DEPARTMENT OF
ECOLOGY
State of Washington

# Sediment Cleanup User's Manual (SCUM)

*Guidance for Implementing the Cleanup Provisions of the Sediment Management Standards, Chapter 173-204 WAC*

Publication No. 12-09-057
Original publication March 2015
First Revision December 2017
Second Revision December 2019

## Publication and Contact Information

This guidance is available on the Department of Ecology's website at https://fortress.wa.gov/ecy/publications/SummaryPages/1209057.html

For more information contact:

Toxics Cleanup Program
P.O. Box 47600
Olympia, WA 98504-7600

Phone: 360-407-7170

Washington State Department of Ecology - www.ecology.wa.gov

- Headquarters, Olympia 360-407-6000
- Northwest Regional Office, Bellevue 425-649-7000
- Southwest Regional Office, Olympia 360-407-6300
- Central Regional Office, Yakima 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

**Accommodation Requests**: To request ADA accommodation including materials in a format for the visually impaired, call Ecology at 360-407-7668 or visit https://ecology.wa.gov/accessibility People with impaired hearing may call Washington Relay Service at 711. People with speech disability may call TTY at 877-833-6341.

# Sediment Cleanup User's Manual (SCUM)

*Guidance for Implementing the Cleanup Provisions of the Sediment Management Standards, Chapter 173-204 WAC*

Toxics Cleanup Program
Washington State Department of Ecology
Olympia, Washington

Publication No. 12-09-057
Final originally published March 2015. First Revision December 2017.
Second revision December 2019.

*This page left intentionally blank.*

# Table of Contents

Chapter - Page

**List of Figures** ..... **ix**

**List of Tables** ..... **xi**

**List of Equations** ..... **xv**

**Acknowledgements** ..... **xvii**

**Acronyms & Abbreviations** ..... **xix**

1.1 Purpose ..... 1-23
1.2 How this guidance is organized ..... 1-24
1.3 Framework of the SMS Rule ..... 1-27
1.4 Updating this Guidance Document ..... 1-29

**Chapter 2 Station Clustering and Site Identification WAC 173-204-510 and 173-204-520 ..... 2-1**
2.1 Introduction ..... 2-1
2.2 Identifying Sites & Station Clusters ..... 2-1
2.2.1 Identifying cleanup sites based on benthic criteria ..... 2-2
2.2.2 Identifying cleanup sites based on bioaccumulative criteria ..... 2-4
2.3 Regional Sites and Sediment Cleanup Units ..... 2-5
2.4 Complex and Simple Sites ..... 2-6

**Chapter 3 Remedial Investigation/Feasibility Study Work Plan and Conceptual Site Model WAC 173-204-510 and 173-204-520 ..... 3-1**
3.1 Objectives of Sampling ..... 3-1
3.1.1 Initial investigations (WAC 173-204-510 and 173-204-520) ..... 3-1
3.1.2 Remedial investigations (WAC 173-204-550) ..... 3-2
3.2 Remedial Investigation/Feasibility Study Plans ..... 3-3
3.2.1 Remedial investigation and feasibility study work plan ..... 3-4
3.2.2 Sampling and analysis plan ..... 3-6
3.2.3 Health and safety plan ..... 3-9
3.2.4 Public participation plan ..... 3-11
3.3 Conceptual Site Model ..... 3-12
3.3.1 Physical and habitat features ..... 3-13
3.3.2 Sources of contaminants ..... 3-14
3.3.3 Fate and transport ..... 3-15
3.3.4 Receptors and exposure pathways ..... 3-15
3.3.5 Contaminant distributions and toxicity ..... 3-17
3.3.6 Contaminants of potential concern ..... 3-18
3.3.7 Potential sediment management areas ..... 3-23
3.3.8 Summary and identification of data gaps ..... 3-23
3.4 Study Design Considerations ..... 3-24
3.4.1. Benthic community ..... 3-24
3.4.2. Bioaccumulative chemicals ..... 3-25

3.4.3. Water quality impacts ..... 3-26
3.4.4. Feasibility study and remedial design ..... 3-29

**Chapter 4 Field Sampling Methods and Selection of Analytical Parameters and Tests ..... 4-1**
4.1 Introduction ..... 4-1
4.2 Selecting Analytical Parameters and Biological Tests ..... 4-2
4.2.1 Selection of chemical analytes ..... 4-2
4.2.2 Consideration of site-specific conditions ..... 4-2
4.2.3 Selection of biological toxicity tests ..... 4-7
4.2.4 Tools to evaluate bioavailability ..... 4-12
4.2.5 Selection of bioaccumulation tests or direct measurements of site-specific tissue chemistry ..... 4-13
4.3 Frequency and Timing of Sampling ..... 4-14
4.3.1 Frequency of sampling ..... 4-14
4.3.2 Timing of sampling ..... 4-15
4.3.3 Phasing of sampling and analysis ..... 4-17
4.3.4 Schedule ..... 4-18
4.4 Sampling Locations ..... 4-18
4.4.1 Initial investigations ..... 4-19
4.4.2 Remedial investigations ..... 4-20
4.4.3 Incremental Sampling Methodology ..... 4-21
4.4.4 Water depth ..... 4-23
4.4.5 Sampling depth interval ..... 4-24
4.4.6 Other factors ..... 4-25
4.5 Field Sampling Methods ..... 4-26
4.5.1 Station positioning ..... 4-26
4.5.2 Sampling equipment ..... 4-26
4.5.3 Recommended sampling equipment and procedures ..... 4-28
4.5.4 Porewater sampling ..... 4-29
4.5.5 Decontamination procedures ..... 4-29
4.5.6 Sample compositing ..... 4-30
4.5.7 Sediment volumes, sample containers, and labels ..... 4-31
4.5.8 Field documentation ..... 4-32
4.5.9 Disposal of contaminated sediments ..... 4-32
4.6 Sample Handling Procedures ..... 4-33
4.6.1 Sample storage requirements ..... 4-33
4.6.2 Chain-of-custody procedures ..... 4-34
4.6.3 Delivery of samples to analytical laboratories ..... 4-35

**Chapter 5 Chemical Analyses, Biological Testing, and Quality Assurance/Quality Control ..... 5-1**
5.1 Chemistry Analytical Methods ..... 5-1
5.1.1 Sediment Chemistry ..... 5-1
5.1.2 Tissue chemistry ..... 5-6
5.2 Bioassay Testing ..... 5-8
5.3 Bioaccumulation Testing ..... 5-8
5.3.1 Laboratory bioaccumulation testing ..... 5-8

5.3.2 In situ bioaccumulation testing ..... 5-9
5.3.3 Collection of field organisms ..... 5-10
5.4 Quality Assurance and Quality Control ..... 5-10
5.4.1 Laboratory accreditation ..... 5-10
5.4.2 Data quality objectives ..... 5-11
5.4.3 Sediment chemistry ..... 5-12
5.4.4 Tissue chemistry ..... 5-12
5.4.5 Marine and estuarine sediment toxicity test conditions ..... 5-13
5.4.6 Freshwater sediment toxicity test conditions ..... 5-14
5.5 Quality Assurance Review ..... 5-15
5.5.1 QA1 review ..... 5-15
5.5.2 QA2 review ..... 5-16
5.6 Electronic Data Submittal and Record-Keeping ..... 5-16

**Chapter 6 Data Interpretation and Remedial Investigation Report ..... 6-1**
6.1 Introduction ..... 6-1
6.2 Remedial Investigation Report ..... 6-1
6.3 Data Reporting, Calculating Sums, and Summary Statistics ..... 6-6
6.3.1 Data reporting ..... 6-6
6.3.2 Calculating chemical sums ..... 6-8
6.3.3 Addressing non-detects in chemical sums ..... 6-13
6.3.4 Calculating summary statistics for a dataset ..... 6-15
6.3.5 Significant figures and rounding ..... 6-18
6.4 Data Analysis and Presentation ..... 6-19
6.4.1 Graphing datasets ..... 6-20
6.4.2 Mapping datasets ..... 6-21
6.4.3 Risk assessment results (optional) ..... 6-23
6.4.4 Source control, recontamination, and natural recovery evaluations ..... 6-23
6.5 Revised Conceptual Site Model ..... 6-24
6.6 Proposed Cleanup Levels and Cleanup Standards ..... 6-25
6.7 Identifying Site Boundaries, Sediment Cleanup Units, and Proposed Sediment Management Areas ..... 6-27

**Chapter 7 Establishing Sediment Cleanup Standards WAC 173-204-560 ..... 7-1**
7.1 Introduction ..... 7-1
7.2 Sediment Cleanup Levels ..... 7-2
7.2.1 The two-tier framework ..... 7-2
7.2.2 Establishing the SCO and CSL ..... 7-3
7.2.3 Establishing sediment cleanup levels ..... 7-4
7.3 Sediment Cleanup Standards ..... 7-7

**Chapter 8 Risk-Based Benthic Sediment Cleanup Standards WAC 173-204-562 and 173-204-563 ..... 8-1**
8.1 Introduction ..... 8-1
8.2 Marine and Freshwater Chemical Criteria ..... 8-3
8.3 Marine and Freshwater Biological Criteria ..... 8-3
8.3.1 Selection of biological tests ..... 8-4
8.4 Establishing Site-Specific Standards ..... 8-5
8.4.1 Introduction ..... 8-5

8.4.2 Use of alternate biological tests ..... 8-6
8.4.3 Development of site-specific chemical criteria ..... 8-6

**Chapter 9 Risk-Based Bioaccumulative Sediment Cleanup Standards WAC 173-204-561 ..... 9-1**
9.1 Introduction ..... 9-1
9.1.1 Approaches for addressing risk-based sediment concentrations for bioaccumulative chemicals ..... 9-2
9.1.2 Spreadsheet to calculate risk-based concentrations ..... 9-4
9.2 Option 1: An Approach Using Sediment Data Only ..... 9-4
9.2.1 Option 1, Part 1: Use of natural and regional sediment background ..... 9-5
9.2.2 Option 1, Part 2: Use of risk-based sediment concentrations based on secondary exposure pathways ..... 9-5
9.3 Option 2: An Approach Using Sediment and Tissue Data ..... 9-9
9.3.1 Calculating tissue concentrations protective of human health ..... 9-9
9.3.2 Calculating tissue concentrations protective of higher trophic levels ..... 9-12
9.3.3 Calculating risk-based sediment concentrations from risk-based tissue concentrations ..... 9-17

**Chapter 10 Natural and Regional Background WAC 173-204-505, 173-204-560 10-1**
10.1 Introduction ..... 10-1
10.1.1 Definitions of natural and regional background ..... 10-2
10.1.2 How natural and regional background can be used ..... 10-3
10.2 Establishing Natural Background Concentrations ..... 10-4
10.2.1 Establishing natural background for marine sediment ..... 10-4
10.2.2 Establishing natural background for freshwater sediment ..... 10-5
10.3 Establishing regional background concentrations ..... 10-5
10.3.1 Ecology-led regional background studies ..... 10-6
10.3.2 Other approaches for establishing regional background ..... 10-9
10.3.3 Identifying and addressing outliers ..... 10-16
10.3.4 Use of ProUCL to calculate statistics ..... 10-17

**Chapter 11 Practical Quantitation Limit-Based Sediment Cleanup Standards WAC 173-204-560 ..... 11-1**
11.1 Introduction ..... 11-1
11.1.1 Definition of PQL ..... 11-2
11.1.2 Use of PQLs ..... 11-2
11.2 Approaches to Establishing a PQL-Based SCO/CSL ..... 11-3
11.2.1 Identifying current laboratory PQLs ..... 11-3
11.2.2 Programmatic approach for establishing the PQL-based SCO/CSL ..... 11-3
11.2.3 Site-specific approach for selecting a PQL-based SCO/CSL ..... 11-4
11.2.4 Comparison of background or risk-based concentrations to PQLs ..... 11-4
11.3 Using the PQL-Based SCO/CSL as a Sediment Cleanup Level ..... 11-5

**Chapter 12 Feasibility Study, Selecting Cleanup action Alternatives, Cleanup Action Plan WAC 173-204-550(7), 173-204-570, 173-204-575 ..... 12-1**
12.1 Introduction ..... 12-1
12.2 Feasibility Study Report Requirements ..... 12-1
12.3 Sediment Cleanup Units and Sediment Management Areas ..... 12-3

12.3.1 Physical factors ..... 12-4
12.3.2 Chemical factors ..... 12-5
12.3.3 Biological factors ..... 12-5
12.3.4 Example of identifying sediment cleanup units or sediment management areas ..... 12-6
12.4 Remedy Selection Process ..... 12-6
12.4.1 Cleanup expectations ..... 12-7
12.4.2 Minimum requirements ..... 12-7
12.4.3 Elements of a remedy ..... 12-9
12.4.4 Identifying and evaluating cleanup action alternatives ..... 12-18
12.4.5 Permanent solutions to the maximum extent practicable ..... 12-21
12.5 Reasonable Restoration Timeframe ..... 12-25
12.6 Sediment Recovery Zones ..... 12-26
12.7 Cleanup Action Plan ..... 12-26
12.8 References for Alternative Technologies ..... 12-27

**Chapter 13 Monitoring and Compliance with Sediment Cleanup Standards WAC 173-204-560 ..... 13-1**
13.0 Introduction ..... 13-1
13.1 Monitoring Objectives ..... 13-1
13.2 Source Control Monitoring ..... 13-3
13.3 Protection Monitoring ..... 13-5
13.4 Performance Monitoring ..... 13-6
13.4.1 Performance standards ..... 13-6
13.4.2 Cleanup Standards Monitoring ..... 13-7
13.5 Confirmation Monitoring ..... 13-10
13.6 Determining Compliance with Sediment Cleanup Standards ..... 13-11
13.6.1 Using sediment data to evaluate compliance ..... 13-12
13.6.2 Using tissue or porewater chemistry data in a weight-of-evidence approach ..... 13-15

**Chapter 14 Sediment Recovery Zones WAC 173-204-590 ..... 14-1**
14.1 Introduction ..... 14-1
14.1.1 When a sediment recovery zone is required ..... 14-1
14.1.2 Criteria Ecology considers for authorization ..... 14-2
14.2 Requirements for a Sediment Recovery Zone ..... 14-2
14.2.1 Minimum requirements ..... 14-2
14.2.2 Renewal, expansion, or reduction of an SRZ ..... 14-3
14.2.3 Monitoring and compliance requirements ..... 14-4
14.2.4 Recontamination ..... 14-4
14.2.5 Enforcement ..... 14-6
14.2.6 Closure ..... 14-6

**Chapter 15 Applicable Laws and Required Permits for Cleanup Actions ..... 15-1**
15.1 Applicable Laws ..... 15-1
15.1.1 Relevant and appropriate requirements ..... 15-1
15.1.2 Applicable laws ..... 15-2
15.2 Exemption from Procedural Requirements ..... 15-4
15.2.1 Substantive requirements ..... 15-4

15.3 Required Permits, Approvals, and Reviews ..... 15-5

**Chapter 16 Removal of Creosote-Treated Pilings and In-Water Structures..... 16-1**
16.1 Introduction..... 16-1
16.2 Policy for Removal of Creosote-Treated Pilings ..... 16-2
16.2.1 Removing creosote-treated piling within a cleanup site footprint..... 16-3
16.2.2 Removing creosote-treated piling outside a cleanup site footprint ..... 16-4
16.2.3 Removing creosote-treated piling near other in-water actions ..... 16-4
16.2.4 State-funded in-water actions ..... 16-5
16.3 Methods and Best Management Practices for Removing Pilings ..... 16-5
16.3.1 Piling removal methods ..... 16-6
16.3.2 Piling removal BMPs ..... 16-7
16.4 History of the Environmental Effects and Use of Pilings in Washington State16-13
16.5 Literature Resources for BMPs and PAH Effects..... 16-15
16.5.1 Piling removal BMPs ..... 16-15
16.5.2 Case Studies..... 16-15
16.5.3 Rules and Regulations ..... 16-16
16.5.4 Scientific Literature ..... 16-16

**Chapter 17 References..... 17-1**

**Appendix A Sampling Guidance for NPDES Permits under the Sediment Management Standards.....1**
A.1 Sediment Management Standards for Permitted Discharges.....1
A.1.1 Introduction .....1
A.1.2 Benthic criteria and selection of study-specific parameters .....2
A.2 Types of Monitoring and Objectives .....4
A.3 Sampling Station Locations .....5
A.3.1 NPDES permit baseline or maintenance monitoring.....5
A.3.2 SIZ maintenance monitoring .....7
A.4 Sampling and Analysis Plan Requirements .....8
A.5 Field Sampling Methods .....11
A.6 Chemistry and Biological Analytical Methods .....11
A.7 Data Report .....11

