Although the case studies represented a crucial internal validation and refinement step for this project, presenting an overview of each of the case studies in this section further illustrates how the matrices should be used. The case studies provide examples of how information in the matrices relates to “real world” remedial monitoring plans. In addition to many examples of how monitoring needs and tools were identified at the sites covered in these case studies, and how information in the matrices could be used to reach similar conclusions, a key message throughout the case studies is that readers should consider site-specific conditions during review of information provided by the matrices.

C.2 Bremerton, Washington (Puget Sound Naval Shipyard)

C.2.1 Site Description

Puget Sound Naval Shipyard (PSNS) is currently a 1,350 acre site that serves as a home port for Navy vessels, including aircraft carriers. The site has six major piers, six large dry docks, and more than 400 buildings supporting industrial operations throughout the complex. The site is contained in the marine environment of operable unit (OU) B which includes the nearshore portion of Sinclair Inlet that extend east and west along the shorelines of the Bremerton Naval Complex in Puget Sound, Washington.

C.2.2 Problem

The primary contaminants of concern are PCBs and mercury. The remedial investigation concluded that concentrations of these contaminants in fish tissue, assumed to be present due to elevated concentrations in site sediment, were associated with unacceptable levels of human health risk. Ecological risk was found to be insignificant.

C.2.3 Description of Selected Remedies

Remedies included dredging, capping, and monitored natural attenuation (Figure C.1).

C.2.3.1 Dredging

Approximately 200,000 cubic yards of sediment containing PCBs was dredged in an area of 32 acres and disposed of in excavated confined aquatic disposal (CAD) cells. CAD cells were located on Navy owned submerged land. Sediments with PCB concentrations greater than the remedial action level of 12 mg/kg organic carbon (OC) were removed by dredging. Sediments that were also dredged where mercury concentrations exceed 3 mg/kg and PCB concentrations exceed 6 mg/kg OC. An accumulation of sediments above the acceptable level at the mouth of Drydock 1 were also dredged. While PCBs in this area were below 6 mg/kg OC, mercury had been found above 3 mg/kg nearby.

The remedial design required that areas targeted for dredging be dredged to a minimum depth of 2 feet. With an allowance for overdredge depth and side slopes, the volume of impacted sediments dredged for environmental remediation is estimated at 200,000 in-place cubic yards. Dredging was accomplished mechanically with a clamshell bucket.

C.2.3.2 Capping

Capping remedies were applied to isolate impacted sediments in a 13-acre area and in the CAD cells on Navy-owned submerged land, occupying approximately 10 acres. For intact sediments, both thick and thin layer caps were used. Thin layer caps used at the site were a nominal thickness of at least 20 cm. This layer was not intended to provide a complete "seal" over the bottom, but to provide a layer of clean sediment to mix with underlying sediments, thereby facilitating natural recovery. In some areas, a 3-ft thick cap was constructed as needed to isolate sediment, withstand erosional forces, and provide a clean surface for improved ecological habitat. CAD cells were capped with a nominal 4-6 ft thick layer of clean import material.

C.2.3.3 Monitored Natural Recovery

MNR was used to remediate sediments offshore of the southwestern portion of the Bremerton Naval Complex and in areas not specifically remediated by dredging or capping. Natural recovery was also assumed to be a key remedial strategy in thin-layer capping. The key process associated with natural recovery was chemical transformation (mineralization) of PCBs rather than physical isolation of impacted sediments through natural sedimentation.

C.2.4 Retrospective Application of the Matrices to Bremerton Remedial Monitoring

C.2.4.1 Introduction

The following section provides a comparison of the monitoring needs and tools identified for the site remedies by the matrices to the actual monitoring conducted on the site. This section illustrates how information in the matrices relates to "real world" remedial monitoring plans and how site-specific conditions must be considered when reviewing information provided by the matrices.

For each monitoring phase relevant to the site (e.g., dredging performance monitoring, capping construction monitoring, etc.), tables are provided that contain the following information:

- **Potential monitoring needs and tools:** Possible monitoring needs identified by the matrices and the list of tools provided in the matrices that are associated with each monitoring need.
- **Site:** Whether the monitoring need was relevant to the site or a particular monitoring tool was used at the site.
- **Critical considerations identified in the matrices:**
    - For all monitoring needs, this field contains a brief description of the need, as presented in the matrices.
    - For monitoring tools used at the site, this field contains a sample of the information from the matrices that is particularly relevant to the site monitoring program. Information was obtained directly from matrices monitoring tool fields (e.g., "Special Considerations", "Uncertainty in

Addressing Monitoring Need", "Difficulty in Locating Tool in Marketplace", etc.).

