieved by defining particular monitoring objectives associated with specific areas of environmental concern, remediation or risk management infrastructure, or natural environment. As such an LTM plan may have several specific objectives, each with their own metric for achievement.

## **2.2 Scope of LTM at the Site**

Provide general information about the scope of the LTM at the site. Some examples of LTM activities may include, but are not limited to, the following:

- Inspect, maintain and repair engineered containment systems (landfills, dams, tailings caps, etc.)
- Monitor wells and other as-built features
- Maintain security
- Monitor environmental indicators
- Provide reports
- Perform information management tasks

Each key component of the LTM activities and each portion of the site addressed in the plan should be identified so the reader has a big picture look at the overall scope of the LTM plan.

### 3.0 SITE BACKGROUND

#### 3.1 List of Documents

List all documents that have been prepared for the site and where they are archived. This relates to s. 2.1 of the Site Closure Tool.

Document #	Report Title	Author	Date	Archive Location	Internal Document Identifier #
1					
2					
3					
4					
5					
etc.					

#### 3.2 Site Identification

Complete the following table. If required by the custodial department, attach a site layout plan as well as a plan showing pre- and post-remediation conditions. This relates to s. 2.4 of the Site Closure Tool.

FCSI No. of Contaminated Site	
DFRP Number	
Exact Site Name as listed in IDEA	
Site Address (street address, municipality, province/territory)	
Reporting Organization	
Legal description or metes and bounds:	
Approximate Site area	
Centre of site coordinates (in lat/long or UTM)	

### 3.3 Site Description

Provide a clear record of what space and media fall under the LTM plan such that future managers understand the full extent of the property for which activities are to be conducted.

The site description should include the following:

- Physical Site Conditions:
  
  
  
  
  
  
  
  
  
- Regional Setting:
  
  
  
  
  
  
  
  
  
- Elevation/Topography:
  
  
  
  
  
  
  
  
  
- Climate and Weather:
  
  
  
  
  
  
  
  
  
- Geologic Setting:
  
  
  
  
  
  
  
  
  
- Demography:
  
  
  
  
  
  
  
  
  
- Lines and Other Property Rights:

Describe the physical boundaries of the site or portions of the site to which the LTM plan applies. This may also include activities outside the site boundary if, for example, a groundwater plume has moved offsite and groundwater use restrictions are deemed necessary.

The description should be supplemented with maps, GIS coordinates, survey benchmark reference points, photographs, as-built drawings, or other means of describing the physical boundaries of the site/portion. Identify the location of areas such as buffer zones, location of specific waste management areas, boundaries of groundwater plumes, location of surface waters, and location of residual hazards to the extent that they can be physically mapped out.

Address characteristics of any offsite location affected by the department's LTM responsibility, including current uses, potential future uses, and liens, reserves and other property rights. This includes any offsite location where residual hazards are or are anticipated to be located (e.g., offsite soil contamination or groundwater plumes) for which the custodian department is responsible for conducting LTM activities, if applicable, as well as potential effects that the offsite activities may have on the site (e.g., industrial, agricultural, or residential uses).

Most of the characteristics listed should describe the site in its entirety. However, to the extent that specific areas of environmental concern (AEC) characteristics are important for LTM management, these characteristics and settings should be clearly identified in the description of the unique AECs. For example, an AEC of the site may border a wetland or a residential subdivision, making LTM responsibilities different for that particular AEC. There may be multiple watersheds onsite, which would also require the descriptions to allow for characterization of the unique aspects of the watersheds.



#### **4.0 CULTURAL, NATURAL, AND HISTORICAL PRESERVATION**

Identify any threatened and endangered species, archeological and cultural resources

Identify any Aboriginal land claims or treaty rights.

Identify other natural and cultural resource issues that may be specific to the site.

## 5.0 SUMMARY OF REMEDIAL/RISK MANAGEMENT ACTIVITIES

Provide a brief summary of all remedial activities from Steps 7-9 of the Federal Approach to Contaminated Sites in the sections below.