**Appendix B Sediment Management Annual Review Meeting (SMARM) Papers.....1**
Program development clarification and issue papers.....1
Sampling and testing requirements issue papers .....2
Chemical testing.....2
Bioassays.....3
Bioaccumulation testing.....4

**Appendix C Bioassay Methods .....1**
C.1 Marine and Freshwater Microtox® 100 Percent Sediment Porewater Toxicity Test1
C.1.1 Microtox.....1
C.1.2 Sample collection and holding times .....2
C.1.3 Microtox test procedure .....2
C.1.4 Data preparation.....4
C.1.5 Statistical analysis.....5
C.1.6 Data interpretation .....5

C.1.7 Quality control .....6
C.2 Conducting Bioassays on Sediment Containing Polycyclic Aromatic Hydrocarbons Exposed to Ultraviolet Radiation.....7
C.2.1 Conditions determining type of bioassays .....7
C.2.2 Laboratory testing conditions and considerations .....8
C.3 Bioassay Reference and Control Sediment .....10
C.3.1 Control Sediment Sample .....10
C.3.2 Reference Sediment Sample .....11

**Appendix D: Analytical Methods and Detection/Quantitation Limits for Sediment and Tissue.....1**
D.1 Introduction.....1
D.2 MDL and PQL Definitions .....2
D.3 Sample Preparation Methods .....3
D.3.1 Inorganic preparation methods .....4
D.3.2 Organic preparation methods.....4
D.4 Analytical Methods .....5
D.5 Laboratory Survey Results.....6
D.6 Example of Establishing PQL-Based Cleanup Levels.....7
D.6.1 Introduction .....7
D.6.2 Laboratory surveys .....7
D.6.3 PQL survey results.....7
D.6.4 Establishing PQLs as cleanup levels .....8
D.6.5 Recommended PQL.....9
D.6.6 Comparison of PQLs to MDLs.....9
D.6.7 Notes on terminology .....9

**Appendix E Assessing Human and Ecological Health Risks .....1**
E.1 Introduction .....1
E.2 Human Health Risk Assessment .....1
E.2.1 Fish and shellfish consumption – default RME .....3
E.2.2 Direct contact with and ingestion of sediment.....10
E.3 Ecological Risk Assessment.....14
E.3.1 Scope of the ecological risk assessment .....15
E.3.2 Ecological risk assessment approach .....16

**Appendix F Statistics for Addressing Non-Detects and Evaluating Compliance .....1**
F.1 Statistical Methods for Addressing NDs .....1
F.1.1 Calculating group sums for individual samples .....2
F.1.2 Calculating Kaplan-Meier-based TEQ sums with available software tools 5
F.1.3 Graphing and presenting datasets.....12
F.1.4 Calculating summary statistics for a distribution.....13
F.1.5 Resources .....16
F.2 Stratified Random Sampling in Compliance Monitoring.....17
F.2.1 Identify strata.....17
F.2.2 Allocate samples among strata .....18
F.2.3 Estimate population parameters .....18

**Appendix G Potential Best Management Practices for Sediment Cleanup Projects...1**

G.1 Introduction ....1

**Appendix H Remedy Selection Case Studies ....1**
H.1 Case Study #1: Complex Site Evaluation ....1
H.1.1 Description of cleanup action alternatives ....1
H.1.2 Screening cleanup action alternatives against minimum requirements ....2
H.1.3 Evaluation and screening of alternatives using benefits criteria ....3
H.1.4 Evaluation and relative benefits criteria ranking of alternatives ....4
H.2 Case Study #2: Complex Site Evaluation ....7
H.2.1 Cleanup action alternatives ....7
H.2.2 Screening cleanup action alternatives against minimum requirements ....8
H.2.3 Evaluation and screening of alternatives using benefits criteria ....8
H.2.4 Evaluation and relative benefits criteria ranking of alternatives ....9
H.3 Case Study #3: Simple Site Evaluation Considering Risk Reduction ....13
H.3.1 Cleanup action alternatives ....13
H.3.2 Screening cleanup action alternatives against minimum requirements ....15
H.3.3 Evaluation and screening of alternatives using benefits criteria ....16
H.4 Case Study #4: Simple Site Evaluation with Minimal Cleanup Action Alternatives ....19
H.4.1 Cleanup action alternatives ....19
H.4.2 Screening cleanup action alternatives against minimum requirements ....20
H.4.3 Evaluation and screening of alternatives using benefits criteria ....20
H.4.4 Evaluation and relative benefits criteria ranking of the alternatives ....21
H.5 Case Study #5: Sediment Cleanup Unit Evaluation ....21
H.5.1 Cleanup action alternatives ....22
H.5.2 Screening cleanup action alternatives against minimum requirements ....23
H.5.3 Evaluation and screening of alternatives using benefits criteria ....23
H.5.4 Evaluation and relative benefits criteria ranking of alternatives ....23

**Appendix I Natural Background Data ....1**
I.1 Introduction ....1
I.2 Calculation of Natural Background Threshold Values ....2
I.2.1 Dioxin/Furan TEQs ....2
I.2.2 PCB TEQ ....3
I.2.3 cPAH TEQ ....3
I.2.4 Metals ....4

**Appendix J Determining Toxicity of Naturally Occurring Chemicals ....1**
J.1 Introduction ....1
J.2 Approaches to Toxicity Test Exposures ....1
J.3 Natural versus Anthropogenic Sources of Chemicals ....2
J.3.1 Ammonia as a natural chemical ....2
J.3.2 Ammonia in reference sediment ....3
J.4 Summary ....3

**Appendix K Spreadsheets for Calculating Risk-Based Concentrations for Sediment and Tissue ....1**
K.1 Introduction ....1

**Appendix L False Positive and False Negative Error Rates Associated with Simulated Compliance Scenarios.....1**
L.1 Methods.....1
L.1.1. False positive error rate scenarios.....2
L.1.2 False negative error rate scenarios.....2
L.1.3. Error rate calculation.....3
L.2 Results.....4
L.2.1 Point-by-point comparison to the cleanup level (Option A).....4
L.2.2 Comparison of the arithmetic mean to the cleanup level (Option B).....5
L.2.3 Alternate approach: Comparison of the 95th UCL of the mean to the cleanup level.....7
L.3 Discussion.....8
L.3.1 Option A – Point-by-point comparison to the cleanup level.....8
L.3.2 Option B – Comparison of the mean to the cleanup level.....9
L.3.3 Alternative approach – Comparison of the 95th UCL of the mean to the cleanup level.....10

**Appendix M SCUM Revisions.....1**
M.1 Introduction.....1
M.2 Revisions Made for 2019 Version.....2
M.3 Revisions Made for 2017 Version.....5

# List of Figures

Chapter-Page

Figure 1-1. Sediment cleanup decision process.....1-8

Figure 2-1. Process for identifying station clusters of potential concern and sediment cleanup sites.....2-9
Figure 2-2. SMS framework for establishing the Sediment Cleanup Objective (SCO) and the Cleanup Screening Level (CSL), used to identify sediment cleanup sites, evaluate sediment cleanup sites, and establish sediment cleanup standards.....2-10

Figure 3-1: RI/FS Work Plan outline and checklist.....3-30
Figure 3-2. Sediment SAP outline and checklist.....3-33
Figure 3-3. Example of a site CSM graphic figure for a sediment cleanup site.....3-35
Figure 3-4. Example of a site CSM flow chart diagram for a sediment cleanup site.....3-36

Figure 4-1. Selection of appropriate amphipod species for marine/estuarine toxicity tests.....4-36

Figure 6- 1: Sample depiction of inverse distance weighted interpolated concentrations and Thiessen polygons calculated for a set of sampling locations.....6-17
Figure 6-2. Boxplots for two censored datasets.....6-30

Figure 6-3. Probability or quantile-quantile (Q-Q) plots for a censored dataset (the same data shown in the bottom row of boxplots in Figure 6-2). ..... 6-31
Figure 6-4. A normal distribution Q-Q plot generated in ProUCL under Graphs > Multi-QQ > With NDs. ..... 6-32
Figure 6-5. Empirical cumulative distribution function (ECDF) plots for the two datasets shown in the boxplots in Figure 6-2. ..... 6-33
Figure 6-6. Simple site with sample stations shown as colored and scaled dots. ..... 6-34
Figure 6-7. Simple site with interpolation of data. ..... 6-35
Figure 6-8. Simple site with bioassay pie chart and color showing exceedances (no-exceedance / SCO / CSL). ..... 6-36
Figure 6-9. Complex site with overlapping footprints. ..... 6-37
Figure 6-10. Complex site with overlapping CoCs normalized to cleanup levels ("exceedance factors"), summed to portray areas of highest concern. ..... 6-38
Figure 6-11. Plan view and cross sections of contaminant distributions. ..... 6-39

Figure 7-1. SMS framework for establishing sediment cleanup levels. ..... 7-1

Figure 8-1. Framework for establishing sediment cleanup levels, WAC 173-204-560. Benthic criteria are highlighted. ..... 8-1

Figure 9-1. SMS framework for establishing sediment cleanup levels, WAC 173-204-560, Chapter 7. ..... 9-1
Figure 9-2. Development of tissue and sediment concentrations based on bioaccumulative risks to higher trophic level species and human health. ..... 9-32
Figure 9-3. Directions for using the spreadsheets in Appendix K. ..... 9-33

Figure 10-1. SMS framework for establishing sediment cleanup levels, WAC 173-204-560 (Chapter 7). Natural and regional background criteria are highlighted. ..... 10-1

Figure 11-1. SMS framework for establishing sediment cleanup levels, WAC 173-204-560. PQL criteria are highlighted. ..... 11-1

Figure 12-1. Example of sediment cleanup units or sediment management areas. ..... 12-31

Figure 13-1. Evaluating compliance with a sediment cleanup standard. ..... 13-16

Figure 16-1. Cut piling stubs exposed on the intertidal beach at the Wyckoff Superfund Site on Bainbridge Island, WA. . ..... 16-27
Figure 16-2. Wrapped piling at the Squamish Terminal in Squamish, British Columbia. ... 16-27
Figure 16-3. Process of piling removal that includes sequencing using different methods. .. 16-29
Figure 16-4. Piling removal using the vibratory hammer method. ..... 16-31
Figure 16-5. Partially excavated piling stub on intertidal beach at the former Port Gamble sawmill in Port Gamble, WA. ..... 16-31
Figure 16-6. Decayed piling stubs in eelgrass at the former Port Gamble sawmill in Port Gamble, WA. ..... 16-32
Figure 16-7. Removing pilings at the former mill site in Port Gamble Bay, WA. ..... 16-32

Figure 16-8. Removing pilings at the former Asarco Tacoma Smelter in Tacoma, WA. ..... 16-33
Figure 16-9. Piling removal containment area - former mill site in Port Gamble Bay, WA. 16-33

Appendix A: Figure A-1. Examples of monitoring station locations using 6 and 18 stations. .... 19
Appendix A: Figure A-2. Examples of monitoring station locations using 10 stations. ..... 20
Appendix A: Figure A-3. Examples of SIZ maintenance monitoring station locations. ..... 21

Appendix C: Figure C-1. Example of an acceptable UV spectral output. ..... 14
Appendix C: Figure C-2. Example of an acceptable UV spectral output (0 - 400 nm range). ..... 14

Appendix D: Figure D-1. TEQs associated with reported PQLs. ..... 8
Appendix D: Figure D-2. Mid-range TEQs/PQLs. ..... 9

Appendix E: Figure E-1. Recommended default RME for evaluating human health risk at sediment cleanup sites. ..... 24

Appendix F: Figure F-1. Boxplots for two censored datasets. ..... 20
Appendix F: Figure F-2. Probability (or Q-Q) plots for a censored dataset (the same data shown in the bottom row of boxplots in Figure F-1). ..... 21
Appendix F: Figure F-3. A normal Q-Q plot generated in ProUCL 4.1 under Graphs > Multi-QQ > With NDs. ..... 22
Appendix F: Figure F-4. Empirical cumulative distribution function (ECDF) plots for the two datasets shown in the boxplots in Figure F-1. ..... 23
Appendix F: Figure F-5. Scatterplots of censored dataset. ..... 24

Appendix H: Figure H-1. Case Study #3. Relative ratio of the overall post-remediation and long-term risk reduction at the site relative to costs. ..... 34

Appendix L: Figure L-1. Illustration of the simulated distributions used to estimate the false positive rates. ..... 12
Appendix L: Figure L-2. Illustration of the simulated distributions used to estimate false negative rates. ..... 13
Appendix L: Figure L-3. False positive rates for Option A. ..... 14
Appendix L: Figure L-4. False negative rates for Option A. ..... 15
Appendix L: Figure L-5. False positive rates for Option B. ..... 16
Appendix L: Figure L-6. False negative rates for Option B. ..... 17
Appendix L: Figure L-7. False positive rates for the alternative approach. ..... 18
Appendix L: Figure L-8. False negative rates for the alternative approach. ..... 19

# List of Tables

Table 4-1. Chemicals that may be analyzed on a site-specific basis. ..... 4-37
Table 4-2. Conventional sediment and water quality parameters applicable to sediment. ..... 4-38
Table 4-3. Marine and low-salinity estuarine sediment toxicity tests. ..... 4-39

Table 4-4. Freshwater bioassay tests adopted in the SMS rule and additional tests. 4-41
Table 4-5. Advantages and disadvantages of sediment samplers. 4-42
Table 4-6. Minimum sediment sample sizes and acceptable containers for physical/chemical analyses and sediment toxicity tests. 4-44
Table 4-7. Storage temperatures and maximum holding times for physical/chemical analyses and sediment toxicity tests. 4-46

Table 5-1. Sediment chemistry recommended analytical methods. 5-18
Table 5-2. Tissue chemistry recommended analytical methods. 5-22
Table 5-3. Quality control procedures for organic analyses. 5-23
Table 5-4. Quality control procedures for metals analyses. 5-25
Table 5-5. Quality control procedures for conventional analyses. 5-27
Table 5-6. Reporting limits for PCDD/PCDFs. 5-28
Table 5-7. Quality control procedures for PCDD/PCDF analyses. 5-29
Table 5-8. Quality control acceptance criteria for PCDD/PCDF analyses. 5-31
Table 5-9. Marine and estuarine sediment toxicity test conditions. 5-32
Table 5-10. Freshwater sediment toxicity test conditions. 5-33

Table 6-1. Toxicity Equivalency Factors (TEFs) for the minimum[a] required cPAHs. 6-28
Table 6-2. Toxicity Equivalency Factors (TEFs) for dioxin/furan congeners. 6-28
Table 6-3. Toxicity Equivalency Factors (TEFs) for dioxin-like PCB congeners. 6-29
Table 6-4. Recommended methods for estimating summary statistics (after Table 6-11 in Helsel, 2012). 6-29

Table 8-1. Marine and freshwater sediment chemical criteria for protection of the benthic community. 8-8
Table 8-2. Marine biological criteria (SCO & CSL and performance standards) for each biological test. 8-11
Table 8-3. Marine biological tests, species, and applicable endpoints. 8-13
Table 8-4. Freshwater biological criteria (SCO/CSL and performance standards) for each biological test. 8-14
Table 8-5. Freshwater biological tests, species, and applicable endpoints. 8-15

Table 9-1a. Recommended exposure parameters for calculating human health risk-based concentrations for ingestion of sediment and direct contact with sediment. See Table 9-1b for parameters based on early life exposure. 9-25
Table 9-1b. Risk parameters and exposure pathways used for calculating risk-based sediment concentrations for early life exposure to cPAHs. 9-26
Table 9-2. Human health risk-based sediment concentrations for ingestion of sediment and direct contact with sediment (calculated using the spreadsheets in Appendix K and the recommended exposure parameters in Table 9-1a). 9-27
Table 9-3. Recommended exposure parameters for calculating human health risk-based tissue concentrations for consumption of fish/shellfish. 9-28
Table 9-4. Human health risk-based tissue concentrations for consumption of fish/shellfish (calculated using the spreadsheets in Appendix K and the recommended exposure parameters in Table 9-3 and fish consumption rates at the 90 percentile from Ecology 2013b). 9-29
Table 9-5. Aquatic-dependent wildlife representing indicator higher trophic level receptors. 9-31

Table 10-1. Calculated values (90/90 UTL) for marine sediment natural background from the data sets in Appendix I and Bold study (DMMP, 2009). 10-21
Table 10-2. Calculated values (90/90 UTL) for regional sediment background…….10-22

Table 11-1. Programmatic sediment and tissue PQLs used to establish the PQL-based SCO and CSL. ..... 11-1

Table 16-1: Environmental effects on aquatic life of PAHs from creosote-treated structures.16-23