- **Notes on actual site-specific monitoring program:** Information on actual monitoring needs identified or monitoring tools used at the Site.

Tables are provided at the end of this case study (all five possible monitoring phases are represented in this case study due to the application of MNR, capping, and dredging at Bremerton):

- Table C.1: Dredging Construction Monitoring
- Table C.2: Capping Construction Monitoring
- Table C.3: Capping Performance Monitoring
- Table C.4: MNR Performance Monitoring
- Table C.5: Remedial Goal Monitoring

C.2.4.2 Key Considerations for Using the Matrices: Highlights from Bremerton Remedial Monitoring

This section highlights how information presented in the matrices should be evaluated in the context of site-specific considerations, using the Bremerton remedial monitoring program as an example.

- **All monitoring needs listed in the matrices may not be relevant to the site**. For example, the "Ecotoxicological risks" monitoring need was not relevant to Bremerton, because ecological risk assessment conducted as part of the remedial investigation concluded that ecological risk was insignificant (Table C.5).

- **Information for monitoring tools may not always be relevant to the site**. For example, sediment profile photography was chosen as one of the tools to assess ecological recovery at Bremerton (Table C.5). Information provided for this monitoring tool in the "Monitoring Tool Logistical Complexity" field of the matrices is not an important consideration for selecting this tool because it notes that the tool is "Limited to use in soft-bottom sediments". As all sediment at Bremerton were relatively soft (slits and sands), this information would likely be of minor importance when considering this tool for use at a site like Bremerton.

- **Several monitoring tools are often selected to address a single monitoring need**. For example, four of the six monitoring tools identified in the matrices for addressing capping design specifications during the construction monitoring phase for capping were used at Bremerton (Table C.2). Several tools were selected because each tool offered its own advantages and disadvantages relative to site-specific monitoring conditions. Some of the information provided in the matrices highlights these advantages and disadvantages, and a sample of this information is presented in the "Critical considerations identified in matrices" column of Table C.2. For example, the matrices note that information provided by bathymetric survey is easily interpreted and widely available tool for assessing coverage of caps, although it lacks resolution and accuracy of the more advanced acoustic sub-bottom profiling monitoring tool (Table C.2). A disadvantage of acoustic sub-bottom profiling noted in the matrices was relevant to areas of Bremerton where the texture and composition of cap materials were similar to the underlying sediment, making interpretation of acoustic sub-bottom profiling data to assess cap presence and thickness difficult. To supplement this information, sediment coring and sediment surface photography was used to provide easily-interpreted visual information regarding cap thickness and/or coverage; however, these tools provided information only at a few discreet points rather than the continuous, site-wide coverage provided by bathymetric survey and acoustic sub-bottom profiling.

- **Monitoring tools can be used to address more than one monitoring need**. For example, sediment sample chemical analysis is one of the tools selected for addressing downstream deposition and ecotoxicological risks during dredging and capping construction monitoring (Tables C.1 and C.2), chemical flux through cap during capping construction monitoring (Table C.3), chemical natural recovery processes during MNR performance monitoring, and bioaccumulation and human health risks during remedial goal monitoring (Table C.5). In most cases at Bremerton, data obtained using this tool could be used to provide information for all of these needs. For example, samples collected during cap placement or during dredging could be potentially useful for addressing rates of chemical natural recovery processes, especially when these locations were resampled during the years following remediation. During evaluation of monitoring tools for different needs at sites like Bremerton, dual uses of data produced by monitoring tools addressing different monitoring needs should be taken into consideration when evaluating potential monitoring tools.

- **Among the information and references provided by the matrices, a single piece of information may be the key to identifying monitoring tools**. Sediment coring was one of the monitoring tools selected to address capping design specification during the construction monitoring phase for capping at Bremerton (Table C.2). The matrices note that this monitoring tool may damage the cap ("Special Considerations" field). This information would be critical to RPMs at a site like Bremerton, where both thin (0.5-ft) and thick (3-ft) caps were applied. As coring would likely damage thin caps, RPMs did not utilize this monitoring tool in all areas at Bremerton. Coring was restricted to assessing the performance of thick caps, although shallow (non-penetrating) coring techniques were used to avoid damage or release of underlying contaminated sediment.