### 5.1 Risk Drivers

This information could be summarized in tabular form for ease of reference, an example table is provided below.

Summary of past activities at site	
Current activities and proposed future use for site	
Areas of Environmental Concern (AECs)	
Sources of contamination	
Affected media and Contaminants of Concern (COCs)	
Main human health driver(s) for remediation/risk management measures at the Site	
Main ecological driver(s) for remediation/risk management measures at the Site	
Approach to establishing remedial objectives: generic or site-specific	
Is the Site impacted by another site (i.e., off-site contamination sources)?	
Physical Risks	
Other (specify)	

## 5.2 Summary of Remedial Objectives

In previous reports, the contaminated site remediation and/or risk management objectives will have been defined. A brief summary should be provided that describes those objectives. If there are multiple areas of concern, provide a summary for each AEC. AECs can be grouped where the same objectives were applied and remedial actions were implemented. Explain what the drivers were for the remedial objectives for all media, and why there was any divergence from use of generic criteria. Note: Include Site Specific Target levels (SSTLs), if established for the site or a particular AEC.

e.g., the remedial objectives for this site were:

1. The removal of approximately 500 m<sup>3</sup> of contaminated soil in excess of Canada Wide Standards for Petroleum Hydrocarbons in Soil Tier 1, for commercial land use with coarse-grained soil, as presented in Table 1 below:

**Table 1: CWS-PHC Tier 1 Remediation Criteria (mg/kg).**

<b>Fraction 1</b>	<b>Fraction 2</b>	<b>Fraction 3</b>	<b>Fraction 4</b>
<b>(C6-C10)</b>	<b>(&gt;C10-C16)</b>	<b>(&gt;C16-C34)</b>	<b>(&gt;C34)</b>
320	260	1,700	3,300

2. Implement access control measures for any contaminated soils which could not be removed due to accessibility.
3. Observations of decreasing PHC concentrations in ground water over time at designated monitoring wells.

## 5.3 Summary of Remediation / Risk Management Approach

Summarize all actions (not just those resulting in LTM requirements) taken relative to site contaminants including:

- Remediation or risk management cleanup actions;
- Closing, stabilizing, and decontaminating and decommissioning onsite facilities;
- Closing waste containment facilities, thus indicating how risk has been managed and what implications may be put to future monitoring results.

The discussion should:

- Describe the condition of offsite areas of contamination to the extent that they are unique to those areas versus the site-wide conditions;

- Provide a synopsis of the original exposure pathways and describe how or if pathways have been terminated;
- Include the level of redundancy in those actions such that future managers can understand the implications of perceived failures and/or proposed changes in site use;
- Clearly reflect uncertainties and assumptions regarding the remediation process, thus alerting future managers to those elements of the model and/or remedy that may be based on erroneous or missing data;

#### **5.4 Site Conditions Once Remediation/Risk Management Objective(s) Have Been Met**

Identify the location and nature of residual contaminants and physical hazards. It is the presence of these residual hazards that necessitates development and implementation of the LTM plan. Readers seeking more detailed data can be directed to the appropriate documents. The information in this section can be presented in graphical form (i.e., annotated maps) or other forms such that the location of the contaminants or residual hazards can be identified.

If applicable, identify the assumptions and uncertainties used in developing the remediation objectives. Explicitly identify that which is not known or understood so that monitoring data can be properly evaluated and contingency plans maintained where appropriate. Assumptions will be modified or removed as monitoring data are collected and a better understanding of the site is developed.

Clearly articulate assumptions that were made during R/RM selection, and selection of LTM activities, etc., such that future managers can test those assumptions to determine if they are still valid.

An updated post remediation/risk management conceptual site model should be included to summarize all available site-specific information related to contaminant sources and release mechanisms, affected media, contaminant transport and environmental fate, and receptor exposure.

The following table can be used and is related to s. 4.2 of the Site Closure Tool. If no Risk Assessment was completed, include a narrative description of the residual risks that exist at the site, why no RA was required or conducted and a description of the measures taken to manage the residual risks.