Appendix A: Table A-1. Marine benthic chemical criteria. ..... 13
Appendix A: Table A-2. Marine biological criteria (SQS and SIZmax and performance standards) for each biological test. \ ..... 15
Appendix A: Table A-3. Marine biological tests, species, and applicable endpoints. ..... 17
Appendix A: Table A-4. Recommended freshwater biological tests, species, and applicable endpoints. ..... 18

Appendix C: Table C-1. Photo-activated Polycyclic Aromatic Hydrocarbons. ..... 13

Appendix D: Table D-1. Sediment Method Detection Limits and Practical Quantitation Limits [1] ..... 11
Appendix D: Table D-2. Tissue Method Detection Limits and Practical Quantitation Limits [1] .. 17

Appendix E: Table E-1. Recommended exposure parameters for calculating human health risks from consumption of fish and shellfish. ..... 41
Appendix E: Table E-2. Evaluation criteria Ecology will consider when reviewing and approving a new fish dietary survey to establish a fish consumption rate. ..... 42
Appendix E: Table E-3. Factors to consider when developing a site-specific RME scenario. .... 43
Appendix E: Table E-4. Recommended exposure parameters for calculating human health risks from direct contact with and ingestion of sediment. ..... 45

Appendix F: Table F-1. Recommended methods for estimating summary statistics (after Table 6-11, Helsel 2005). ..... 19

Appendix G: Table G-1. Best management practices that may be applicable to sediment cleanup projects. ..... 3

Appendix H: Table H-1. Case Study #1. Screening of cleanup action alternatives against minimum requirements. ..... 24
Appendix H: Table H-2. Case Study #1. Benefits criteria scoring. ..... 25
Appendix H: Table H-3. Case Study #1. Comparison of costs and benefits of alternatives. ..... 27
Appendix H: Table H-4. Case Study #1. Summary of the alternatives evaluation and ranking. . 27
Appendix H: Table H-5. Case Study #2. Screening of cleanup action alternatives against minimum requirements. ..... 29
Appendix H: Table H-6. Case Study #2. Benefits criteria scoring. ..... 30
Appendix H: Table H-7. Case Study #2. Summary of the alternatives evaluation and ranking. . 33

Appendix I: Table I-1. Ecology-approved organics data. ..... 7

Appendix I: Table I-2. Ecology-approved data for metals. ..... 8
Appendix I: Table I-3. Ecology approved data for dioxins/furans. ..... 9
Appendix I: Table I-4. EIM data qualifier codes and descriptions. ..... 11
Appendix I: Table I-5. Kaplan-Meier-based TEQ Sums for dioxin/furans, PCBs, and cPAHs… 12

Appendix L: Table L-1. Description of the simulation scenarios used to assess false positive and false negative error rates associated with compliance monitoring tests. ..... 11

# List of Equations

Equations 9-1a,b …….9-6
Equation 9-2…….9-7
Equation 9-3…….9-8
Equation 9-4…….9-8
Equations 9-5a,b …… …...9-11
Equation 9-6……...9-11
Equation 9-7……...9-15
Equation 9-8……...9-16
Equation 9-9……...9-17

Appendix C: Equation C-1……5
Appendix C: Equation C-2……5

Appendix E: Equation E-1. Calculation of cancer risks for fish and shellfish consumption……...3
Appendix E: Equation E-2. Calculation of noncancer risks for fish and shellfish consumption….4
Appendix E: Equation E-3. Calculation of cancer risks for sediment ingestion and dermal contact ……10
Appendix E: Equation E-4. Calculation of noncancer risks for sediment ingestion and dermal contact ……...11
Appendix E: Equation E-5…….13
Appendix E: Equation E-6…….13

*This page left intentionally blank*

# Acknowledgements

The Department of Ecology, Toxics Cleanup Program (Ecology) would like to thank the following authors of this guidance document:

- Department of Ecology: Chance Asher, Laura Inouye, Russ McMillan, Pete Adolphson, Dave Bradley, Pete Kmet, and Ivy Anderson.
- Teresa Michelsen (Avocet Consulting)
- Lorraine Read (TerraStat Consulting Group)

Ecology would like to thank the following people for their technical support on this guidance document:

- Elaine Heim (Ecology, Technical Editor)
- Ecology: Celina Abercrombie, Hugo Froyland, Ian Mooser, Sharon R. Brown, Gina Casteel
- Chris Waldron (Pioneer Technologies Corporation)
- Will Hafner (NewFields)
- Roger McGinnis (Hart Crowser)

Ecology would like to thank the following people for their contribution to reviewing this guidance document and/or attending technical workshops:

Ecology: Dawn Hooper (Facilitation), Joyce Mercuri, Connie Groven, Peter Striplin, John Evered, Susannah Edwards, Fu-Shin Lee, Brendan Dowling, Laura Klasner, Norm Peck, Jim Pendowski, Jing Liu, Ron Timm, Lucy McInerney, Grant Yang, Bob Warren, Xuan Li, Priscilla Tomlinson, Erica Fot, Andy Kallus.

Kym Anderson (Port of Seattle); Scott Becker, Nicole Ott, Gene Revelas (Integral); Bill Beckley (Ridolfi); Dan Berlin, Greg Brunkhorst, Mark Larsen, Clay Patmont, Sara Potter, Cindy Fields (Anchor QEA); Larry Dunn (Lower Elwha Tribe); Sue Dunnihoo (ARI); Mike Ehlebracht (Hart Crowser);Will Ernst, Nick Garson (Boeing Company); Anne Fitzpatrick (AECOM/Geosyntec); David Fox, Kristin Kerns, Rebecca Weiss (USACE); Erik Gerking (Port of Everett); Dina Ginn (NAVFAC); Kathy Godtfredsen, Nancy Judd, Susie McGroddy (Windward Environmental); Jill Hedgecock (URS); Brad Helland; Kris Hendrickson, Steve Shaw (Landau Associates); Allison Hiltner, Erika Hoffman, Lon Kissinger, Ravi Sanga, Anita Singh (Environmental Protection Agency, Region X); Kris Holm; Don Hurst (Colville Confederated Tribes); James Keithly, Mike Mendes (ERM);

Kathy Kreps (TestAmerica); Rick Moore (CH2MHill); Tom Newlon, Steve Thiele (Stoel, Rives); Rory O'Rourke (Port Gamble S'Klallam Tribe); James Rasmussen (Duwamish River Cleanup Coalition); Pete Rude, Allison Crowley, Dave Schuchardt (City of Seattle); Zanna Satterwhite, Claudia De La Via, Nancy Musgrove, Steve Woodward (GeoEngineers); Senecal (WSPA); Erika Shaffer, Abby Barnes, Tim Goodman, Christopher Robertson (Washington Department of Natural Resources); Alex Smith (Port of Olympia); Kate Snider, Allison Geiselbrecht, Amanda McKay, Amara Vandervort (Floyd Snider); Glen St. Amant (Muckleshoot Tribe); Jeff Stern, Debra Williston, Colin Elliott, Diane McElhany, Francis Sweeney (King County); Steward (Teck American); Mike Stoner (Port of Bellingham); Jennifer Sutter (Oregon Department of Environmental Quality); Denice Taylor (Suquamish Tribe); Brian Hester, Mary Ann Rempel-Hester (EcoAnalysts), Tim Thompson (SEE), Randy Thurston (Washington Department of Fish and Wildlife)

# Acronyms & Abbreviations

| Acronym or Abbreviation | Definition |
|---|---|
| AA | Atomic absorption |
| AET | Apparent Effects Threshold |
| AKART | All known, available and reasonable technologies |
| ANOVA | Analysis of Variance |
| AOI | Area of interest |
| ARARs | Applicable or relevant and appropriate requirements |
| AVS | Acid volatile sulfides |
| BAF | Bioaccumulation factor |
| BAZ | Biologically active zone |
| BCA | Bias-corrected and accelerated |
| BMP | Best management practices |
| BSAF | Biota to sediment accumulation factor |
| BW | Body weight |
| CAD | Confined aquatic disposal |
| CAP | Cleanup action plan |
| CBR | Critical body residue |
| CDF | Cumulative distribution factor |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| CLARC | Cleanup Levels and Risk Calculation |
| CLP | Contract Laboratory Program |
| CoC | Contaminants of concern |
| CoPC | Contaminants of potential concern |
| cPAH | Carcinogenic polycyclic aromatic hydrocarbon |
| CSF | Cancer slope factor |
| CSL | Cleanup screening level |
| CSM | Conceptual site model |
| CWA | Clean Water Act |
| CZM | Coastal Zone Management Act |
| DCA | Disproportionate cost analysis |
| DDT | Dichlorodiphenyltrichloroethane |
| DL | Detection limit |
| DMMP | Dredged Material Management Program |

| Acronym or Abbreviation | Definition |
|---|---|
| DQOs | Data quality objectives |
| DO | Dissolved oxygen |
| ECDF | Empirical cumulative distribution function |
| ED | Exposure duration |
| EDL | Estimated detection limit |
| EDR | Engineering design report |
| EIM | Environmental Information Management System database |
| EMNR | Enhanced monitored natural recovery |
| ENR | Enhanced natural recovery |
| EPA | Environmental Protection Agency (federal) |
| ERED | Environmental Residue-Effects Database |
| ESA | Endangered Species Act |
| FCR | Fish consumption rate |
| FSF | Fish diet fraction |
| FPM | Floating Percentile Method |
| FS | Feasibility study |
| GC | Gas chromatography |
| GI | Gastro intestinal conversion factor |
| GPS | Global positioning system |
| HAZWOPER | Hazardous waste operations |
| HHRA | Human health risk assessment |
| HPA | Hydraulic Project Approval |
| HPLC | High-pressure liquid chromatography |
| HSP | Health and safety plan |
| ICP | Inductively coupled plasma |
| IDW | Inverse distance weighting |
| IID | Independently and identically distributed |
| IQR | Interquartile range |
| IRIS | Integrated Risk Information System |
| ISM | Incremental sampling methodology |
| JARPA | Joint Aquatic Resources Permit Application |
| KM | Kaplan-Meier |
| LOAEL | Lowest observed adverse effect level |
| LOER | Lowest observed effect residue |
| MDD | Minimum detectable difference |
| MDL | Method detection limit |
| MIS | Multiple increment sampling |
| MLE | Maximum likelihood estimates |

| Acronym or Abbreviation | Definition |
|---|---|
| MLLW | Mean lower low water |
| mmol | Millimoles per liter |
| MNR | Monitored natural recovery |
| MPRSA | Marine Protection, Research, and Sanctuaries Act |
| MS | Mass spectrometry |
| MTCA | Model Toxics Control Act |
| NEPA | National Environmental Policy Act |
| NHPA | National Historic Preservation Act |
| NOAA | National Oceanic Atmospheric Administration |
| NOAEL | No observed adverse effect level |
| NPDES | National Pollution Discharge Elimination System |
| NRDA | National Resource Damage Assessment |
| OCDF | Octachlorodibenzofuran |
| ORNL | Oak Ridge National Laboratory |
| OSHA | Occupational Safety and Health Administration (federal) |
| OSV Bold | Ocean Survey Vessel Bold |
| OSWER | Office of Solid Waste and Emergency Response |
| PAHs | Polycyclic aromatic hydrocarbons |
| PBT | Persistent, bioaccumulative toxin |
| PCBs | Polychlorinated biphenyls |
| PCDD/PCDF | Polychlorinated dibenzo-*p*-dioxins and Polychlorinated dibenzofurans |
| PCP | Pentachlorophenol |
| pH | Potential hydrogen |
| PLP | Potentially Liable Person(s) |
| PPP | Public participation plan |
| PPRTV | Provisional peer reviewed toxicity values |
| PQL | Practical quantitation limit |
| PSEP | Puget Sound Estuary Protocols |
| PSET | Portland Sediment Evaluation Team |
| QA/QC | Quality Assurance/Quality Control |
| Q-Q | Quantile-quantile |
| RCW | Revised Code of Washington |
| RI/FS | Remedial Investigation/Feasibility Study |
| RfD | Reference dose |
| RL | Reporting Limit |
| RME | Reasonable maximum exposure |
| ROS | Regression on order statistics |
| RPD | Relative percent differences or Redox potential discontinuity |
| RSET | Regional Sediment Evaluation Team |

| Acronym or Abbreviation | Definition |
|---|---|
| SAP | Sampling and Analysis Plan |
| SAPA | Sediment Sampling and Analysis Plan Appendix |
| SCO | Sediment Cleanup Objective |
| SEA | Shorelands and Environmental Assistance Program |
| SEF | Sediment Evaluation Framework |
| SEM | Simultaneously Extracted Metals |
| SEPA | State Environmental Policy Act |
| SIZ | Sediment impact zone |
| SMA | Sediment management area |
| SMS | Sediment Management Standards |
| SOPs | Standard Operating Procedures |
| SPI | Sediment Profile Imaging |
| SPMEs | Solid phase microextraction |
| SQS | Sediment Quality Standards |
| SRZ | Sediment recovery zones |
| SSD | Species sensitivity distribution |
| SUF | Site use factor |
| SVOC | Semi-volatile organic compounds |
| SWI | Sediment-water interface |
| TEQs | Toxicity equivalence |
| TEF | Toxicity equivalency factor |
| TBT | Tributyltin |
| TOC | Total organic carbon |
| TRA | Tissue residue approach |
| TRV | Toxicity reference value |
| TVS | Total Volatile Solids |
| U&A | Usual and Accustomed |
| UCL | Upper Confidence Limit |
| UECA | Uniform Environmental Covenants Act |
| USACOE | United States Army Corps of Engineers |
| USEPA | United States Environmental Protection Agency |
| USFWS | United States Fish and Wildlife Service |
| UTLs | Upper tolerance limit |
| UV | Ultraviolet |
| WAC | Washington Administrative Code |
| WDFW | Washington State Department of Fish and Wildlife |
| WDNR | Washington State Department of Natural Resources |
| WPCA | Water Pollution Control Act |

# Chapter 1
# Introduction

## 1.1 Purpose

The purpose of this document is to provide guidance to staff at the Washington State Department of Ecology (Ecology), potentially liable persons (PLPs), and consultants who conduct cleanup of contaminated sediment sites using the Sediment Management Standards (SMS; Chapter 173-204 WAC ), Part V Sediment Cleanup Standards. This guidance is intended to be used when implementing the sediment cleanup decision process for contaminated sediment in Washington State.

Under the SMS cleanup rule,

- "Sediment" is defined as: " *settled particulate matter located at or below the ordinary high water mark, where the water is present for a minimum of six consecutive weeks, to which biota (including benthic infauna) or humans may potentially be exposed, including that exposed by human activity (e.g., dredging)."* (WAC 173-204-505(22)).

- "Contaminant" is defined as "*…any hazardous substance that does not occur naturally or occurs at greater than natural background levels."* (WAC 173-204-505(7)).

The approaches and information in this guidance manual were developed to supplement the SMS rule requirements, with the goal of balancing protectiveness, predictability, and flexibility at cleanup sites. This guidance includes options for employing streamlined approaches for simpler sites. It is recognized that larger and more complex sites may need more comprehensive approaches that require more judgment and site-specific flexibility. While this guidance represents Ecology's recommendations at this time, modification to these approaches may be warranted at individual sites as science and technology evolve. This guidance manual replaces previous versions of the Sediment Cleanup User's Manual (SCUM), as well as the former Sampling and Analysis Plan Appendix (SAPA). Information contained in the SAPA has been incorporated into this document.

## 1.2 How this guidance is organized

The remaining chapters of this guidance document follow the organization of the sediment cleanup decision process presented in the SMS Part V, Sediment Cleanup Standards (Figure 1-1).

Chapter 2 discusses the process of station cluster screening and site identification. Ecology evaluates reported data to determine if an area qualifies as a cleanup site that requires further investigation or cleanup action. If so, then the site is listed as a MTCA site. Once Ecology and/or a PLP determine that the site is a priority for investigation and cleanup, an Agreed Order is developed and signed to begin the RI process.

Chapters 3 through 6 address RI/FS tasks:

- Chapter 3 describes development of the RI/FS Work Plan. This is the first step in the cleanup process. The RI/FS Work Plan includes a summary of pertinent information and data available for the site, leading to development of an initial conceptual site model (CSM). As part of the CSM, chemicals of potential concern (CoPCs) are screened based on current data. In addition, anticipated exposure pathways to humans and wildlife are identified. Based on the initial CSM, data gaps are identified that form the basis of the RI/FS work plan.

- Chapter 4 describes field sampling methods, including selection of analytical methods and bioassays; frequency and timing of sampling; station locations; field sampling methods; and sample handling procedures. This chapter also provides recommendations for developing a study design. Each of these elements is included in the RI Work Plan development described in Chapter 3.