- **Selection of monitoring tools should consider prior monitoring tools used at the site**. Analysis of edible biota tissues was selected as a monitoring tool to assess the reduction of human health risks in the remedial goal monitoring phase (Table C.5). For this monitoring need, the matrices note that this tool yields data with low uncertainty, and is often the best tool for evaluating human health risks associated with the consumption of site-related biota. In addition, information produced by this monitoring tool (e.g., PCB concentration in fish fillets) was directly compared to data collected during the Bremerton remedial investigation, providing an effective before-and-after comparison of remedial effectiveness. In addition, data were directly linked to the site-specific human health risk assessment performed during the remedial investigation and could be interpreted in a decision-making framework that specified benchmark concentrations of PCBs in tissue associated with unacceptable human health risk. Along with benchmark concentrations in sediment that were associated with unacceptable levels of human health risk, benchmark concentrations in fish served as guidelines by which to evaluate the attainment of remedial goals and enable decisions regarding the termination or continuation of remedial goal monitoring.

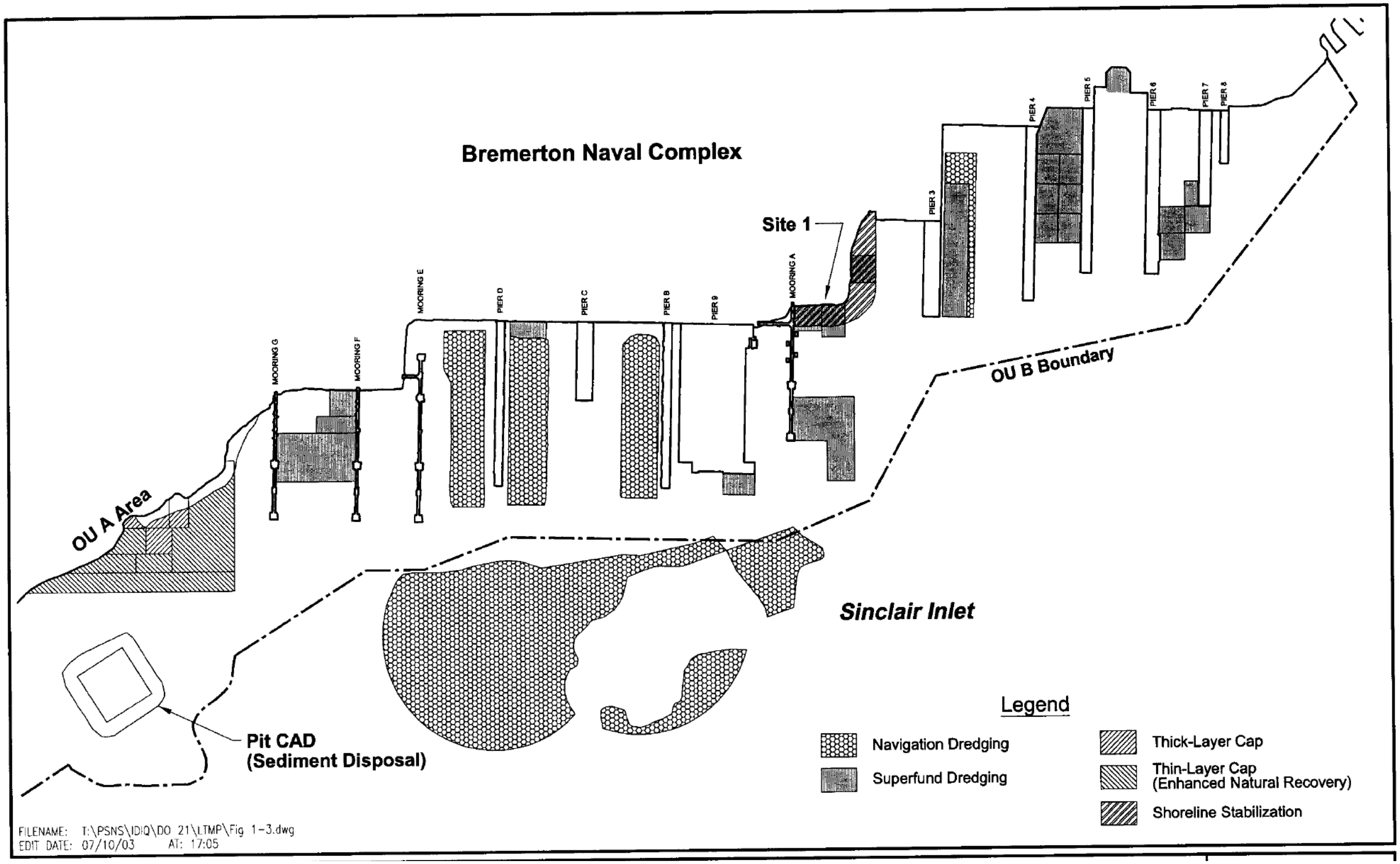

Figure C.1. Remedial actions at Bremerton Naval Complex.