***Summary of Residual Risk Management Requirements***

<b>Contaminant of Concern</b> (repeat if more than one operable pathway)	<b>Operable Pathway</b>	<b>Risk Management Measure Recommended in Risk Assessment</b>	<b>Risk Management Measure Implemented</b>	<b>RM Measure Complies with Goals of RA Recommend- action?</b>	<b>Subject to LTM?</b>

## 6.0 STAKEHOLDER INVOLVEMENT

Describe the plan for community involvement, including the roles and responsibilities during the LTM plan development, modification and implementation. This section could also include the key points at which public meetings will be held, specific activities requiring community involvement, and the extent to which the LTM plan may rely on community involvement to provide assistance in maintaining controls. The following table from the Site Closure Tool can be used to document not only public consultation, but any stakeholder consultation.

### *Stakeholder Communications History*

The custodian has made an effort to identify stakeholders with an interest in the final outcome of the remedial or risk management measures undertaken at the site. The list below should indicate important dates (e.g. of community meetings) and documents that have been provided to stakeholders. In the row beside the date and nature of contact, indicate which stakeholders were involved.

Date and Nature of Contact	Local Residents	Expert Support (e.g., Health Canada)	Regulators	Custodian	Site Consultant	Key Issues / Conclusions

### *Summary of Expert Support Involvement*

Provide a description what input, and the extent of input, Federal Expert Support (ES) departments had in the risk management of the site. This includes CEAA related elements and FCSAP Expert Support input. Indicate if the ES advice was followed, and if not, describe why.

## 7.0 REGULATORY MANAGEMENT

Provide the regulatory and institutional framework for the LTM activities in the LTM plan. The regulatory compliance requirement should be discussed along with the applicable LTM activity.

Identify all of the LTM activities that are specifically required by regulation, permits, licenses or other third party enforceable agreements and the enforcement mechanisms.

Identify LTM activities that will be conducted pursuant to regulatory orders, directives, or policies.

Identify any other requirements addressed in the LTM plan, such as agreements with third parties (e.g., land use or access agreements)

A description of the monitoring activities and associated study design information should be included according to the categories listed in Section 9.4 below.



## **8.0 AUTHORITY AND ACCOUNTABILITY**

The legal authorities under which LTM will be conducted should be identified and documented. These authorities lead to the types of LTM activities that will be conducted at the site.

Identify key organizations or groups responsible for carrying out LTM activities for the site including descriptions of their roles and responsibilities. The plan should include clear identification of the responsible manager/Department and other involved parties as well as how those positions relate to regulators. These key individuals should be identified by a process that involves the custodian department, regulators, land managers, and stakeholders. An organizational chart may be used to convey this information clearly and succinctly.

In addition, when other parties will carry responsibility for performance of specific LTM activities, those parties and the scope of their responsibilities must be clearly identified (i.e., when the land manager will maintain use restrictions or regulators will monitor resource use). Any agreement that states authority and accountability should be identified and referenced.

In addition to identifying the assignment of responsibilities, this section should also identify the communication requirements, especially the knowledge management activities such as reporting and information archiving.

## 9.0 LONG TERM MONITORING REQUIREMENTS

### 9.1 Engineered Controls

Engineered controls are barriers or treatment systems that have been put into place to limit human and ecological receptor exposure to chemical and physical hazards at a contaminated site. Examples include landfills; stabilized structures; sediment caps; groundwater treatment systems; and containment technologies.

Describe each engineered control that is being implemented, and how it is being implemented and maintained as part of the LTM program. Included in the discussion on the engineered controls should be an explanation of the surveillance and maintenance activities by which effectiveness will be monitored, as well as the roles and responsibilities for maintaining the engineered controls.

In addition, this section could, if applicable, include a discussion on the role of advances in science and technology on adaptive management of the LTM for the site. When appropriate, this section could describe how new technologies will be integrated into the LTM program.

Summarize key activities necessary to maintain physical engineered controls, such as caps and permeable treatment walls, and provide references for more detailed information.