- Chapter 5 discusses chemical analyses and biological testing; quality assurance and quality control (QA/QC) requirements; and record-keeping and data submittal requirements. This information should be part of the RI Work Plan.

    - Appendix D includes more information on analytical methods, detection, and practical quantitation limits for sediment and tissue.

- Chapter 6 describes the contents of an RI Report. The chapter also describes data evaluation procedures for working with data sets; analyzing and presenting the data; conducting statistical analyses; updating the CSM; identifying proposed cleanup levels and cleanup standards; and determining site boundaries and proposed sediment management areas

- Appendix F includes more information on the use of statistics for addressing non-detects and information on how to use the Kaplan-Meier (KM) approach for summing Toxicity Equivalence Quotients (TEQs).

Chapters 7 through 11 describe the overall sediment cleanup standards framework, how to calculate each component of the framework, and how to establish site-specific cleanup levels and cleanup standards for the RI and FS reports:

- Chapter 7 presents the two-tiered cleanup standards framework and process for establishing sediment cleanup standards (including sediment cleanup levels, depths of compliance, and areas of compliance). The chapter addresses how the various risk-based (benthic, ecological higher trophic levels, and human health), background-based, and practical quantitation limit (PQL)-based values are used to:
  - Establish the sediment cleanup objective (SCO).
  - Establish the cleanup screening level (CSL).
  - Determine the sediment cleanup level by adjusting upwards from the SCO based on technical possibility and net adverse environmental impacts.
- Chapter 8 presents the freshwater and marine benthic biological and chemical criteria. The chapter also discusses how to establish site-specific criteria if necessary.
  - Appendix C includes specialized testing methods for certain bioassays.
- Chapter 9 describes methods for developing site-specific risk-based concentrations for protection of human health and higher trophic levels for bioaccumulative chemicals. This includes development of risk-based concentrations for tissue, as well as methods for back-calculating protective tissue concentrations to sediment concentrations.
  - Appendix E includes more information and describes methods for conducting in-depth human health and ecological risk assessments as needed. Such assessments may be required at complex sites at the discretion of Ecology.
  - Appendix K includes a series of spreadsheets for calculating risk-based concentrations for tissue and sediment.
- Chapter 10 describes how to determine and apply natural and regional background concentrations as part of establishing the SCO and CSL, respectively.
  - Appendix I includes the data used to establish natural background for marine areas, and more information regarding calculations and treatment of data

- Chapter 11 describes the development of PQL-based SCOs and CSLs.
    - Appendix D includes the information from laboratory surveys that Ecology conducted to establish appropriate PQLs.

Chapters 12 through 15 address FS tasks, cleanup, compliance monitoring, sediment recovery zones (SRZs), and applicable laws and required permits:

- Chapter 12 discusses the remedy selection process including sediment cleanup technologies; development and selection of cleanup alternatives, and the development of sediment cleanup units and sediment management areas. The chapter also describes the disproportionate cost analysis process for selecting the proposed remedies in the FS Report and the final remedies in the cleanup action plan and consent decree.
    - Appendix H includes case studies to demonstrate how to conduct the disproportionate cost analysis.
- Chapter 13 describes monitoring requirements and statistical methods for determining compliance with cleanup standards after construction. Long-term compliance monitoring is also discussed for cases in which the cleanup standards will not be met immediately after cleanup.
    - Appendix L includes detail on the statistics and simulations ran to develop the recommended approach for determining compliance.
- Chapter 14 describes the requirements associated with SRZs. An SRZ may be: a) included as part of the final remedy in the cleanup action plan and consent decree; or b) established as part of a reopener if compliance monitoring determines that recovery is slower than expected or unanticipated recontamination has occurred.
- Chapter 15 describes the federal, state, local, and tribal laws that may apply to sediment cleanup as well as the permits or approvals that may be required to conduct cleanup. This information will be used to support development of sediment cleanup standards, implementation of performance requirements, and necessary permits and approvals for cleanup construction. This information will be included in the cleanup action plan.
    - Appendix G includes a list of potential best management practices that may be applicable when conducting sediment cleanup.
- Chapter 16 includes best management practices for removal of creosote-treated pilings.
- Chapter 17 contains references.

## 1.3 Framework of the SMS Rule

The SMS rule was adopted in 1991 and revised in 1995 and 2013. The most recent revisions focused on Part V of the SMS rule, and include:

- Integrating the SMS and Model Toxics Control Act (MTCA), Chapter 173-340 WAC cleanup requirements where feasible.
- Clarifying requirements for protection of human health from sediment contamination.
- Clarifying requirements for protection of higher trophic level species from sediment contamination.
- Promulgating numeric chemical and biological standards for freshwater sediment to protect the benthic community.

The goal of the SMS is to reduce and ultimately eliminate adverse effects on biological resources and threats to human health from surface sediment contamination. The sediment cleanup decision process governs the cleanup of contaminated sediment sites, including how sites are identified, investigated, cleaned up, and monitored.

The Model Toxics Control Act, Chapter 70.105D RCW, authorizes Ecology to regulate environmental cleanups and is the implementing authority for Part V of the SMS. The SMS provides Ecology with a uniform set of procedures and requirements for managing contaminated sediment. The goals of the SMS may be achieved by coordinating activities to comply with other state and federal statutes, such as MTCA, the Water Pollution Control Act (WPCA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the State Environmental Policy Act (SEPA).

The SMS rule has six sections:

- Part I: General Information. Includes anti-degradation and administrative polices.
- Part II: Definitions. These definitions apply to Parts I–VI of the rule, unless a definition in Part V supersedes Part II definitions.
- Part III: Sediment Quality Standards. This section has numeric chemical and biological benthic criteria for marine sediment. In addition, there are narrative standards for the freshwater benthic community and protection of human health. The Sediment Quality Standards (SQS) correspond to the long-term goals for sediment quality in Washington State. Sediments that meet the SQS criteria are expected to have no adverse effects on the benthic community. The numeric chemical SQS criteria are based on the results of biological testing and may be revised as new data are developed regarding the toxicity of contaminants in sediment.

- Part IV: Sediment Source Control. This section includes a process for managing sources of sediment contamination. This portion of the rule includes:
    - Mechanisms for verifying that discharges (under the National Pollution Discharge Elimination System, or NPDES) with the potential to impact receiving sediment a) have received all known, available, and reasonable methods of prevention, control, and treatment prior to discharge; and b) have received the application of best management practices.
    - Monitoring procedures necessary for evaluating the potential for a discharge to impact receiving sediment.
    - Procedures for determining whether a source is eligible for a sediment impact zone, which would authorize the receiving sediment to exceed the SQS.
    - Methods for determining what restrictions (e.g., on size or level of contamination) would apply if such a sediment impact zone is authorized.
    - Managing dredged material disposal activities.
- Part V: Sediment Cleanup Standards. This part of the rule is adopted under MTCA only. The goal of the sediment cleanup decision process is to provide a framework for timely decisions and expeditious cleanup of contaminated sediment sites (Figure 1-1). This includes a decision process for:
    - Identifying contaminated sites (WAC 173-204-510 through 173-204-530).
    - Determining the appropriate regulatory authority for cleanup and compliance with other authorities (WAC 173-204-540 and 173-204-575).
    - Procedures for conducting a remedial investigation (RI) and feasibility study (FS) (WAC 173-204-550).
    - Procedures for selecting appropriate cleanup standards on a site-specific basis (WAC 173-204-560 through 173-204-564).
    - Procedures for selecting appropriate cleanup alternatives and compliance and monitoring requirements (WAC 173-204-570).
    - Establishing sediment recovery zones (WAC 173-204-590).
- Part VI: Sampling and Testing Plans and Recordkeeping. This part of the rule includes requirements for sampling plans, reporting, and records.

## 1.4 Updating this Guidance Document

SCUM is a living guidance document and is intended to be updated in odd years (e.g., 2017, 2019) when there are enough substantive changes to warrant an update. Revisions to this guidance will undergo a public process through the Sediment Management Annual Review Meeting (SMARM). SMARM is a joint meeting of the Dredged Material Management Program and the Washington State Department of Ecology's Sediment Management Standards (SMS) program, and is open to the public. Ecology will identify areas in SCUM that require updating and, depending on the type of updates, either update the public at SMARM or make proposed updates available for public review and comment through SMARM or other appropriate process. Members of the public may submit proposed changes for consideration to Ecology prior to SMARM, at SMARM, or during the public comment periods. Oral comments heard during the meeting and written comments received after the meeting will be considered before revisions to this document are finalized.

The most recent version of SCUM will be available online and revisions will be recorded in Appendix M as needed. Appendix M includes a record of when revisions were made, what sections were revised, and a brief summary of the topics addressed. If applicable, Appendix M will cross-reference to the specific SMARM issue paper in Appendix B that discusses the revisions in more detail.

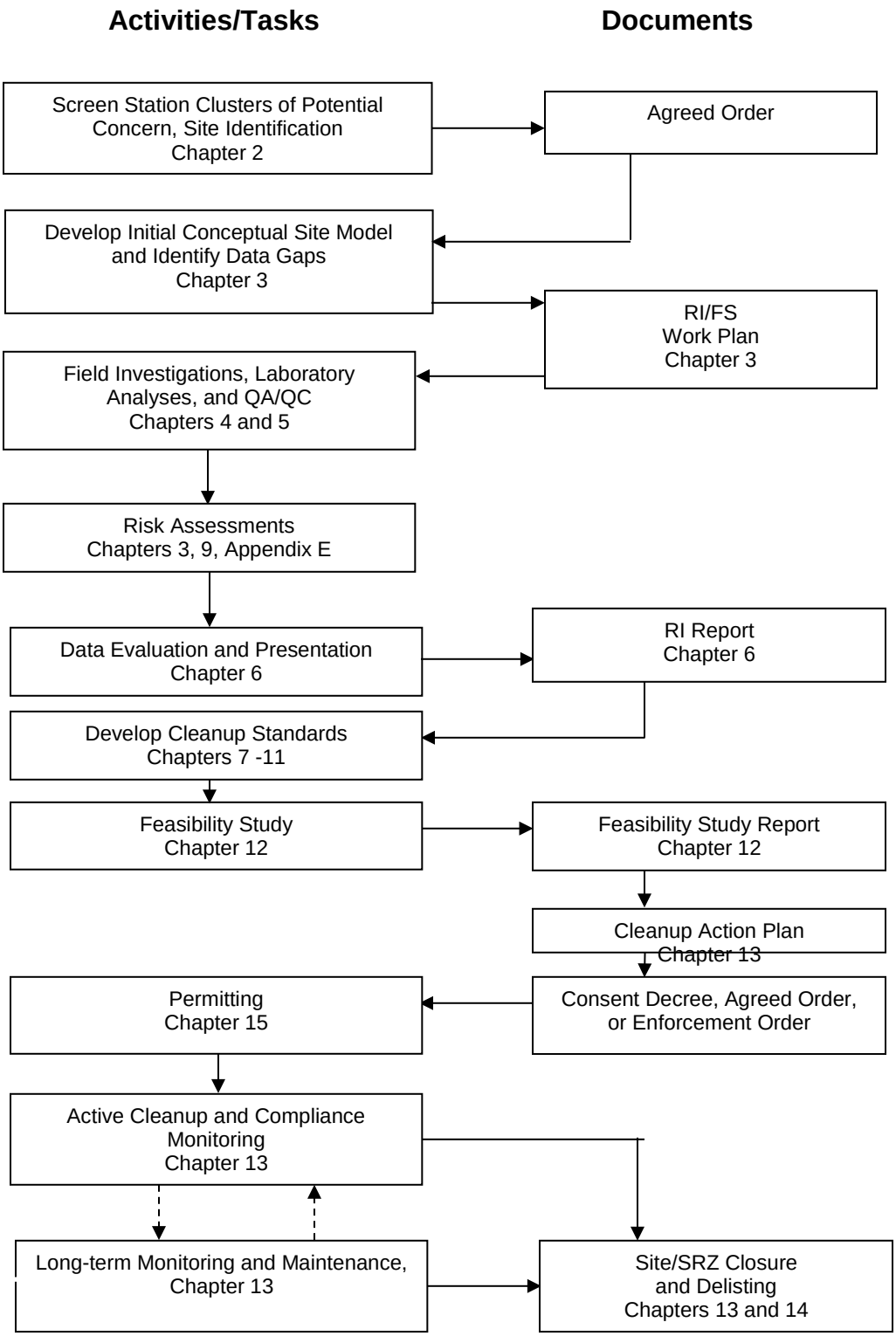



**Figure 1-1.** Sediment cleanup decision process.

# Chapter 2
# Station Clustering and Site Identification
# WAC 173-204-510 and 173-204-520

## 2.1 Introduction

This chapter presents methods for identifying station clusters of potential concern and sediment cleanup sites. "Stations" are typically GPS-mapped locations where sediments are sampled for analysis. "Station clusters" are defined as any number of stations that are determined by Ecology to be spatially related and chemically similar.

The process of identifying station clusters is conducted internally by Ecology, with identified PLPs having an opportunity to provide information and comment. Different types of sites are also discussed in this chapter, including sediment cleanup units and simple versus more complex sites, since the type of site may affect the content and complexity of the RI/FS process.

## 2.2 Identifying Sites & Station Clusters

A sediment cleanup site can be identified using a number of methods:

- Through the site identification process outlined in WAC 173-204-510 through 520, where sediment data is evaluated to identify station clusters of potential or low concern. Clusters of potential concern are further evaluated through a hazard assessment to confirm the presence of a cleanup site. This process is used for sediment-only sites that are not part of an upland site. Subsections 2.2.1 and 2.2.2 below describe this process.

- By identifying a sediment cleanup unit (see Section 2.3) as part of an upland cleanup site, if sediment contamination is confirmed.

- By identifying the sediment cleanup site as part of a development-related construction project, such as encountering contaminated sediment during construction of a new terminal or pier. In this case, it may not be necessary to formally identify the site if the contaminated sediments are appropriately addressed as part of the project.

Ecology determines clusters by evaluating data from a potential cleanup site. Station clusters may be adjacent to other station clusters with chemically dissimilar contamination and/or may represent highly contaminated areas within a surrounding but relatively low-concentration area (at or below natural or regional background).

According to WAC 173-204-510 through 520, station clusters of potential concern exceed the CSL, and station clusters of low concern exceed the SCO but are at or below the CSL. Station clusters at or below the SCO meet the long-term goal for sediment quality in Washington State and are not considered to be of concern.

The site identification procedures in this chapter assume that adequate data has been collected from an area where a known or suspected release of contaminants has occurred. If there has not been adequate sampling, or if an initial investigation with sparsely distributed sampling stations is not adequate to confirm the presence of contamination or biological effects, additional sampling may be required as part of the site identification process.

It is preferable to use data that are less than 10 years old when identifying station clusters. Older data may not be representative of current site conditions due to natural recovery processes or potential new or ongoing sources of contamination. This is particularly true when a) the source of contamination is known or suspected to be historical; b) the chemicals of concern degrade rapidly in the environment; or c) the area has a high sedimentation rate. Older data may be used at the discretion of Ecology. However, if such data are used to identify sediment cleanup sites, additional effort during the RI should be placed on collecting data that are more representative of current conditions.

The site identification procedures described in Sections 2.2.1 and 2.2.2 are complementary. Section 2.2.1 addresses toxicity to the benthic community, while Section 2.2.2 addresses bioaccumulative impacts to humans and upper trophic levels (e.g., fish, wildlife, and birds). Either or both procedures may be used to identify a site or a station cluster of potential concern.

In some cases, there may be sufficient evidence to identify a site for either benthic toxicity or bioaccumulative risks, but not both. In that case, the site would be identified based on the pathway with the best evidence, but both benthic toxicity and bioaccumulative risks would still need to be screened and further evaluated during the RI/FS process (see Chapter 3).

### 2.2.1 Identifying cleanup sites based on benthic criteria

This section describes the process to identify cleanup sites using the benthic criteria in WAC 173-204-562, WAC 173-204-563, and Chapter 8 in this guidance. Part V of the SMS provides a step-by-step process for identifying station clusters of potential concern (WAC 173-204-510) and hazard assessment and identification of cleanup sites (WAC 173-204-520). These are detailed below and in Figure 2-1.

The SMS rule has a two-tiered decision-making framework (chemical and biological criteria at the SCO and CSL) to protect the functions and integrity of the benthic community, and is used for the initial evaluation of station clusters and sites identification. The SCO includes chemical and biological criteria. Sediment values at or below the SCO are predicted to have no adverse

effects on the benthic community. Sediment values above the SCO but at or below the CSL are expected to have minor adverse effects on the benthic community.