Table C.1. Monitoring needs and tools identified by the matrices for dredging construction monitoring compared to the Bremerton monitoring plan.

Monitoring Matrices Output			Site Monitoring Plan	Critical Issues Identified in Matrices	Site Monitoring Program Notes
Potential Needs	Need Description	Tools			
Acute dewatering effects	Assess acute effects or short-term changes due to discharge of dewatering effluent	Toxicity testing	Not used		Dredged sediments were not dewatered, as they were placed in a CDF cell.
		Caged organisms	Not used		
Bioaccumulation	Assessment of bioaccumulation potential to pelagic and possibly benthic species due to chemicals released due to sediment resuspension during remedial activity	Bioaccumulation testing	Unknown		Unknown if this need was monitored during dredging.
		Caged organisms	Unknown		
		Passive sampling devices	Unknown		
		Sediment sample chemical analysis (bioavailability extraction)	Unknown		
		Sediment and water sample chemical analysis	Unknown		
Downstream deposition	Assessment of downstream deposition to surface sediment	Sediment sample chemical analysis	Likely used	Rugged, simple tool. May be difficult to separate contamination associated with remedial activity from background contamination and requires collection of pre-remedy samples from downgradient locations prior to remedial activity.	No site-specific details were available regarding this monitoring need, although downstream deposition was likely monitored. Sediment samples were likely analyzed for physical parameters and COCs. Data likely compared to samples collected before dredging. Site managers recommended that surface and deep samples be collected.
		Sediment traps	Not used		
		Sediment profile photography	Not used		
		Current velocity measurement	Not used		
Dredging design specifications	Assess if mass removal meets design specifications (cut lines, topography, etc.)	Bathymetric survey	Likely used	Other acoustic survey methods (e.g., side scan sonar, acoustic sub-bottom profiling) may be more accurate. Widely available and easily interpreted.	No site-specific details were available regarding this monitoring need, although design specifications were likely assessed. Site managers recommended that pre-remedial and post-remedial bathymetry be conducted using the same methods and equipment.
		Ex situ dredge measurement	Not used		
		Side scan sonar	Not used		

Table C.1, dredging construction monitoring, *continued*

Monitoring Matrices Output			Site Monitoring Plan	Critical Issues Identified in Matrices	Site Monitoring Program Notes
Potential Needs	Need Description	Tools			
Excavation operations	Assess excavation operations including dredging, transport, dewatering, treatment, transport and disposal	Dredging observation	Used	Observational data easily interpreted.	Monitored during dredging.
Sediment resuspension	Assess physical water quality impairment due to sediment resuspension during remedial activity	Continuous suspended sediment monitoring	Used	Can provide continuous, real-time information on suspended sediments.	Water column monitoring conducted to ensure water quality criteria were not exceeded outside the designated dilution zones and dredged sediment was not resuspended in water column. Monitoring conducted using continuous monitoring probes in water column to measure endpoints (e.g., turbidity) associated with suspended sediment.
		Discrete suspended sediment monitoring	Not used		
		Real-time biomonitoring	Not used		
Ecotoxicological risks	Assessment of toxicity to pelagic and possibly benthic species due to chemicals released from sediment resuspension during remedial activity	Toxicity testing	Recommended later	Routine monitoring tool. Monitoring data may be affected by conditions independent of remedial activity or contamination.	Water column monitoring conducted to ensure that water quality criteria were not exceeded outside the designated dilution zones. In retrospect, site managers recommended that toxicity testing would have been useful in evaluating ecotoxicity in sediment potentially affected by downstream deposition during dredging. Only water column chemistry was monitored. Dissolved oxygen and standard water quality parameters monitored continuously with the use of probes. Discreet samples were obtained for COCs and compared to water quality guidelines.
		Caged organisms	Not used		
		Passive sampling devices	Not used		
		Sediment sample chemical analysis (bioavailability extraction)	Not used		
		Real-time biomonitoring	Not used		
		Sediment and water sample chemical analysis	Used	Inexpensive and simple. Can be compared to established criteria; however, simple chemical analysis usually overestimates toxicological risks.	
Volatile compounds in air	Air monitoring of volatile compounds at the dredge, transport, and disposal sites	Volatile organic compound monitoring	Not used		Volatile compounds were unlikely to be present in dredged sediment at this site.
Backfilling requirements	Assess need for backfilling following dredging.	Sediment sample chemical analysis	Unknown		Unknown if this need was monitored during or after dredging.
Presence of hot spots	Assess presence of hot spots following dredging.	Sediment sample chemical analysis	Unknown		Unknown if this need was monitored during or after dredging.