Include a description of the following elements for all components of the engineered controls:

- **Maintenance Methods.** Describe how routine maintenance will be performed on LTM engineered controls.
- **Maintenance Frequency.** Identify the frequency for routine preventive maintenance activities and the trigger levels for determining when corrective measures are required.
- **Maintenance Reporting Requirements.** Identify reporting requirements for routine maintenance activities and determine the trigger levels for reporting events or maintenance needs (e.g., repairs).

A description of the monitoring activities for engineered controls and associated study design information should be included according to the categories listed in Section 9.4 below.

### 9.2 Institutional/Administrative Controls and Land Use Planning

Describe the institutional/administrative controls being implemented, and how they are being implemented and maintained, as part of the LTM program.

This should include a description of other use/access restrictions required to maintain protectiveness and the location of where these controls are in effect at the site. Controls on off-site properties that are required for the remedy should be included in this discussion.

Describe the overall strategy for institutional controls that demonstrates protectiveness should a control fail. An explanation of the surveillance and maintenance activities by which effectiveness will be monitored, as well as the roles and responsibilities for maintaining the institutional controls should be provided.

Include a description of the following elements:

- **Site/Portion Land Use Maps.** Provide maps depicting land use and land use restrictions for the site and specific portions addressed by the LTM plan. Identify potential LTM implications if the land use changes.
- **Land Use Definitions.** Define the scope of activities intended within each land use category, so that managers have a clear understanding of how the definitions were used when describing land use.
- **Land Use Policies.** Discuss the key policies impacting land use at the site and/or portion of the site addressed by the LTM plan.

Include a graphical representation of current and anticipated future land use accompanied by definitions of those uses.

A description of the methods and inspection activities selected to monitor institutional controls and associated study design information should be included according to the categories listed in Section 9.4 below.

### **9.3 Evaluating Key Risk Management Assumptions and Ecosystem Recovery**

Describe the key assumptions of the risk assessment and risk management strategy that require monitoring to ensure protectiveness at a dynamic site, and/or key measures of long-term ecological recovery. These could include hydrological data, groundwater contaminant concentrations following treatment, sediment deposition patterns, decreased contaminant tissue concentrations in fish populations, and measures of climate change where permafrost freezeback is an important element of remedial design. Evaluation of post-remediation re-vegetation success and fish habitat recovery are also included under this section.

A description of the monitoring activities to evaluate key RM assumptions and ecosystem recovery and associated study design information should be included according to the categories listed in Section 9.4 below.

#### 9.4 LTM study design information

A post-remediation/risk management conceptual site model should be included to summarize available site-specific information regarding contaminant sources, affected media, transport pathways, and receptor exposure. A description of the following study design elements for each monitoring activity identified in Section 7.0 and Sections 9.1 to 9.3 should be included in the LTM Plan:

- **Objectives of Monitoring Activities.** State the objectives of the monitoring or inspection activity.
- **Medium.** Identify the medium that is being monitored (or will be monitored) and the metric that will be measured. For institutional controls, indicate the types of inspection activities required.
- **Locations.** Identify the locations on site where the monitoring activities will take place. Maps indicating the sampling locations should be provided and the rationale for selecting the monitoring locations should be outlined.
- **Timing:** Identify the index period when the samples will be collected and/or inspections will take place.
- **Frequency.** Identify the frequency of monitoring/inspections.
- **Method.** Identify the data collection and data analysis methods to be employed for the monitoring activity and/or the methodology to be used for routine inspections. The statistical design of the monitoring program should also be outlined. The data collection methodology should be justified with regards to the statistical design (*e.g.*, is the sample size and sampling frequency sufficient to meet the statistical data quality objectives given natural variability at the site?).
- **Quality Assurance.** Describe the quality assurance program under which monitoring activities and/or inspections will be conducted. Many of the specific details of the maintenance and monitoring will be covered in other documents and should be referenced in the LTM Plan. Procedures for QA/QC associated with sampling and analysis of media should follow the same or equivalent standards as those of a Phase II or III Environmental Site Investigation. Statistical data quality objectives (*e.g.*, level of significance, statistical power) should also be stated.
- **Monitoring Decision Rules.** Describe the monitoring decision rules used to interpret the monitoring results for each objective. The action levels (triggers), temporal considerations, and alternative actions to be considered for implementation should be stated. This includes a description of how the data will be interpreted and what the threshold criteria are for determining when contingent actions are warranted, as well as a description of possible contingent actions. The linkage between monitoring and inspection observations and emergency response and/or corrective actions should be clearly explained. If appropriate, include a discussion of onsite or offsite areas that are subject to a release (failure) and the contingency measures in place. Describe the emergency response and reporting procedures including public notification requirements.