Once Ecology has identified station clusters, those of potential concern are identified by screening with either the chemical or biological criteria as follows:

*Step 1.* Chemical Data. For each chemical, average the three stations with the highest chemical concentrations of that chemical. The three highest stations need not be adjacent as long as they are part of the same station cluster. If the average for any chemical exceeds the CSL, that station cluster is of potential concern. Repeat this step for all chemicals in the cluster that have benthic criteria (Chapter 8, Table 8-1).

*Step 2.* Bioassay Override (Optional). If a station cluster of potential concern is identified in Step 1, bioassay results may be used to confirm or override the chemistry results. Alternatively, chemical analysis and biological testing may be conducted concurrently and the bioassay results override the chemistry results.

*Step 3.* Biological Data**.** For stations that have bioassay results, if at least three stations exceed the CSL biological criteria, then the station cluster is of potential concern.

*Step 4.* Station Clusters of Low Concern**.** If Steps 1–3 do not result in identification of a station cluster of potential concern, the cluster is determined to have low or no concern for benthic toxicity. The cluster does not require further evaluation for benthic toxicity unless new information indicates an increase in chemical concentrations (WAC 173-204-510).

*Step 5.* Confirmation as a cleanup site. If a station cluster of potential concern is identified in Steps 1–3, evaluate it further using the hazard assessment procedures in WAC 173-204-520. This may include evaluating additional existing information (such as historic site uses, drainage patterns, potential sources, etc.) or gathering new data if existing data are insufficient (e.g., old or sparse). If new information is obtained, repeat Steps 1 - 3. The cluster of potential concern is confirmed to be a cleanup site if it still meets the criteria in Steps 1-3. Alternatively, Ecology may determine that the initial information used to identify the station cluster of potential concern is sufficient for site identification, particularly when the data are recent, representative, and sufficient in quantity and quality.

### 2.2.2 Identifying cleanup sites based on bioaccumulative criteria

This section describes the process to identify potential cleanup sites using the criteria for bioaccumulative effects in WAC 173-204-560, 173-204-561, and 173-204-564. Part V of the SMS provides a step-by-step process for identifying clusters of potential concern (WAC 173-204-510) and hazard assessment and identification of cleanup sites (WAC 173-204-520), detailed below.

Consistent with the benthic criteria, the SMS rule has a two-tiered decision-making framework (the SCO and CSL) to protect humans and upper trophic levels from bioaccumulative effects (Figure 2-2). The SCO is the long-term sediment quality goal. The CSL reflects slightly higher tolerance for human health risk and biological effects, and is used for identifying station clusters of potential concern and site identification.

*Step 1.* Identify a cluster of potential concern. A station cluster of potential concern can be identified when at least three stations exceed the CSL for the same chemical. This applies when the CSL has been established based on bioaccumulative chemicals. For example, if each of three stations in a cluster exceed regional background (see Chapter 7). The three stations that exceed CSLs need not be adjacent as long as they are part of the same station cluster (i.e., exhibit chemical similarity and are spatially related).

*Step 2.* Confirmation as a cleanup site. If a cluster of potential concern is identified, it may be defined as a cleanup site, or it may be defined as an area for potential further investigation, at the discretion of Ecology.

Because numeric bioaccumulative CSLs for sediment have not been promulgated by rule and are currently established on a site-specific basis, the process to address bioaccumulatives requires more discretion and site-specific evaluation than the benthic process described in Section 2.2.1. The CSL, if it is risk-based, generally won't be established at the time of station cluster screening and site identification. In those instances, the following considerations may be used to conduct station cluster screening and site identification for bioaccumulatives:

- Chemical signature. A clear pattern of chemical concentrations associated with a source or upland site and/or with other chemicals in the cluster indicates a likely bioaccumulative chemical of concern associated with that site or source. Information about potential sources or sites is needed to conduct this evaluation.

- The CSL based on background. At many sites, risk-based sediment concentrations of bioaccumulative chemicals are below background and/or PQLs. A list of the most commonly found chemicals where the risk based concentrations typically fall below background is found in Section 3.3.6. For these and other similar chemicals, conduct

screening by comparing the station to background concentrations. Use regional background if established, or natural background in areas where regional background has not yet been established. Use the PQL only if it has been determined that it is above regional background, or neither regional nor natural background has been established.

If at least three stations in a cluster exceed regional background or the PQL (whichever is higher) for the same bioaccumulative chemical, it may be designated a cluster of potential concern at Ecology's discretion (WAC 173-204-520(d)).

- Tissue Data. Tissue data will seldom be available at this early stage of the process, but it is possible that some may have been collected. If tissue data of sufficient quantity and quality and appropriate for the site is available, it may be possible to evaluate whether bioaccumulative chemicals are elevated in tissues at or near the site. It may also be possible to use paired sediment/tissue data (e.g., from laboratory bioaccumulation tests or the area) to determine if sediment chemical concentrations are bioavailable, or determine appropriate screening levels in sediment.

- Regional Studies. Information from adjacent sites, large-scale regional studies, or other relevant data may help establish whether bioaccumulative concentrations of chemicals in a cluster are of concern. Such information could include site-specific sediment cleanup levels calculated for similar or nearby sites; source or sediment transport modeling indicating depositional areas; natural recovery rates, etc.

Because very large areas could be identified by these initial screening processes, Ecology will use its discretion to determine whether a bioaccumulative station cluster of potential concern will be identified as a cleanup site. A weight of evidence approach detailed above will be used to identify cleanup sites based on bioaccumulative risks. Some station clusters of potential concern may simply be retained for further study and monitoring (case in point, if concentrations are close to background and natural recovery is occurring).

## 2.3 Regional Sites and Sediment Cleanup Units

In some areas of the state (e.g., urban bays) contamination from a variety of different sites and sources are co-mingled, potentially creating a very large site. These sites have widespread low level chemical concentrations (typically in the subtidal areas) as well as higher chemical concentration areas (typically in the nearshore), with a greater variety of contaminants near source areas or upland cleanup sites. In such areas, Ecology may establish a sediment cleanup unit within the site, which is associated with the individual facilities and contaminants at the cleanup site itself (WAC 173-204-500(4)(a)).

Sediment cleanup units within a larger site can be differentiated from adjacent sediment cleanup units and the surrounding area in the same manner that stations clusters of potential concern are identified. For example, sediment cleanup units can be determined based on chemical similarity among a group of adjacent stations, and consistency of that chemical signature with the conceptual site model and source of contamination. The outer boundary may be apparent based on a decline in chemical concentrations to natural or regional background, or a change in chemical signature to that of a surrounding area, or it may need to be further defined during the RI. Sediment cleanup units may be proposed by Ecology or by PLPs interested in cleaning up a focused area within a larger site to settle responsibilities for that unit. For more information on how to identify sediment cleanup units see Chapter 12 Section 12.3.

Sediment cleanup units may be remediated separately from other sediment cleanup units and from the more widespread lower-level contamination. Such an approach allows nearshore high-risk areas to be cleaned up and source control conducted, which is expected to significantly reduce risk and lower concentrations over time throughout the larger site. PLPs in these areas should work closely with Ecology to identify the sediment cleanup unit(s) for which they are responsible and contribute, if determined appropriate by Ecology, toward cleanup of the larger site through a settlement fund.

## 2.4 Complex and Simple Sites

Ecology recognizes that sediment sites vary greatly in their complexity and thus, in the types of studies and information needed to select a final cleanup remedy. This guidance provides alternative approaches throughout the cleanup process that depend on whether a site is simple or more complex. The conceptual site model described in Section 3.3 and included in the RI Work Plan should serve as the starting point for determining which RI tasks are needed and what data needs to be collected to support the FS and a cleanup decision for the site.

In some cases, an entire site may be simple and straight-forward. In other cases, certain aspects of the cleanup can be simplified while others may need more complex investigation and analysis. A simpler approach is not necessarily limited to smaller sites if the approach is appropriate to the circumstances, and it may be applied to sediment cleanup units as well as entire sites. Additional proposals may be considered at any point in the RI/FS process.

Ultimately, Ecology has the discretion to determine which aspects of the RI/FS can be simplified, with input from the PLPs and public comment at appropriate points in the process. In general, a site may be considered simple where (as a whole or in combination):

- There are a limited number of risk driver chemicals of concern and sources of contamination.
- Chemical distribution and exposure pathways are not complex.
- The physical and hydraulic features of the site are straightforward.

- The site is small or isolated.
- A permanent cleanup action alternative is implementable and the PLP is willing to perform the cleanup.

The simple versus complex site approaches presented throughout this guidance should be applied with the intent of streamlining the entire RI/FS process. The streamlining process may include any combination of the following factors:

- A limited number of risk driver chemicals of concern, sources of contamination, or pathways/receptors of concern.
- Co-location of contaminants and a clear chemical signature.
- Stability of sediment.
- Potential for successful source control.
- Trade-offs between the cost and timeliness of remediation vs. continuing further study.
- Limited number of feasible and/or cost effective remedies.

Simplified approaches are designed to save time and be more cost effective, while being just as or more protective than a complex investigation or decision process. Simplified approaches include:

- Conducting RI tasks that are clearly focused on filling specific data gaps identified by a conceptual site model that are required to make cleanup decisions.

- Applying simpler screening approaches based on background for bioaccumulative chemicals where risk-based concentrations are typically below background (avoids complex data collection, site-specific risk calculations, and back-calculation to sediment).

- Conducting in-depth risk assessments only when specifically required for larger and more complex sites with sensitive receptors.

- Establishing cleanup levels for indicator (risk driver) chemicals after an appropriate screening process.

- Reserving more complex site investigations (e.g., transport modeling, source modeling, and natural recovery evaluations) for sites where these processes are critical to decision-making.

- Limiting the number of FS alternatives considered for sites with limited options (e.g., dredging and construction projects).

- Streamlining and simplifying the FS alternatives evaluation and disproportionate cost analysis when the PLP is willing to implement an active and fully protective cleanup alternative.

Each time a simpler approach is available, PLPs may choose to conduct a more detailed evaluation on a site-specific basis. Site managers may also use their discretion to require a more detailed evaluation if it appears to be necessary for that site. For example, if the site is highly vulnerable to climate change impacts such as sea level rise (Ecology 2017a). These alternatives are intended to provide greater flexibility to achieve protective cleanups faster and more cost-effectively, without limiting the ability to conduct more detailed or focused evaluations.

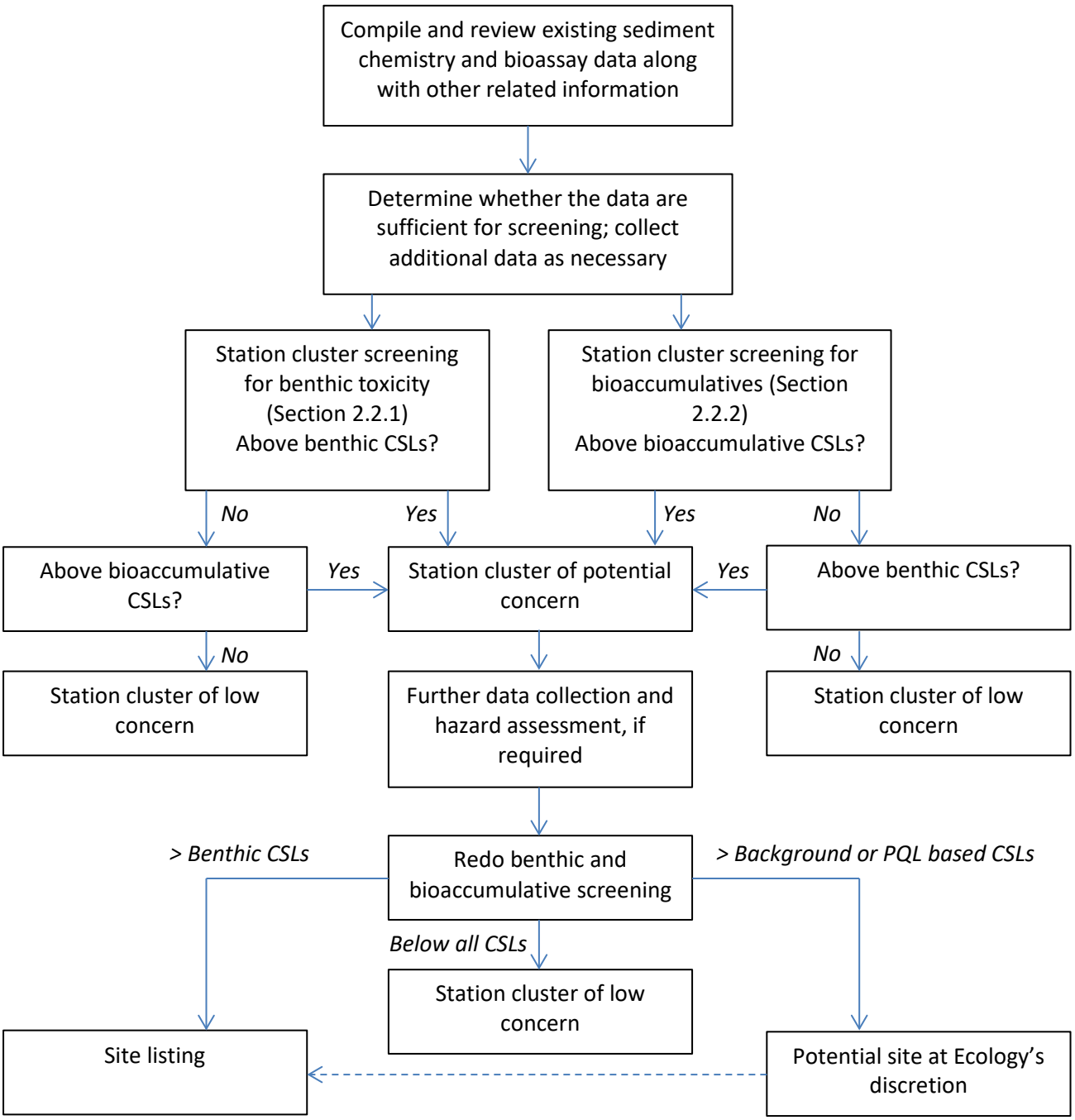



**Figure 2-1.** Process for identifying station clusters of potential concern and sediment cleanup sites.

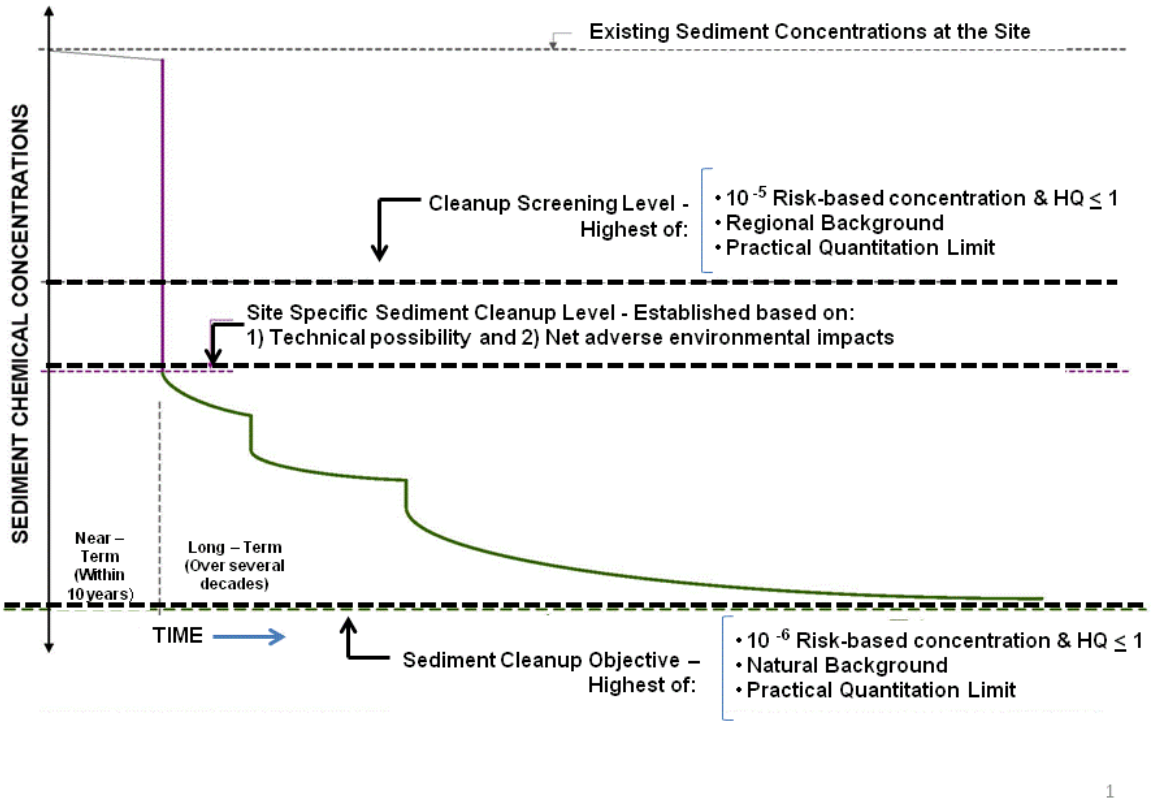



**Figure 2-2.** SMS framework for establishing the Sediment Cleanup Objective (SCO) and the Cleanup Screening Level (CSL), used to identify sediment cleanup sites, evaluate sediment cleanup sites, and establish sediment cleanup standards.