Table C.1, dredging construction monitoring, *continued*

Monitoring Matrices Output			Site Monitoring Plan	Critical Issues Identified in Matrices	Site Monitoring Program Notes
Potential Needs	Need Description	Tools			
Presence of residual mass	Assess presence of residual mass following dredging.	Sediment sample chemical analysis	Unknown		Unknown if this need was monitored during or after dredging.
Impacts on hydrodynamics and sediment transport	Assessment of the physical impacts of dredging on hydrodynamics and sediment transport.	Hydrodynamic analysis	Unknown		Unknown if this need was monitored during or after dredging.

Table C.2. Monitoring needs and tools identified by the matrices for capping construction monitoring compared to the Bremerton monitoring plan.

Monitoring Matrices Output			Site Monitoring Plan	Critical Issues Identified in Matrices	Site Monitoring Program Notes
Potential Needs	**Need Description**	**Tools**			
Bioaccumulation	Assessment of bioaccumulation potential to pelagic and possibly benthic species due to chemicals released from sediment resuspension during remedial activity.	Bioaccumulation testing	Not used		The minimal amount of capping was assumed to result in no significant displacement of impacted sediments and would not lead to bioaccumulation of PCBs in biota in surrounding areas.
		Caged organisms	Not used		
		Passive sampling devices	Not used		
		Sediment sample chemical analysis (bioavailability extraction)	Not used		
		Sediment and water sample chemical analysis	Not used		
Capping design specifications	Assess lateral extent, thickness, and/or uniformity of cap.	Acoustic sub-bottom profiling	Used	Used primarily to detect detecting extent, thickness, and uniformity of cap. One of the tools with highest levels of certainty in addressing monitoring need.	Several tools were used to confirm the ROD requirement that the cap meets the minimum specifications of a 3-foot thickness and to verify complete coverage of target areas. Sub-bottom profiling was conducted during and after placement of the cap to map surface features of the cap and estimate thickness of the cap. Sampling followed same sampling pattern as earlier bathymetric surveys. Bathymetric survey conducted before, during, and after placement of the cap to understand site and map surface features of the cap and estimate thickness of the cap. Site managers recommended that both pre-remedial and post-remedial bathymetry be conducted using the same methods and equipment. Four shallow (non-penetrating) cores collected and inspected visually to confirm presence and thickness of cap. Surface photography (underwater video) was conducted to supplement acoustic sub-bottom profiling and bathymetry. Conducted before and after construction to understand site and map surface features of the cap.
		Bathymetric survey	Used	Other acoustic survey methods (e.g., side scan sonar, acoustic sub-bottom profiling) may be more accurate; widely available, inexpensive, and easily interpreted.	
		Sediment coring	Used	May serve best as validation tool for continuous methods such as acoustic sub-bottom profiling. Coring may damage cap.	
		Sediment profile photography	Not used		
		Sediment surface photography	Used	Limited to sediment surface and limited by site conditions (turbidity). Easily interpreted visual method.	

Table C.2, capping construction monitoring, *continued*

Monitoring Matrices Output			Site Monitoring Plan	Critical Issues Identified in Matrices	Site Monitoring Program Notes
Potential Needs	**Need Description**	**Tools**			
Downstream deposition	Assessment of downstream deposition to surface sediment.	Sediment sample chemical analysis	Used	Rugged, simple tool; May be difficult to separate contamination associated with remedial activity from background contamination and requires collection of pre-remedy samples from downgradient locations prior to remedial activity.	Downstream deposition of cap material and chemically-impacted sediment was hypothesized to occur near the fringe (0-20 ft) of the cap. Monitoring results demonstrated deposition up to 600 ft from fringe of the cap. Chemical analysis of sediment samples collected near margins (0-20 ft) of some caps following cap placement. Samples were analyzed for physical parameters and COCs. Data were compared to samples collected before cap placement. Site managers recommended that surface and deep samples be collected. Sediment traps were used to indicate sediment deposition as far as 1000 ft from the fringe of the cap.
		Sediment profile photography	Used	Data are point based; Allows visual inspection; May be difficult to visually distinguish freshly deposited layers or identify cap material or contaminated sediments visually.	
		Sediment traps	Not used		
		Current velocity measurement	Not used		
Ecological suitability of cap material	Assessment of cap material for use as a clean substrate capable of supporting ecological recovery.	Toxicity testing	Not used		Sediment used for cap was characterized prior to use to ensure suitability for ecological recovery. Chemical analysis was likely used to address the suitability of cap sediment, with results compared to ecological screening criteria to ensure that chemicals in cap material were not high.
		Bioaccumulation testing	Not used		
		Cap sample chemical analysis	Likely used	Simple tool, although simple chemical analysis may overestimate toxicological and bioaccumulation risks.	
		Cap sample physical analysis			
		Macroinvertebrate community census			
Physical suitability of cap material	Assessment of cap material for engineering purposes.	Cap sample physical analysis	Used	Highly relevant tool for assessing physical characteristics of capping material.	Sediment used for cap was characterized prior to use to ensure engineering purposes. Among standard analyses to evaluate long-term physical stability of cap material as surface sediment, physical analyses were conducted to evaluate the potential for cap material to liquefaction during seismic events, as the site is located in an area that has a relatively high incidence of earthquakes.