- **Reporting Requirements.** Describe reporting requirements for the results of the monitoring activities. Also address reporting requirements when monitoring outcomes or inspections indicate that some sort of corrective measure or emergency response is warranted.

## 9.5 Documenting LTM Requirements

Use the following tables to summarize the LTM requirements described in s 7.0 and 9.1 to 9.3.

### *Description of Long-Term Monitoring Requirements*

List risk management measures requiring long-term monitoring (e.g., maintaining equipment, monitoring contaminants, ensuring prohibitions on building construction, restrictions on property use, maintaining barriers, evaluating risk assessment and/or risk management assumptions at dynamic sites)

Measure	Objective	Brief Description	Frequency and Duration	Responsibility

*Documentation of Long-Term Monitoring*

List the long-term monitoring plans and progress reports that have been prepared for the site	Report

*Long-Term Monitoring Log*

Record the frequency, duration and most recent assessment of each long-term monitoring event.	Activity	Date of Last LTM Event	Where Documented (Document Number)	RM Measures Operating as Intended

## **10.0 FUNDING AND RESOURCE REQUIREMENTS**

### **10.1 Funding**

Provide the rational for the anticipated costs of the LTM activities based on technical requirements for LTM programs and activities at the site. Include assumptions used to develop the cost estimate, as well as assumptions for determining when sites or portions of a site will start and stop LTM activities.

Discussion should include a description of the cost model used and should identify those activities that are provided on a site-wide basis (e.g., site-wide fence maintenance), those activities that can be provided on a unit-cost basis (e.g., cost to monitor a single well); and those costs generated for activities at a specific portion of a site (e.g., costs associated with a specific groundwater plume, disposal cell, etc.).

If possible, a cost model may be developed and used in estimating site specific cost estimates to ensure consistency among the sites.

### **10.2 Human Resources**

Describe the human resource needs including all technical functions and qualifications necessary for the implementation of the LTM plan.

## **11.0 INFORMATION AND RECORDS MANAGEMENT**

Information associated with LTM of a federal site can be divided into two key types: 1) records that document past operations and activities; and 2) monitoring data generated as part of the implementation of a LTM plan. The Site Closure Tool provides a means of summarizing long-term monitoring planning and progress; however more detailed documentation will likely be required. The information documented for LTM should:

- Identify information critical to implementing LTM at the site, and describe how these records and data will continue to be identified as critical to implementation of LTM.
- Identify the methods and means by which information will be preserved (this includes all types of data deemed necessary (e.g., maps, photos, reports, databases, etc.)).
- Describe how and where records will be stored, the length of time they will be stored, and for what purpose the records are being maintained.
- Describe how record access will be enabled and the measures necessary to ensure compatibility with information hardware and software at future dates in light of continual technological advances in information management.
- Identify the means by which the public will be afforded access to records.
- Identify which of the LTM records for the site are anticipated to be requested by the public and which records may be made accessible.



## **12.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS**

Provide a summary of all the monitoring activities required as part of the LTM plan for the site. For reports including monitoring data, all major activities during the monitoring event should be summarized and conclusions and recommendations provided. A summary of trends observed in the new data compared to historical data for each impacted medium should also be included. Any new information that refines the assumptions and/or uncertainties inherent in the risk management and LTM plan should also be summarized. An indication of the extent of uncertainties in the results should be provided.

## **13.0 REFERENCES**

Include a complete list of all the documents cited in the report.