The risk-based concentration information shown is for human health, assuming those concentrations are lower than ecological risk. However, the risk-based concentration for a site would actually be the lowest of ecological or human health risk.

# Chapter 3
# Remedial Investigation/Feasibility Study Work Plan and Conceptual Site Model
# WAC 173-204-510 and 173-204-520

## 3.1 Objectives of Sampling

The SMS rule Part V, Sediment Cleanup Standards, sets forth a decision process for identifying contaminated sediment areas (WAC 173-204-510 through 173-204-520); conducting a remedial investigation (RI) (WAC 173-204-550, this chapter and Chapter 6) and a feasibility study (FS); and determining appropriate cleanup remedies (WAC 173-204-550 and 173-204-570, Chapter 12). The objectives of field sampling vary depending on which stage the site is in. Field sampling is typically conducted for the following purposes:

- Initial investigations of potential contaminated sites (Section 3.1.1).
- Remedial investigations of confirmed contaminated sites (Sections 3.1.2 and 3.2).
- Source control for NPDES permitted discharges (Appendix A).
- Dredged material management.

### 3.1.1 Initial investigations (WAC 173-204-510 and 173-204-520)

The primary objectives of sediment sampling and analyses during an initial investigation of a potential contaminated sediment site are to:

- Identify station clusters of potential concern.
- Identify and list sites based on exceedances of the CSL criteria.
- Gather initial information on sources, contaminants of concern, chemical concentrations, and extent of contamination.

Initial investigations may be carried out by PLPs, Ecology, or as part of aquatic lands lease transfers and renewals, or other property transfers (due diligence).

Such sampling and analyses must be sufficient to establish whether there are exceedances of the CSL criteria for site listing purposes (such as numeric chemical or biological benthic criteria,

background, etc.; see Chapter 2), but the spatial extent of such exceedances need not be defined as part of an initial investigation. Unless there are plans to dredge or otherwise disturb the sediment, sampling and analyses conducted as part of an initial investigation may focus on surface sediment.

### 3.1.2 Remedial investigations (WAC 173-204-550)

The primary goals of sediment sampling and analyses conducted during the RI for a contaminated sediment site are to: 1) collect, develop, and evaluate sufficient information to fully characterize the site; 2) establish sediment cleanup standards (Chapters 7 through 11); and 3) select a cleanup action (Chapter 12).

The scope of the RI depends on factors unique to the site that include: a) the nature and extent of contamination; b) the exposure pathways and areas of concern; c) the natural resources potentially at risk or impacted by the site; d) the characteristics of the site or sediment cleanup unit; e) and the cleanup action alternatives likely to be evaluated under WAC 173-204-570 through 173-204-575. The conceptual site model (CSM) is a tool to organize and summarize available information about a site and determine data gaps that need to be filled in order to establish cleanup standards and select cleanup action alternatives.

The specific objectives of sediment sampling and analyses conducted during a remedial investigation of a contaminated sediment site are to:

- Fill data gaps and refine the conceptual site model.
- Confirm sources of contaminants, releases, and fate and transport into the environment.
- Determine whether the sources of contamination have been controlled.
- Identify the nature and extent of contamination in surface sediment.
- Identify the nature and extent of contamination in subsurface sediment, to the extent necessary to protect receptors and plan cleanup action s.
- For bioaccumulative chemicals, determine the degree of contamination in tissues of fish and/or shellfish at the site (optional).
- Identify contaminants of potential concern (CoPCs) and confirm contaminants of concern (CoCs). The term *contaminants* in this context includes chemicals that are toxic (e.g., metals) or bioaccumulative (e.g., dioxins/furans) for humans or aquatic life, as well as other substances (e.g., wood waste) that may cause toxicity to the benthic community.

- Gather information on natural or regional background concentrations in sediment and/or tissue, if not already available.
- Determine site boundaries.
- Develop cleanup standards.
- Collect preliminary information needed for the design and selection of cleanup actions. This includes vulnerabilities the site may have to climate change impacts such as sea level rise or flooding (Ecology 2017a).

The scope of the RI should be tailored to the size and complexity of the site or sediment cleanup unit. The CSM can be used to determine which of the above objectives need to be completed for a particular site. For example, at a simple site (Chapter 2, Section 2.4) where a protective and permanent remedy could readily be implemented, the RI could be simplified. Sampling could focus on information needed for the specific remedy and for determining the site boundary (Chapter 12, Appendix H). At more complex sites, the RI could involve more extensive and phased sampling necessary to fill data gaps identified in the CSM (e.g., identify sources, assess multiple pathways, establish cleanup standards, select among cleanup action alternatives, etc.).

The contents of an RI/FS Work Plan, Sampling and Analysis Plan (SAP), and other associated plans to accomplish these objectives are described in Section 3.2. The CSM is described further in Section 3.3 and general study design considerations based on the CSM are described in Section 3.4.

## 3.2 Remedial Investigation/Feasibility Study Plans

Prior to an RI/FS, several plans are developed to guide the field investigations, analytical work, and decision-making for the site or sediment cleanup unit, including:

- The RI/FS Work Plan (Section 3.2.1).
- An SAP for each phase of sampling, including a quality assurance plan (Section 3.2.2).
- A health and safety plan for each phase of sampling (Section 3.2.3).
- The public participation plan (Section 3.2.4).

Each of these plans is described in detail below.

### 3.2.1 Remedial investigation and feasibility study work plan

Before beginning the RI/FS, a work plan must be approved by Ecology, generally in conjunction with the Agreed Order. The work plan includes the goals of the RI/FS, activities to be performed, how the data will be used, what types of conclusions will be reached, who will perform the tasks, how the tasks will be managed, and the schedule. Figure 3-1 provides an outline and checklist for the RI/FS Work Plan, which includes the following suggested sections:

- Introduction. The introduction should state the objectives of the investigation and include general site information such as the site name; name, address, and phone number of the project coordinator; and a legal description of the site.

- Site information. This should include a summary of available information for the site, such as site history, past and present sources of contamination at the site (including a list of owners and operators of sources). A map of existing site conditions should be included that shows the site location; surface and subsurface topography; surface and subsurface structures; utility lines (if known); navigational lanes; lease areas; and the locations of historical and ongoing sources of contaminants for the sediment.

- CSM and data gaps. A CSM should be developed based on existing information that summarizes sources; transport pathways; exposure pathways; human and ecological receptors); potential vulnerabilities to climate change (Ecology 2017a), CoPCs; and data gaps including where data quality and completeness could be improved (Section 3.3). This information forms the basis for the field investigations described later in the work plan and should be updated throughout the RI/FS.

- Field investigations and data collection. This section of the work plan should include a general overview of the field investigations and other data collection anticipated to be needed for the RI (site characterization) and FS (information necessary for selecting cleanup action alternatives). The rationale and goals of each activity should be identified and designed to fill specific data gaps. Details of sampling and analytical methods should be included in the SAP (Section 3.2.2).

- Data management and analysis. This section should describe how data collected during field investigations will be managed and analyzed. An overview of data analyses, validation, and quality assurance methods should be provided. This would include statistical techniques; methods for mapping and calculating areas and volumes of contaminated sediment; and a description of databases, computer programs, or models used to analyze or plot data. A short description of the types of analyses that will be performed and the products of each analysis should be presented to indicate what data gaps or RI goals the analysis would fulfill.

- Risk assessments. The requirements for addressing risks to human health and the environment are included in Chapters 8 and 9 and involve calculating risk-based concentrations. However, depending on the size and complexity of the site, Ecology may determine that a more in-depth risk assessment should be conducted (see Appendix E for further discussion of when this may be appropriate). If a more in-depth risk assessment is planned, this section should describe the techniques that will be used to assess human health and ecological risks. All equations, assumptions, and references for toxicity data should be provided (see Appendix E). This section should describe how the field investigations will support the risk assessment and identify any additional data gathering that will be needed. A risk assessment work plan can also be provided as an appendix to the RI/FS Work Plan.

- Development of proposed cleanup standards and site boundaries. This section should present the methods and sources of information that will be used to identify the SCO and CSL, and develop proposed cleanup standards (Chapters 7 through 11), and associated site boundaries (Chapter 6).

- Identification of sediment management areas (see Section 3.3.7 and Chapter 12, Section 12.3) which includes the horizontal and vertical boundaries where separate cleanup technologies would be proposed. Potential sediment management areas may be identified in the RI/FS Work Plan based on the preliminary CSM (Section 3.3.7), then updated once the RI is complete (Chapters 6 and 12).

- Identification and screening of available cleanup action technologies, and development of cleanup action alternatives for each sediment management area (Chapter 12).

- Evaluation of cleanup action alternatives for each sediment management area, including threshold criteria, evaluation criteria, and disproportionate cost analysis (Chapter 12).

- Identification of the reasonable restoration timeframe and whether an SRZ may be required. This section should describe the methods that will be used for this analysis, including any natural recovery, source control, or recontamination studies or modeling that will be conducted (Chapters 12 and 14).

- Selection of preferred alternatives and associated cleanup standards and points of compliance for each sediment management area, including any interim remedial action levels (Chapter 12).

- Project administration. This section should provide information on task management and quality control, including the roles of various agencies and oversight of contractors, subcontractors, and laboratories that will be used.

- Schedule. This section should include the schedule for activities described in the RI/FS Work Plan.

### 3.2.2 Sampling and analysis plan

Although the specific details of individual SAPs will vary, they should contain certain elements. Figure 3-2 provides a recommended checklist for SAPs. If the SAP is associated with an RI/FS Work Plan, it is not necessary to repeat information found in the work plan. A brief summary of the data gaps and associated field investigations will suffice. For Phase II SAPs, a more detailed introduction and summary may be needed. This could include a summary of pertinent aspects of the site, the updated CSM, the Phase I data results, and data gaps to be filled in Phase II.

The specific sampling and analysis tasks conducted will be based on the data gaps identified by the current CSM (whether a preliminary CSM or an updated one after rounds of sampling). The following key elements may be needed to complete the RI/FS, depending on the scope and complexity of the site:

- Surface sediment concentrations. Surface sediment sampling with sufficient sampling density should be included to adequately characterize the areal and vertical distribution and concentrations of contaminants, and to establish points of compliance where the SCO and CSL are met. Physical properties of sediment that affect toxicity and habitat quality, such as grain size and TOC, should be determined. This information can be used to accurately determine the area or volume of sediment that will require remediation. It can also identify potential risks to human health and the environment, assess source control effectiveness, and help select appropriate cleanup actions.

- Biological toxicity. Acute and chronic biological toxicity testing using bioassays and/or benthic community analysis may be performed to confirm any benthic chemical criteria exceedances. These tests can also assess the synergistic effects of multiple chemicals, the toxicity of chemicals without benthic criteria, and impacts from other contaminants such as wood waste.

- Tissue concentrations (optional). Concentrations of bioaccumulative chemicals in tissues of fish and/or shellfish from the site can be measured to assess risks to human health and higher trophic levels, and to develop site-specific biota-sediment accumulation factors for back-calculation of sediment cleanup levels. Alternatively, laboratory or field bioaccumulation tests can be used.

- Surface water or porewater contaminant concentrations. Contaminant concentrations in surface water or porewater may be measured at sites where it is suspected that contaminants in sediment or other sources (e.g., wood waste, dense creosoted pilings, contaminated groundwater, etc.) may result in exceedance of water quality standards (see

Section 3.4.3). Porewater evaluations may also be used in a weight-of-evidence approach to assess bioavailability of chemicals for risk assessment, assist in screening CoPCs, and to select an appropriate remedial design (Chapter 4). The need and appropriateness of porewater and surface water evaluations will be determined on a site-specific basis.

- Fate and transport and natural recovery considerations. If natural recovery or fate and transport modeling is used to evaluate source control or select cleanup action alternatives, then the following:

    - Sediment dating, sediment chronologies (evaluation of the time period in which contaminants may have been deposited, or significant events in the sediment column such as dredging), and dredge horizon evaluations

  can be used to assess:

    - Sediment accumulation; mixing; deposition rates; species distribution; susceptibility of CoPCs to degradation or transformation; grain size; and other particle characteristics such as shape, density, plasticity, type of carbon, etc.

- Source investigations. To determine the effectiveness of source control, sufficient information is needed about the sources of contaminants to sediment. This includes the location and chemical characteristics of any permitted and unpermitted discharges, as well as information on sediment quality impacts from these discharges, in order to evaluate the potential for recontamination. Any necessary source control actions and a potential timeframe to address sources should also be identified.

- These investigations should focus on sources under the PLP's regulatory authority or control that are associated with the site or sediment cleanup unit. Clearly identifiable sources that are not directly associated with the site, but could pose a recontamination problem, should be documented. However, a full characterization of these sources and identification of potential source control measures is not required.

- Sediment removal evaluations. Chemical concentrations and/or physical properties of sediment may be characterized using composite samples representative of those areas that may be dredged for cleanup. This data can inform options for dredged material disposal (e.g., open-water, confined aquatic disposal, or upland disposal). This characterization may be confined to areas that are targeted for removal. Characterization may not be needed in areas where sediment is expected to remain in place or be capped, unless cap integrity could be affected.

- Elutriate, column leaching, and column settling tests may also be performed on sediment targeted for removal. These tests provide information on the potential for water quality

exceedances during dredging and the design of confinement structures. These tests would typically be conducted during remedial design, once cleanup alternatives have been selected.

**The SAP should include the following basic elements:**

- An overview of the field sampling, including objectives, regulatory requirements, schedule, and summary of how the tasks relate to the CSM and data gaps (Section 3.3).
- Detailed descriptions of each sampling task including the type, number, location, depth, and date of samples to be collected, and which samples will be composited (Chapter 4).
- Sampling methods, including a description of:
    - Positioning methods
    - Sampling gear and operation
    - Criteria for sample acceptance
    - Compositing procedures
    - Sample containers and handling procedures
    - Observations, testing, or analyses that will be performed in the field (Chapter 4).
- Recordkeeping and reporting procedures (Chapter 5).
- Identification of key personnel and responsibilities.
- Parameters to be analyzed and biological tests to be performed (Section 3.3.6 and Chapter 4).
- Methods of chemical analyses and biological testing that will be used and the laboratories at which the analyses and testing will be performed (Chapter 5).
- Standard operating procedures and test protocols.
- A quality assurance plan (standard operating procedures and test methods that include this information can be appended to the SAP) containing descriptions of the following:
    - Quality assurance responsibilities
    - Quality assurance objectives
    - Chain of custody procedures
    - Instrument calibration techniques
    - Use of reference and standard materials
    - Use of spikes, blanks, replicates, and control samples

- Required quality assurance audits and reports, including frequency, preventive maintenance schedules, routine procedures used in data validation, and corrective actions.

**The SAP should include a brief description of the responsibilities of the sampling personnel including the project manager, field crew, and QA/QC coordinator:**

- Project manager. This person is responsible for overall management of the investigation and serves as the point of contact with Ecology.

- Field crew. For most sediment sampling, the field crew will generally consist of a chief scientist and one or more field technicians:

  - The chief scientist is responsible for overseeing all aspects of the field sampling; ensuring adherence to the SAP; ensuring accurate station locations; making decisions on deviations from the plan necessitated by field conditions; completing chain-of-custody forms; and keeping necessary records (e.g., field logs).

  - The field technicians are generally responsible for assisting with sample collection, handling, and storage. One member of the field crew should be the safety officer.

- QA/QC coordinator. This person is responsible for preparing the quality assurance project plan, interactions with the analytical laboratories, and data validation activities.

### 3.2.3 Health and safety plan

The health and safety of the sampling team is a primary concern during sampling operations. The process for addressing project safety should be organized, comprehensive, and well-documented. All SAPs must include a health and safety plan (HSP) as an appendix or attachment that covers all aspects of worker safety while employees are engaged in sediment sampling and analyses (see Figure 3-2). An HSP is also required for work in any other area known to be contaminated by toxic materials.

The HSP must meet the requirements of the Occupational Safety and Health Act of 1970 (29 U.S.C. Sec. 651 et seq.) and the Washington Industrial Safety and Health Act (Chapter 49.17 RCW). It should include the following, as applicable:

- Description of tasks to be performed.