Table C.2, capping construction monitoring, *continued*

Monitoring Matrices Output			Site Monitoring Plan	Critical Issues Identified in Matrices	Site Monitoring Program Notes
Potential Needs	Need Description	Tools			
Sediment resuspension	Assess physical water quality impairment due to sediment resuspension during remedial activity	Continuous suspended sediment monitoring	Used	Can provide continuous, real-time information on suspended sediments.	Water column monitoring conducted to ensure that water quality criteria were not exceeded outside the designated dilution zones and that a turbidity wave did not form, indicating suspension of cap material or chemically-impacted sediments. Continuous monitoring probes were deployed in water column to measure endpoints (e.g., turbidity) associated with suspended sediment.
		Discrete suspended sediment monitoring	Not used		
		Real-time biomonitoring	Not used		
Ecotoxicological risks	Assessment of toxicity to pelagic and possibly benthic species due to chemicals released due to sediment resuspension during remedial activity.	Toxicity testing	Recommended later	Routine monitoring tool; Monitoring data may be affected by conditions independent of remedial activity or contamination.	Site managers recommended assessing ecotoxicity in the water column and sediments potentially affected by downstream deposition during cap placement due to the potential to disturb contaminated sediment during remedial activity. Assessment focused on the water column, although in retrospect, site managers recommended sediment ecotoxicity monitoring. In retrospect, site managers recommended that this monitoring tool would have been useful in evaluating ecotoxicity in sediments potentially affected by downstream deposition during cap placement. Monitoring sediments in the buffer zone around the cap both before and after cap placement may have been useful.
		Caged organisms	Not used		
		Passive sampling devices	Not used		
		Sediment sample chemical analysis (bioavailability extraction)	Not used		
		Real-time biomonitoring	Not used		
		Sediment and water sample chemical analysis	Used	Inexpensive and simple; Can be compared to established criteria; however, simple chemical analysis usually overestimates toxicological risks.	Only water column was monitored; Dissolved oxygen and standard water quality parameters monitored continuously with the use of probes. Discreet samples were obtained for COCs and compared to water quality guidelines.

Table C.3. Monitoring needs and tools identified by the matrices for capping performance monitoring compared to the Bremerton monitoring plan.

Monitoring Matrices Output			Site Monitoring Plan	Critical Issues Identified in Matrices	Site Monitoring Program Notes
Potential Needs	**Need Description**	**Tools**			
Cap stability	Assess settlement and stability of cap over time.	Acoustic sub-bottom profiling	Likely used	Used primarily to detect detecting extent, thickness, and uniformity of cap. One of the tools with highest levels of certainty in addressing monitoring need.	Monitoring conducted to identify erosion of the cap, sediment movement, or mixing of cap with underlying sediment. For all tools, Site managers recommended that the same equipment and methods used to assess cap design (construction) be used for this monitoring need. Acoustic sub-bottom profiling was used to very capping design specifications during and immediately after placement of the cap; however, it was unclear if it was used to assess cap performance years after cap construction. Bathymetric survey was conducted along same sampling points as prior surveys. Thickness of the cap (3+ ft) not a limiting factor in the use of bathymetry for measuring the stability of this cap. Shallow (non-penetrating) cores collected and inspected visually to confirm presence and thickness of cap. Sediment profile photography was used to visually inspect cap profile.
		Bathymetric survey	Used	Other acoustic survey methods (e.g., side scan sonar, acoustic sub-bottom profiling) may be more accurate. Widely available and easily interpreted.	
		Sediment coring	Used	Subsurface profile easily interpreted from sediment core to yield information regarding cap thickness, although coring may damage cap.	
		Sediment profile photography	Used	Data are point based. Allows visual inspection. May be difficult to visually distinguish freshly deposited layers or identify cap material or contaminated sediments visually.	
		Sediment surface photography	Not used		
		Settlement plate	Not used		
		Side scan sonar	Not used		
		Cap sample physical analysis	Used	Relevant tool for assessing physical characteristics of cap useful for predicting susceptibility to erosion.	
Chemical flux through cap	Assessment of chemical flux through the cap.	Passive sampling devices	Not used		Monitoring focused on the transport of PCBs from underlying sediment. Samples of cap analyzed chemically for PCBs. Cap samples collected via shallow coring to avoid penetrating cap, and vertical profile of PCBs in core used to assess vertical migration of PCBs towards cap surface.
		Sediment sample chemical analysis	Used	Chemistry of subsurface profile easily interpreted to address contaminant migration through cap, although potential to damage cap.	
		Seepage meter/Flux sampler	Not used		
		Trident Probe	Not used		
		Surface sediment pore water	Not used		
Impacts on hydrodynamics and sediment transport	Impacts on hydrodynamics and sediment transport.	Hydrodynamic analysis	Not used		Local hydrodynamics were not assumed to be affected by the size and thickness of the cap relevant to size and depth of the basin.