## **APPENDIX E:**

### **Long-Term Monitoring Plan Review Checklist**

## Long-Term Monitoring Plan Review Checklist

This report review form is for checking the completeness of required information in the Long-Term Monitoring Plan, and is organized according to the recommended report format provided in Appendix D.

Consultant company name:

Draft or Final Report:

Report authors:

Signed: Y / N

Report review completed by:

Organization:

Site name and location:

FCSI Site identification #:

Section	Review Criteria	Complete (yes, no, n/a)	Applicable Report Section	Comments/Required Changes	Required Changes Complete
<i>- - -Does this site need to comply with a specific jurisdictional checklist? If yes, consult that checklist for your review.- - -</i>					
<b>1.0 EXECUTIVE SUMMARY</b>					
a.	Is the site description and background to the work adequately summarized?				
b.	Are the long-term monitoring objectives (goals) summarized?				
c.	Are the long-term monitoring activities that were completed summarized?				
d.	Are environmental conditions at end of the monitoring activities summarized for each AEC and for each impacted media?				
e.	Has a summary been provided with respect to trends observed in the new data in comparison to the historical data for each impacted media?				
f.	Is it demonstrated that the site conditions meet the long-term monitoring objectives (goals):				
	Comparison between monitoring data and relevant decision rules?				
	Statement of whether exit criteria for any/all of the monitoring objectives have been met?				
g.	Are all major Conclusions and Recommendations provided?				
<b>2.0 INTRODUCTION</b>					
a.	Is there a brief description of the site, historical contamination issues, and remedial/risk management measures used to address human health and ecological risks?				

b. Is the rationale for why LTM is required at the site briefly explained?				
c. Are the objectives (goals) for the monitoring plan defined?				
d. Is the scope of LTM at the site adequately summarized and a general description of monitoring activities provided?				
<b>3.0 SITE BACKGROUND</b>				
a. Is a list of documents previously prepared for the site included?				
b. Is the site identification information provided in Section 3.2 adequate (all categories completed)?				
c. Are the general site conditions described according to the categories provided in Section 3.3?				
d. Are the physical boundaries of the site or portions of the site requiring LTM clearly described, along with any offsite location requiring LTM?				
e. Are relevant site features shown on supporting maps, photographs, and/or drawings?				
structures such as buildings etc.				
vegetation				
topography				
surface water features				
land use on site and adjacent land use				
appropriate scale and north arrow				
geology and hydrogeology, sediment, vapour, fill				
physical site boundaries				
portions of the site requiring LTM				
areas of environmental concern (AEC) and location of residual hazards				
<b>4.0 CULTURAL, NATURAL, AND HISTORICAL PRESERVATION</b>				
a. Are Species at Risk, archaeological and cultural resources clearly identified for the site?				
b. Are any Aboriginal land claims or treaty rights, and/or other natural and cultural resource issues affecting the site documented?				
<b>5.0 SUMMARY OF REMEDIAL/RISK MANAGEMENT ACTIVITIES</b>				
a. Are the risk drivers at the site clearly summarized according to Section 5.1?				

summary of past and current activities, as well as proposed development plan for the site				
identification of the sources of contamination, Areas of Environmental Concern (AECs), and affected media and contaminants of concern (COCs)				
summary of main human health and ecological risks that led to remediation/risk management measures, as well as any physical hazards				
summary of off-site contamination sources that are impacting the site				
b. Are the remedial objectives clearly summarized (Section 5.2)?				
is a list of remedial/risk management objectives for the site and/or AECs provided?				
where appropriate, have numerical remedial objectives for contaminated media been identified, including area and depth considerations?				
has the approach taken to identify remedial objectives (e.g., generic or risk-based) been identified and the rationale briefly explained?				
c. Are the remediation/risk management actions clearly summarized and discussed according to all of the criteria listed in Section 5.3?				
d. Are site conditions following the attainment of remediation/risk management objectives clearly described?				
are the location and nature of residual contamination and physical hazards clearly identified, preferably on a site drawing or map?				
are the assumptions used to develop the remediation objectives identified, along with an indication of uncertainties?				
is an updated post-remediation/risk management conceptual site model included?				
<b>6.0 STAKEHOLDER INVOLVEMENT</b>				
a. Is the plan for community and stakeholder involvement clearly explained, including roles, responsibilities, and communication strategies?				
b. Has a brief summary of Federal Expert Support involvement been provided?				
<b>7.0 REGULATORY MANAGEMENT</b>				
a. Are LTM activities that are specifically required by regulation, permits, licenses, or other third party enforceable agreements identified and the mechanisms for enforcement explained?				
b. Are other requirements for the LTM plan explained, such as land use and access agreements with third parties?				