- Key personnel and responsibilities.

- Chemical and physical hazards associated with the site (including chemicals used during the investigation):
    - Hazards associated with these substances
    - Physical hazards associated with shipboard and land-based sampling activities
    - Heat and cold stress
    - Locations of subsurface utilities and obstructions on the site
    - Falling hazards
    - Confined spaces.

- Individual job safety analysis to describe safety and health risks for each task and operation.

- Air monitoring plan (if necessary), including ambient air monitoring, personal monitoring, monitoring equipment, and use and calibration of monitoring equipment.

- Personal protective equipment that will be used for site tasks. Criteria for upgrading and downgrading protective equipment based on monitoring and changes in ambient chemical concentrations or other site hazards.

- Work zones, including control zone, decontamination zone, and exclusion zone, and the methods to demarcate these areas.

- Decontamination procedures for personnel, protective equipment, and sampling equipment.

- Procedures for disposal of contaminated media and equipment.

- Safe work practices, including operation of sampling equipment and general site safety.

- Standard operating procedures, including fit tests for respirators, if used.

- Contingency plan that includes:
    - Evacuation procedures and criteria
    - Emergency phone numbers (e.g., telephone number of the appropriate Coast Guard District Rescue Coordination Center and/or Harbor Master when operating on a vessel)
    - Addresses of hospitals
    - Maps showing routes to hospitals.

- Personnel training requirements, including health and safety training courses and site briefings.
- Medical surveillance programs.
- Record keeping procedures.

All members of a sampling team working at a hazardous site must have received an initial 40 hours of hazardous waste operations (HAZWOPER) training as prescribed by OSHA Regulation 29 CFR 1910.120, and also must complete an annual 8-hour refresher course. At least one member of the sampling crew must have received supervisory training. Employers must make a medical monitoring program available to all crew members who conduct sampling operations at hazardous sites. All sampling team members must read and understand the contents of the HSP prior to commencing field work, and verify such by signature on the original HSP document.

Special attention should be given to physical dangers such as slip, trip, and fall hazards when working around water. In general, it is recommended that the sample collector(s) avoid skin contact with all sediment and inhalation of odors. Special precautions may have to be taken when working with contaminated sediment, especially near potential or known contaminant sources such as unpermitted outfalls, NPDES permitted outfalls, or hazardous waste sites.

### 3.2.4 Public participation plan

The public participation plan is intended to provide coordinated and effective public involvement, and is frequently an appendix to the RI/FS Work Plan (see Figure 3-1). The public participation plan is described in WAC 173-204-550(5) and should include:

- Public notice and comment periods, the length of comment periods, and where public notices are located.
- Locations where information about the site will be available to the public, such as libraries and community centers.
- Methods that will be used to identify public concerns, such as public meetings, questionnaires, and interviews.
- Methods that will be used to provide information to the public.
- Public participation requirements of other federal, state, or local laws and how they will be addressed.
- Procedures for amending the public participation plan.

## 3.3 Conceptual Site Model

As part of the RI Work Plan, an initial CSM should be developed. This section describes the recommended contents of a CSM, which will vary depending on the complexity of the site. The goal of the CSM is to concisely summarize known information for: a) distributions of contaminants; b) sources; c) release mechanisms; d) migration routes; e) potential human and ecological receptors; and f) potential and complete exposure pathways for the site. The CSM ultimately guides the RI/FS, selection of cleanup standards, and selection and design of cleanup action alternatives.

An important function of a CSM is to identify a complete link between a *contaminant source*, *contaminant release*, *contaminant transport pathway to sediment*, *presence of the contaminant in sediment*, and *exposure of the contaminant (above established risk levels) to receptors*. There are two ways in which this exposure pathway may be incomplete:

1. There may be definitive data showing the absence of one or more elements of the pathway, e.g., contaminant source but no release; contaminant release but not present in sediment; presence of contaminant in sediment but not above established risk levels, etc., or

2. There may be a data gap for one or more elements of the pathway that needs to be filled during the RI.

If there is definitive information demonstrating an incomplete pathway, the RI/FS can focus on the remaining sources, CoCs, and/or areas of the site that present risks to receptors.

In the early stages, it is not unusual if most of the necessary information is incomplete. Therefore, the initial CSM prepared as part of the RI/FS Work Plan forms the basis for a "data gaps section" or separate report that provides the rationale for field investigations, laboratory testing, other forms of data gathering or modeling, and data analysis tasks. The CSM should be refined and updated iteratively as new information is gathered during the RI/FS, such as when any major phase of data collection is completed, or near the end of the RI Report (see Chapter 6).

A CSM should include the following information, to the extent it is known:

- Physical and habitat features at the site, including land and water uses.

- Sources of contaminants, historical and ongoing.

- Transport pathways and transformation/partitioning processes.

- Potential and currently exposed receptors (ecological and human populations) and exposure scenarios.
- Available data on distributions of contaminants and/or toxicity.
- Identification of contaminants of potential concern (CoPCs).
- Potential sediment cleanup units and/or sediment management areas.

An overview of the CSM may be presented as a graphic figure showing the interrelated elements of the site (e.g., Figure 3-3) or as a diagram or summary table with each of the above elements (Figure 3-4). A narrative discussing these elements and documenting sources of information should accompany any figures.

The following sections describe each element of the CSM, and how it can be used to focus and direct the RI.

### 3.3.1 Physical and habitat features

Descriptions of the site that may be relevant to RI/FS activities should be included, such as:

- Topography and bathymetry.
- Surface water features such as rivers, lakes, streams, and wetlands.
- Groundwater flow and discharge areas.
- The nature of the shoreline (natural, riprap, bulkhead, etc.).
- Large-scale influences, such as tides, currents, physical disturbances (vessel traffic, natural scouring and/or deposition, construction), natural sedimentation, etc.
- Climate, particularly aspects that could affect the movement of groundwater; surface water; sediment; sources of contaminants; or the success of restoration or cleanup action alternatives, including potential vulnerabilities to climate change such as sea level rise, flooding, wildfire, and landslide (Ecology 2017a).
- Habitat features, including:
    - Substrate (type of bottom sediment or other material on which the habitat is established, such as sand, cobble, rocks, pilings, etc.)

  - Riparian or aquatic plants
  - Shellfish beds
  - Spawning areas
  - Kelp or eelgrass beds
  - Other habitat that may be of special concern, such as restoration areas.

- Commercial, recreational, and subsistence fishery or shellfishery areas, including Usual & Accustomed fishing areas associated with the site, as well as any areas of the site managed by natural resource agencies or tribes (see also Section 3.3.4 for further discussion of receptors).

### 3.3.2 Sources of contaminants

Historical and current potential sources of contaminants should be identified, including:

- Chemicals used in current or historical processes at the site.

- Chemicals in fuels or hydraulic oils loaded, unloaded, or used at the site.

- Permitted and unpermitted discharges.

- Surface water runoff (overland or through surface water features at the site).

- Known spills.

- Accumulation of wood waste from log rafting or loading/unloading.

- Information about natural or regional background sediment concentrations in the area.

- Sources associated with overwater or nearshore operations, such as dry docks; fuel lines and vessel fueling stations; manifolds; hydraulically operated equipment; large areas of creosoted pilings and bulkheads; and vessel moorage, loading and unloading, and maintenance.

- Accumulation of waste materials such as sand blast grit and paint chips, fly ash, metal debris, pulp mill waste, fish processing waste, etc.

For the initial CSM, it may not be known whether chemicals used at the site were released to sediment, particularly for historical facilities. Unless existing data show they are not present in

sediment, chemicals associated with known operations at the site should be included in the CSM as CoPCs with data gaps.

### 3.3.3 Fate and transport

One of the primary purposes of the RI is to confirm complete transport pathways from sources to sediment, particularly when there is an adjacent upland contaminated site. This will be especially important when the area is a sediment cleanup unit that is part of a much larger sediment site.

When the site has sediment and upland components, the upland component is usually cleaned up (or at least its sources are controlled) before the sediment component. In this case, information should be summarized about historical and remaining sources and transport pathways to sediment from upland sources and releases (groundwater, surface water, permitted and unpermitted discharges, spills, bank erosion, etc.). Upland RI data should be used to determine whether the transport pathways are complete or controlled.

There may be other sources of contamination to sediment, not related to an upland site, such as discharges from outfalls, overland flow, and streams and rivers. If the sediment site has depositional areas, they may receive either cleaner or more contaminated sediment from other areas. Erosional or scoured areas may also transport contaminated sediment offsite. To the extent known, these processes should be described.

CoCs for sediment tend to be tightly bound to sediment and persistent in the environment. Therefore, some fate considerations such as partitioning into the water column, volatilization, and biotransformation are less likely to have a substantial impact on sediment chemical concentrations. However, in some cases, chemicals may be present that are soluble, volatile, etc. Examples of this might include metals, free-phase petroleum, or volatile organics moving through sediment from groundwater or wood waste that generates more soluble substances in sediment. At sites where such processes are important, the processes and CoCs should be described.

### 3.3.4 Receptors and exposure pathways

Typical receptors and exposure pathways at contaminated sediment sites include:

- Benthic community. Exposure of benthic species (species living in or on the sediment, including shellfish) through contact with, ingestion of, or filtration of contaminated sediment.

- Higher trophic level species.

  - Ingestion by species such as bottom-feeding fish of contaminated sediment, organic matter in sediment, and/or contaminated prey organisms such as benthic species.
  - Ingestion by pelagic fish, aquatic birds, and mammals of contaminated fish exposed to contaminated sediment or benthic prey.

- Humans.
  - Ingestion by humans of contaminated fish and shellfish exposed to contaminated sediment.
  - Direct contact with and incidental ingestion of sediment by humans during shoreline recreation, clam-digging, net-fishing, etc.

It is important to evaluate each potential exposure pathway at the site to determine if it is complete or incomplete. In some instances, an exposure pathway may not be complete and should not be carried forward into the RI. Direct contact with sediment may not be a complete exposure pathway, for example, if there is no appropriate habitat, or potential future habitat, for shoreline recreation or clam-digging. When considering both ecological risk and human health, areas of the site where each type of exposure may occur should be identified.

#### 3.3.4.1 Ecological receptors

Benthic organisms are expected to be present at all sediment sites. If there are benthic organisms present at the site that are of special concern for conservation (e.g., Olympia oysters) or considered sensitive, these should be identified. Otherwise, it can be assumed that the marine or freshwater benthic criteria will be protective of the benthic community as a whole.

Nearly every site will have some form of exposure to fish, as well as higher trophic levels. The degree to which ecological exposures are important, and the trophic levels that are most representative of the site, should be identified based on the quality, size, and types of habitat present at the site. Representative species of various trophic levels expected to be present at the site should be described, such as: bottom fish, pelagic fish, shorebirds, aquatic birds, higher trophic-level piscivorous birds (e.g., heron, eagle, osprey), and marine mammals. Any species expected to use the site that are ESA-listed or threatened should be noted (e.g., fish, marine mammals, and/or birds), along with the manner in which they are expected to use the site and any seasonal or habitat limitations on that use.

Ecological risks are generally assessed using standard screening assumptions (see Chapters 8 and 9). This portion of the CSM helps determine whether the benthic standards (Chapter 8) and higher trophic level screening process (Chapter 9) that are provided are sufficient, or whether any special assessments (field, laboratory, or literature-based) need to be conducted.

#### 3.3.4.2 Human receptors

For human health, a default Reasonable Maximum Exposure scenario (RME) is established in the SMS based on tribal fish and shellfish consumption. The default RME refers to the highest level of exposure that is reasonably expected to occur at a site under current and potential future site use (WAC 173-204-561(2)(b)). The RME scenario is intended to represent a high-end (but not worst case) estimate of individual exposures within a realistic range of exposures. The RME is defined as reasonable because it is a product of several factors that are an appropriate mix of average and upper-bound estimates. RME estimates typically fall between the 90$^{th}$ and 99.9$^{th}$ percentile of the exposure distribution (USEPA 2011). RME exposure parameters are presented and discussed in detail in Appendix E and in Appendix E: Table E-1 and Table E-4.

The SMS default tribal RME scenario should generally be used, but may be modified based on site-specific information (WAC 173-204-561(2)(b)(ii). For example, RME exposure parameters in this guidance may not be appropriate for sites involving small lakes and streams or wetlands, particularly if they support minimal food resources and/or access is limited. If modification of the default RME scenario is proposed, Ecology will work with the PLPs, tribes, and stakeholders to select an appropriate site-specific RME scenario. This site-specific process is available because a wide range of potential exposures (e.g., adult versus child) may exist that could result in significantly different risks. If the assumptions used to calculate screening levels and cleanup standards per the default RME scenario are not applicable to the site, they can be modified subject to Ecology's approval. Considerations that may be used to modify the default RME scenario are discussed and presented in Appendix E: Table E-2 and Table E-3. However, note that development and selection of exposure parameters can be a complex and lengthy process. Alternative, simpler processes for developing human health risk-based cleanup standards are available, as described in Chapter 9.

For the purposes of the CSM, identify each exposure pathway that is complete. Specify whether the default RME will be used for human health exposures. If a site-specific RME is proposed, provide justification for the site-specific RME based on the CSM. Describe the default exposure parameters for which adjustments are proposed.

### 3.3.5 Contaminant distributions and toxicity

Existing information should be summarized and mapped for contaminant distributions (such as types of chemicals, concentrations, and vertical distributions) that are found in nearshore soils, groundwater, intertidal sediment, subtidal sediment, and tissue, as well as biological toxicity test data. Historical dredging data may be useful in assessing the depth or distribution of contaminants.

Both chemical and biological test data should be compared to the applicable benthic criteria (Chapter 8, Table 8-1). If natural or regional background concentrations have been established for sediment and/or tissue in the area, it may be useful to compare the sediment and/or tissue data to these values to assist in identifying CoPCs and the extent of the site (See Chapter 10).

In most cases, the data will be insufficient at the RI Work Plan stage to identify site boundaries based on contaminant distributions, but at later stages of the process, this element of the CSM should be refined and updated with that end goal in mind.

## 3.3.6 Contaminants of potential concern

A screening evaluation should be conducted to identify CoPCs that should be investigated during the RI. At the RI Work Plan stage, identification of CoPCs is based on existing data and information (e.g., type of facility, sources, releases, pathways, and receptors). The process used to identify the CoPCs will vary depending on the amount, quality, recency, and representativeness of the sediment data for the site.

### 3.3.6.1 When there is limited or no sediment data

Preliminary CoPCs for a site may be based on analytical groups (e.g., semivolatiles, standard metals, butyltins, PCBs/pesticides, dioxins/furans) that are known or suspected to be:

- Used or manufactured in processes at the site with known or suspected releases.
- Present or elevated in sediment, surface soil, bank soil, or groundwater (especially near the shoreline). Chemicals identified in station cluster screening should also be included (Chapter 2, Section 2.2).
- Chemicals that may be elevated in sediment due to adjacent sites/sediment cleanup units or major sources.

When there is no or very little data for the sediment at a site, the CoPCs should err on the side of inclusiveness for the initial phase of sampling. All standard SMS benthic chemicals (Table 8-1) should be measured, along with any additional analytes associated with processes at the site. Table 4-1 (Chapter 4) lists chemical classes and some specific analytes associated with various types of industries that should be considered.

The RI data will be used to identify the final CoCs, and cleanup standards will be established for individual contaminants once all the data have been collected and evaluated. Alternatively, an initial investigation of sediment may first be conducted to identify CoPCs, among other objectives.

Bioaccumulative chemicals are of particular concern because of the low detection limits that may be required during the RI due to their low risk-based and background concentrations. As stated in WAC 173-204-564(2)(c)(iii), a chemical may have potential to bioaccumulate or biomagnify through the food chain when:

- The chemical is listed as a bioaccumulative contaminant on Ecology's PBT list in WAC 173-333-310; or

- The log of the chemical's octanol-water partitioning coefficient is greater than 3.5 (log $K_{ow} > 3.5$).

If WAC 173-204-564(2)(c)(iii) above is used to identify potential bioaccumulative chemicals, the following process is recommended to appropriately narrow the list. Bioaccumulative chemicals found with > 10% frequency in sediment and tissue in Washington State include:

- High molecular-weight polycyclic aromatic hydrocarbons (PAHs).
- Polychlorinated biphenyl (PCB) congeners.
- Dioxin/furan congeners.
- Dichlorodiphenyltrichloroethanes (DDTs),
- Other pesticides such as dieldrin, lindane, endosulfans, and methoxychlor.
- Chlorinated organics such as hexachorobenzene and pentachlorophenol.
- Metals that have organic forms such as arsenic, mercury, cadmium, and butyltins.