Table C.4. Monitoring needs and tools identified by the matrices for MNR performance monitoring compared to the Bremerton monitoring plan.

Monitoring Matrices Output			Site Monitoring Plan	Critical Issues Identified in Matrices	Site Monitoring Program Notes
Potential Needs	**Need Description**	**Tools**			
Chemical flux from sediment	Assessment of chemical flux from sediment surface to water column.	Passive sampling devices	Not used		Not specifically addressed due to the stability of most areas of the site.
		Seepage meter/Flux sampler	Not used		
		Trident Probe	Not used		
		Surface sediment pore water	Not used		
Chemical natural recovery processes	Assess the progress of or potential for degradation, detoxification, or chemical sequestration of chemicals.	Sediment sample chemical analysis	Used	High confidence in method to describe contaminant degradation and transformation; No ability to provide information on chemical sequestration of contaminants.	The natural attenuation of chemicals in sediment (primarily PCBs) was assumed to be the primary remedial strategy for most of the site. Addressing this need simultaneously addressed overall remedial goals addressing the reduction of bioaccumulation risks and human health risks over time. PCB concentrations in sediment were measured over time, with natural recovery modeling to address chemical natural recovery rates. This tool would not be able to identify reductions in PCB bioavailability (chemical sequestration) that may occur as a result of natural attenuation.
		Passive sampling devices	Not used		
		Sediment sample chemical analysis (bioavailability extraction)	Not used		
		Surface sediment pore water	Not used		
		Laboratory biodegradation experiments	Not used		
		Sediment redox potential	Not used		
		Sediment profile photography	Not used		
Physical natural recovery processes	Assess stability of sediment during recovery and/or isolation of impacted sediment over time.	Acoustic sub-bottom profiling	Not used		Not addressed, as it was assumed that primary means of attenuation would be via chemical transformation of PCBs rather than natural physical isolation of sediment.
		Bathymetric survey	Not used		
		Sediment surface photography	Not used		
		Side scan sonar	Not used		
		Sediment coring	Not used		
		Sediment traps	Not used		
		Sediment sample physical analysis	Not used		
		Isotope analysis	Not used		

Table C.5. Monitoring needs and tools identified by the matrices for remedial goal monitoring compared to the Bremerton monitoring plan.