<b>8.0 AUTHORITY AND ACCOUNTABILITY</b>				
a. Are the key organizations/groups responsible for carrying out LTM activities identified and their roles and responsibilities described?				
b. Are communication requirements and knowledge management activities identified?				
<b>9.0 LONG-TERM MONITORING REQUIREMENTS</b>				
a. Have all engineered controls been adequately described, including the key activities necessary to maintain physical engineered controls? The following should be described:				
Roles and responsibilities for maintaining the engineered controls				
Maintenance methods, including maintenance frequency and reporting requirements				
Monitoring activities required to ensure continued effectiveness of the engineered controls				
b. Have all institutional and administrative controls for the site been adequately described? The following should be included:				
Roles and responsibilities for maintaining the institutional controls				
A description of use/access restrictions required, as well as land use maps indicating restrictions for the site and the specific portions addressed by the LTM plan				
Monitoring activities required to ensure continued effectiveness of the institutional controls				
c. Have all key assumptions of the risk management strategy that require monitoring to ensure on-going protection at a dynamic site been described?				
d. Are there any LTM activities that have been identified through stakeholder involvement (Section 6.0) or that are specifically required by regulation, permits, licenses, or other third party agreements (see Section 7.0)?				
e. Based on the information provided in a-d above, has a comprehensive list of monitoring objectives been identified for the site LTM plan?				
For a large site, have monitoring objectives been provided for each AEC?				
<i>The following list of questions should be used to evaluate the information provided for each monitoring objective.</i>				
f. Has a detailed description of the proposed monitoring activities (e.g., media and metric to be measured, inspection activities) been provided and does the approach seem appropriate to address the monitoring objective?				
g. Are monitoring locations clearly identified, along with a brief rationale for their selection?				

Given the information presented in Section 5.0, are the monitoring locations appropriate and is the number of locations sufficient to address the monitoring objective?				
Have reference sites also been included in the LTM plan?				
h. Have the temporal boundaries (index period for sampling, monitoring frequency, anticipated timeframe until monitoring activities can be stopped) been clearly identified, along with a brief rationale for their selection?				
i. Are the methods for data collection and data analysis explained clearly and are they appropriate to address the monitoring objective?				
If appropriate, is the statistical design for the monitoring activities clearly explained and used to justify decisions regarding sample size and sampling frequency?				
j. Is the quality assurance program under which monitoring activities will be conducted described, including data quality objectives for statistical design (e.g., level of significance, statistical power)				
k. Are the decision rules used to interpret monitoring data clearly outlined?				
Are the action levels (triggers/targets) defined and consistent with the remedial objectives (Section 5.2) and/or outcomes from the site-specific risk assessment?				
Are alternative actions to be considered for implementation when an action level has not been met described, including a contingency plan and emergency response procedures if required?				
If appropriate, are exit criteria representing successful completion of the monitoring objective defined?				
<i>The following list of questions should be used to evaluate the discussion of monitoring results.</i>				
l. Were monitoring results compared to the QA/QC criteria and data quality objectives (DQOs) outlined in the monitoring quality assurance program?				
If any QA/QC criteria or DQOs were <b>not</b> met, was the cause of deviations identified and appropriate recommendations made for changes to future data collection and analysis?				
Are the uncertainties associated with the results presented?				
m. If the monitoring results met the DQOs, were the decision rules used to evaluate the monitoring data?				
Are recommendations made for each monitoring objective according to actions outlined in the decision rules?				
Has trend analysis and comparison to previous monitoring results been carried out where appropriate?				
If the monitoring results are <b>not</b> trending towards meeting the decision rule, have causative factor and uncertainty analyses been conducted and recommendations made for revising the remedial action/risk management				