Monitoring Matrices Output			Site Monitoring Plan	Critical Issues Identified in Matrices	Site Monitoring Program Notes
Potential Needs	**Need Description**	**Tools**			
Bioaccumulation	Assessment of bioaccumulation potential to benthic and/or pelagic species.	Bioaccumulation testing	Not used		Baseline/Site Characterization monitoring revealed bioaccumulative chemicals (primarily PCBs and mercury) present in bottom-dwelling fish. Comparisons of monitoring data (PCB concentrations in sediment) were made to concentrations in sediment expected to result in PCB bioaccumulation in aquatic biota (likely via a PCB bioaccumulation model). Analysis of PCBs and mercury in bottom-dwelling fish and sea cucumbers was also conducted. Selection of this tool allows comparison of data collected during Baseline/Site Characterization monitoring. This tool requires less modeling/extrapolation, but is more-resource intensive.
		Caged organisms	Not used		
		Passive sampling devices	Not used		
		Sediment and water sample chemical analysis	Used	Standard monitoring tool. Simple chemical analysis usually overestimates bioaccumulation potential. Selection of this tool allows comparison of data collected during Baseline/Site Characterization monitoring.	
		Surface sediment pore water	Not used		
		Sediment sample chemical analysis (bioavailability extraction)	Not used		
		Avian chemical analysis	Not used		
		Chemical analysis of biota tissue	Used	Tissue residues in organisms easily interpreted to assess bioaccumulation potential.	
Human health risks	Assessment of exposure of bioavailable chemicals to humans via consumption of aquatic organisms.	Bioaccumulation testing	Not used		Human health risks identified in remedial investigation (primary risk associated with consumption of PCBs bioaccumulated by fish). Monitoring of PCBs in sediment, with comparison of data to site-specific, human health risk-based sediment criteria for PCBs expected to result in minimal bioaccumulation in aquatic biota. Selection of this tool allows comparison of data collected during Baseline/Site Characterization monitoring. Monitoring of PCBs in edible fish and sea
		Caged organisms	Not used		
		Passive sampling devices	Not used		
		Sediment and water sample chemical analysis	Used	Standard monitoring tool. Simple chemical analysis usually overestimates bioaccumulation and subsequent human health risks.	
		Surface sediment pore water	Not used		
		Sediment sample chemical analysis (bioavailability extraction)	Not used		
		Avian chemical analysis	Not used		

Table C.5, remedial goal monitoring, *continued*.

Monitoring Matrices Output			Site Monitoring Plan	Critical Issues Identified in Matrices	Site Monitoring Program Notes
Potential Needs	Need Description	Tools			
		Chemical analysis of edible biota tissue	Used	Best tool for estimating health risks posed by bioavailable chemicals in edible tissue of aquatic organisms are consumed by humans.	cucumbers and comparison to site-specific, human health risk-based criteria was also conducted. Selection of this tool allows comparison of data collected during Baseline/Site Characterization monitoring. This tool requires less modeling/extrapolation, but is more-resource intensive.
Physical benthic habitat quality	Assessment of benthic physical habitat.	Acoustic sub-bottom profiling	Not used		Need to ensure cap material meets design specifications for shoreline restoration of physical habitat quality following dredging and capping. Site managers focused on engineering suitability of cap material (no comparison to needs of biota was conducted).
		Bathymetric survey	Not used		
		Sediment sample physical analysis	Used	Provides simple assessment of physical habitat, but does not predict physical habitat suitability for all species.	
		Laser Line Scan Imaging	Not used		
		Remote sensing	Not used		
		Sediment profile photography	Not used		
		Sediment surface photography	Not used		
		Side scan sonar	Not used		
Ecotoxicological risks	Assessment of toxicity to benthic and/or pelagic species.	Toxicity testing	Not used		Ecological risks were not identified as significant in remedial investigation.
		Caged organisms	Not used		
		Passive sampling devices	Not used		
		Real-time biomonitoring	Not used		
		Sediment and water sample chemical analysis	Not used		
		Rapid Sediment Characterization Tools	Not used		
		Surface sediment pore water	Not used		
		Avian chemical analysis	Not used		
		Chemical analysis of biota tissue	Not used		
Ecological recovery	Assessment of benthic and/or pelagic ecological recovery over time.	Artificial substrate samplers	Not used		Capping activities were hypothesized to disrupt ecological habitat; therefore, ecological recovery was investigated in capped areas only. Recovery was not assessed for other areas, as ecological effects of chemical contamination were found to be minor. In retrospect, site managers recommended that all monitoring efforts should have included monitoring a buffer zone around the cap. Sediment profile photography was applied within
		Avian community or productivity census	Not used		
		Drift net sampling	Not used		
		Fish community census	Not used		
		Macroinvertebrate community census	Recommended later	Highly relevant tool for assessing ecological recovery.	
		Vegetation survey	Recommended later	Highly relevant tool for assessing ecological recovery for sites with vegetation or the potential to support vegetation.	
		Sediment profile photography	Used	Provides qualitative indicator of macrobenthic habitat recovery. Suitable tool for use in soft sediments.	

Table C.5, remedial goal monitoring, *continued*.

Monitoring Matrices Output			Site Monitoring Plan	Critical Issues Identified in Matrices	Site Monitoring Program Notes
Potential Needs	Need Description	Tools			
		Side scan sonar	Not used		the boundary of caps to assess ability of ambient macroinvertebrate fauna to recolonize capped areas. In retrospect, site managers recommended that macroinvertebrate community census and vegetation surveys would have been useful in evaluating ecological recovery.