	plan and/or monitoring program?				
n.	Have monitoring data been used to evaluate assumptions and uncertainties within the post-remediation conceptual site model and refine the model where necessary?				
o.	Has an evaluation of on-going remedy protectiveness been made?				
	Is the remedy functioning as intended by the R/RM plan?				
	Are the exposure assumptions (e.g., land use, exposure pathways, receptors, CoCs), toxicity data, site conditions, and remedial objectives used at the time of remedy selection still valid?				
	Has any additional information been identified that could call into question the protectiveness of the remedy? (e.g., site susceptibility to extreme weather events)				
p.	Has the information provided in m-o above been incorporated into recommendations regarding potential changes to the R/RM plan and site activities?				
q.	Are recommendations made for changes to the scope of the monitoring program based on the outcomes of the monitoring data evaluation?				
	Have the exit criteria been met for any of the monitoring objectives, and if so, does the report recommend stopping monitoring activities associated with the completed objective?				
	Has confidence in the conceptual site model assumptions and remedy performance increased, and if so, does the report recommend decreasing the scope and frequency of associated monitoring activities?				
	Do any recommendations for increased monitoring program scope appear appropriate based on information provided under l-p above?				
r.	Does the report evaluate whether the site can be closed (exit criteria met for all monitoring objectives) and/or include an estimate of how long monitoring activities are anticipated to continue?				
s.	Are LTM requirements summarized and documented appropriately in the tables included in Section 9.4?				
<b>10.0 FUNDING AND RESOURCE REQUIREMENTS</b>					
a.	Is the rationale for anticipated LTM costs explained and the assumptions used to develop the cost estimates clearly identified, including estimated time to completion of LTM activities for each monitoring objective?				
b.	Are the estimated costs for LTM activities divided into site-wide requirements (e.g., fencing), a unit-cost basis where applicable (e.g., costs to monitor a single well), and costs for each AEC?				
c.	Are the human resource needs for implementing the LTM plan clearly identified, including all technical functions and qualifications?				

<b>11.0 INFORMATION AND RECORDS MANAGEMENT</b>				
a. Are the management procedures for documenting information required for implementing the LTM clearly documented and address all of the criteria outlined in Section 11.0?				
<b>12.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS</b>				
a. Are all major activities during the monitoring event summarized and conclusions and recommendations provided?				
b. Has a summary been provided with respect to trends observed in the new data in comparison to the historical data for each impacted medium?				
c. Are Summary, Conclusions and Recommendations consistent with main body of report and Executive Summary?				
d. Are limitations on Conclusions and Recommendations appropriately noted especially as related to liability estimates or cost of future work provided?				
e. Is the extent of uncertainties in the results provided?				
<b>13.0 REFERENCES</b>				
a. Are all sources of information referred to in main body of report properly referenced? (past reports, publicly available records, historical sources, guidance documents etc.)				

<b>Overall Draft Report Quality</b>			<b>Ability to address draft comments</b>	
Total number of items:	0		Total "no" (changes not satisfactory):	0
Total "no" (item completion not satisfactory):	0		Total "yes" (changes satisfactory):	0
Total "yes" (item completion satisfactory):	0		Performance adjusting factor (% of non-adequate changes): <i>Formula: (Total "no" (changes not satisfactory))/(Total number of items – Total "n/a" (item not applicable to this Long-Term Monitoring Plan))</i>	
Total "n/a" (item not applicable to this Long-Term Monitoring Plan):	0			
<b>Percentage of satisfactory completion:</b> <i>Formula: (Total "yes" (item completion satisfactory))/(Total number of items – Total "n/a" (item not applicable to this Long-Term Monitoring Plan))</i>			Overall performance on final report: <i>Formula: (Percentage of satisfactory completion – Performance adjusting factor (% of non-adequate changes))</i>	

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