The above list is used by the DMMP agencies on a regional basis. It was developed based on a comprehensive analysis of bioaccumulative chemicals found in sediment and fish tissue in Washington State that are known to have effects on human health and wildlife (RSET 2009). As such, it can be used as a starting point for a comparison to chemicals used and found at the site. However, for sediment cleanup, it is important to conduct a site-specific evaluation based on the CSM. Several of the chemicals listed above may not be present at many sites or may have more regional use (e.g., pesticides, butyltins), and some sites may have used and released additional site-specific bioaccumulative chemicals not on this list. See Table 4-1 for guidance on the types of industries associated with these chemicals.

For some chemicals, particularly in urban areas, there may be regionally elevated concentrations from sources unrelated to or in addition to those at the site. Based on the sediment regional background studies conducted by Ecology (Chapter 10), the most widespread bioaccumulative chemicals above natural background are:

- Carcinogenic PAHs
- PCB congeners
- Dioxin/furan congeners.

Most sites will have sources of PAHs and historical sources of PCBs, and therefore these groups should be included among the CoPCs. However, although globally widespread, dioxins/furans are more closely associated with specific industries and products (see Table 4-1). Consideration of dioxins/furans should rely carefully on the CSM to determine whether to include these chemicals as CoPCs, since they are among the most expensive chemicals to analyze. Therefore, site managers should use their judgment in determining whether to place dioxins/furans on the CoPC list, based on activities at the site. A similar process should be used for other chemicals that are analyzed on a stand-alone basis, have specific process-related sources, and are expensive to analyze (such as butyltins).

#### 3.3.6.2 When extensive sediment data exists

When there is sufficient existing data (in quantity, quality, and recency), it may be possible to develop a more focused CoPC list. For bioaccumulative chemicals, historical data may have high detection limits that can be problematic for assessing risk and determining whether the chemical is present in sediment. The data should focus on known or suspected sources such as outfalls, groundwater discharge areas, dock operations, etc. Areas of the site and associated CoPCs may be screened separately if there are more data for some areas than others.

Since cleanup standards are not yet established for the site at this point in the process, the SCO may be used as a conservative screening level to identify CoPCs. After the RI is completed, the proposed cleanup standards will be identified in addition to the final CoC list.

***Screening chemicals using benthic criteria***

Existing data should be compared to the appropriate freshwater or marine benthic criteria (Chapter 8, Table 8-1). If the chemical concentrations are below the SCO, then the chemical is not a CoPC for benthic toxicity. If it is a bioaccumulative chemical, it may need further evaluation. If biological toxicity test data exists, the results should be compared to the SCO. If there are exceedances, but no chemistry SCO exceedances, confirmatory biological toxicity testing should be included in the RI. Use of porewater chemistry to screen out chemicals as CoPCs is not appropriate.

***Screening bioaccumulative chemicals***

Include any bioaccumulative chemicals clearly associated with potential source areas. For example, place a chemical on the list if there is a decreasing gradient away from sources or a chemical signature different from other areas, particularly when a) the facility is known to have handled and/or released that chemical; and/or b) that chemical is known to have an elevated regional background.

At this early point in the process, sediment risk-based cleanup levels have not yet been established, because site-specific BSAFs and fish consumption rates (FCRs) have not yet been

determined. However, risk-based cleanup levels for bioaccumulative chemicals will frequently fall below background. In areas where sediment regional background has been established, bioaccumulative chemicals may be screened by comparing existing sediment concentrations to regional background concentrations, if the site manager deems it unlikely that cleanup levels will be established below regional background. If regional background does not exist, sediment natural background should be used. Use of porewater chemistry to screen is not appropriate.

Because bioaccumulative exposures occur on an area-wide basis, sediment concentrations should be averaged on an area-weighted basis for comparison to the natural background or regional background value (see Chapter 13, Section 13.6.1, Option B for procedures). Outliers and elevated values must be included. Sufficient detected data must be available to calculate a mean (see Chapter 6, Section 6.3.4 for appropriate methods). Alternatively, if the PQL is sufficiently low but there is a high proportion of non-detects, an alternative comparison approach may be used (such as point-by-point, Chapter 13, Section 13.6.1, Option A). Otherwise, the site manager may determine that the mean is likely below the background concentration and screen the contaminant out.

It can be difficult at this early point in the process to conduct area-weighted averaging of chemical concentrations in sediment, because the extent of the site is not known, existing data may be unrepresentative of the majority of the site, and much of the historical data may have inappropriately high PQLs or detection limits. Where this is the case, it may instead be appropriate to base initial selection of CoPCs on the more general site-specific factors described above (Section 3.3.6.1) and screen the chemicals further once more representative data have been collected.

If the area is a sediment cleanup unit within a larger site, or is near a similar site where risk-based concentrations have been established for sediment using appropriate methods (e.g., risk equations, exposure assumptions, and BSAF calculations consistent with the SMS), then these risk-based concentrations may be used for screening at the site manager's discretion.

***Screening using indicator chemicals***

If sufficient data exist to determine spatial patterns and relative concentrations in site sediment, indicator chemicals may be selected as CoCs for smaller or less complex sites in order to focus the RI/FS. Indicator chemicals should include:

- Chemicals expected to have the greatest human health and ecological risks.
- Chemicals with the largest footprint, where it is expected that addressing these chemicals will result in cleanup of chemicals that are less frequently detected, lower in concentration, or have a smaller footprint.

- Chemicals representative of each major analytical group (Section 3.3.6.1) associated with the site, particularly if there are multiple sources that may have different vertical or horizontal distributions in sediment. However, chemicals that collectively contribute to a TEQ for comparison to risk-based cleanup standards must be analyzed as a complete group (e.g., carcinogenic PAHs or dioxin/furan congeners).

- Where dioxins/furans congeners and/or dioxin-like PCB congeners are contributing to a dioxin-like TEQ, Ecology may approve combining the natural background TEQ for dioxins/furans and dioxin-like PCBs as the screening value. For example, the Puget Sound natural background TEQ for dioxin/furans is 4 ppt (rounded up from 3.6 ppt TEQ per Chapter 6 Section 6.3.5) and the dioxin-like PCBs TEQ is 0.2 ppt. The combined TEQ would be rounded to 4 ppt. Then, if the dioxins/furans TEQ or combined TEQ add up to less than or equal to 4 ppt TEQ they could be screened out as CoCs for dioxin-like carcinogenic effects. In addition, when these TEQs are combined to screen CoCs, the benthic SCO (Chapter 8, Table 8-1) for Total PCB Aroclors must be met on a station by station basis to screen out Total PCB Aroclors as they are considered a different CoC.

This approach using indicator chemicals is not recommended if the site has been insufficiently characterized or is expected to be large and complex. In such a case, indicator chemicals could be selected after the first phase of data collection, or after the RI is complete, in order to focus the FS.

#### 3.3.6.3 Use of tissue data

Tissue chemistry may be used in a weight-of-evidence approach to screen CoPCs (WAC 173-204-500(4)(d); 173-204-560(7)(b)). For example by comparing to risk-based concentrations in tissue and/or background concentrations in tissue. Tissue concentrations provide an indication of whether bioaccumulative chemicals are entering the food chain at concentrations that present unacceptable risks to humans and higher trophic levels, and they are a more direct estimate of exposure than sediment data. However, because there are multiple sources of chemicals to tissue (sediment, prey, and water-borne sources) and because organisms may range widely beyond the site, this process should only be used to screen out CoPCs rather than screening them in. As noted above, site information and sediment data (if any) should be considered along with tissue data in a weight-of-evidence approach for CoPC screening purposes.

Tissue data used for this comparison should be representative of the site and consistent with the sampling and analysis guidance outlined in Section 3.4.2 and Chapter 4, Section 4.2.5. Chemicals in tissue collected from the site may be compared to natural background concentrations in tissues, if available (see Chapter 13 for information on tissue monitoring). Alternatively, tissue screening levels for human health risk may be calculated using the default equations, exposure scenarios, and exposure parameter values found in Chapter 9, Section 9.2.

### 3.3.7 Potential sediment management areas

Based on all of the above sources of information, the CSM can be used to identify potential sediment management areas (SMAs) within the site or sediment cleanup unit. Sediment management areas are described in Chapter 12, and represent areas within a site or sediment cleanup unit in which different cleanup action s may be taken. SMAs may differ by:

- The types or concentrations of chemicals.
- The depth of contamination.
- Habitats.
- Exposed receptors.
- Aquatic land uses (e.g., navigation lanes).
- Obstructions or structures (docks, pilings).
- Other reasons to be sampled or handled differently in the RI/FS (see Section 12.3 for further description of SMAs).

If preliminary SMAs are needed for a study design, they should be identified in the initial CSM. If smaller or simpler sites do not need them, however, this step is not required. SMAs can also be proposed at the end of the RI or beginning of the FS, after site data have been collected and the CSM has been updated.

### 3.3.8 Summary and identification of data gaps

Key aspects of the CSM should be identified in a summary, followed by a list of the data gaps that need to be filled in each of the above areas. All data gaps should include a statement or question describing the general information that is needed. For example:

- What is the distribution of PCB congeners at the site?
- What is the rate of natural sedimentation in the area?
- Is there an area of contamination near the historic location of the process discharge outfall?
- What is the site-specific BSAF for carcinogenic PAHs?
- What are natural/regional background concentrations for the area?

Include any data gaps that do not require field work, but may require other information gathering, data analysis, or discussion and decision-making during the RI, such as:

- Who owns/operates the outfall observed during the site visit and what types of discharges does it have?

- What is the chemical signature of the PAHs found in sediment at the site (forensic analysis)?
- What fish consumption rate should be used to establish risk-based standards?

In addition, each data gap should fulfill an SMS requirement for the RI/FS, such as identifying CoCs, establishing site boundaries, establishing cleanup standards, evaluating cleanup action alternatives, etc. It may be useful to organize the data gaps in this manner.

The RI tasks should be designed to fill identified data gaps or answer a clear question or purpose. It may be useful to number or letter the data gaps to make this association clear. If a data gap remains unfilled, an explanation should be provided of why it is less important, or how it will be addressed in a later phase (e.g., remedial design).

## 3.4 Study Design Considerations

The following sections include some general study design considerations to fill the data gaps identified as part of the RI/FS Work Plan. Detailed descriptions of field sampling methods and analytical and testing procedures are provided in Chapters 4 and 5. The sections below are organized according to the major objectives of the RI/FS.

### 3.4.1. Benthic community

Because sampling design for sediment has been based on protection of the benthic community since the initial promulgation of the SMS, sampling procedures for this purpose are generally well understood and standardized (see Chapter 4). Concentrations in sediment or biological effects in samples are compared to the numeric chemical and biological benthic standards on a point-by-point basis, and therefore, delineation of site boundaries is relatively straightforward.

Since bioaccumulative risk-based endpoints are now an integral part of site investigations, consideration should be given to designing sediment investigations that simultaneously address both benthic community and bioaccumulative effects, to the extent possible:

- Sediment samples should not be horizontally composited prior to analysis, as this loses information needed for comparison to benthic criteria and may mask concentration gradients and elevated areas. Instead, collect and analyze sediment samples individually, then average the results appropriately for bioaccumulative endpoints (see Section 3.4.2).

- For subtidal sediment samples, the exposure depth is the same for benthic and bioaccumulative endpoints, as it is assumed that fish are eating the benthic community and that both sets of receptors are exposed to chemicals over the biologically active zone

for benthic organisms. Therefore, the same set of data can be used for both benthic and upper trophic level/human health evaluations.

- For intertidal samples, there may be a need to assess depth of the biologically active zone (BAZ) and harvestable resources to ensure protection of the environment and human health. Exposure scenarios for human health typically assume activities such as beach play and clam digging that may involve exposure to sediment at least as deep as targeted shellfish species are found. Depending on the activities, depth of exposure may exceed the BAZ.

Additional considerations for benthic sampling include the following:

- Not all benthic organisms have the same biologically active zone. A biologically active zone for typical subtidal, soft-bottom sediment (10 cm) has been established for Puget Sound that is protective of most benthic organisms. Important resources at the site may be identified for the CSM that require protection and live in a different (typically deeper) biologically active zone. That particular depth should be sampled for evaluation of risk to that organism (e.g., geoduck, burrowing shrimp, horse clam, etc.).

- Freshwater areas vary dramatically in their biologically active zones, by location and type of freshwater environment, as well as by species. For freshwater sites, a site-specific decision will need to be made regarding the representative benthic organisms to be protected and the associated biologically active zones to be sampled.

- In very rocky freshwater environments (e.g., rushing streams), fine-grained sediment may need to be sieved or depositional areas located for sampling.

### 3.4.2. Bioaccumulative chemicals

Sampling design for bioaccumulative chemicals and their associated receptors (humans and upper trophic level ecological receptors) should be based on the following considerations:

- Exposure areas for each specific receptor population should be determined within those designated areas. Samples of target prey organisms (or sediment, for direct exposure pathways) should be collected within those areas. Appropriate indicator species and RME scenarios for humans should be used to limit the number of different exposure areas.

- When determining site-specific relationships between tissue and sediment concentrations, field collection of tissue samples or bioaccumulation tests are preferred over literature-derived BSAFs or modeling (see Chapter 9 for more information on BSAFs).

- Species should be selected, to the extent possible, a) to be representative of feeding guilds at the site; b) have fidelity to the site; c) be in close contact with sediment; and d) whose overall population will not be harmed by collection of the samples.

- The portion of the prey organism analyzed should be consistent with that actually consumed (e.g., whole organisms by ecological receptors, portions of fish/shellfish eaten by human consumers).

- Individual prey organisms collected within an exposure area should be composited for data analysis. The compositing strategy must be representative of the area and provide the minimum number of individuals or tissue volume recommended for a specific analysis. Sessile and motile animals represent very different types of exposures and should be selected with care to appropriately characterize exposure pathways.

- For direct contact pathways, sediment can also be composited over the exposure area and depth. However, as above, it may be ideal to retain spatial information for other objectives of the RI/FS, while averaging the resulting analytical data over the area and depth to characterize exposure.

### 3.4.3. Water quality impacts

In addition to the SMS, water quality criteria (WAC 173-201A-240) are applicable to protect surface water quality that may be impacted by contaminated sediment. While most remediated sediment sites are not likely to result in exceedance of water quality standards, the potential for such exceedances should be assessed when developing the CSM. Where marine and freshwater intersect, in general the most conservative sediment and water quality standards apply. The following provides general guidance on the types of sediment sites that may exhibit water quality issues and study design considerations for these sites.

Water quality impacts may be observed at the following types of sediment sites:

- <u>Sites with insufficiently controlled sources</u>. This includes contaminated groundwater, upland site runoff, and discharges from outfalls. The incomplete remediation of upland sites and insufficiently controlled discharges are the most common source of water quality issues at sediment sites. In most cases, it is desirable to sequence cleanup of upland areas and source control prior to sediment cleanup. However, long-term cleanup action alternatives may be selected for sources such as contaminated groundwater. In this case, intertidal or subtidal sediment should be evaluated at the point of groundwater discharge as part of the cleanup action alternative and long-term monitoring.

  Similarly, some discharges, such as NPDES-permitted municipal CSOs or stormwater discharges, have long-term source control plans. These NPDES permits are administered

through Ecology's Water Quality Program and may need to be conditioned if they are causing impacts to sediment. Unpermitted outfalls should be identified and removed or controlled, if possible, prior to sediment cleanup.

- Sites with free-phase petroleum. When sediment is disturbed through natural processes, by waterfront activities, or during sampling or cleanup, free-phase petroleum can result. This can occur in sediment or upland sites (such as bank soils or groundwater) and appear as sheens and releases of petroleum products or constituents (PAHs, VOCs, etc.) to the water column. Even when upland cleanup has been conducted, pools of residual petroleum products can remain in sediment, especially in heavier products such as creosote. If free-phase petroleum is encountered in sediment, the source of the petroleum and any transport pathways should be identified to ensure the source has been adequately remediated or controlled.

- Sites with organic wastes. These can include wood wastes, pulp mill wastes, food processing wastes, etc. Organic wastes can break down into soluble, toxic compounds such as phenols, methylphenols, and tannins, depending on the source. Biodegradation of organic wastes can depress dissolved oxygen in sediment and overlying surface water, and release degradation products such as sulfides, ammonia, and methane to the water column. Generally, the finer the material, the more severe the water quality impacts (e.g., pulp mill waste or sawdust versus solid wood debris).

- Sites with sensitive biota. Certain sites may have aquatic biota that may be particularly sensitive to chemicals in porewater or surface sediment (e.g., eggs or larvae of spawning fish that may be exposed to photo activated PAHs in the intertidal zone). If the CSM has identified sensitive aquatic biota, a literature review or site-specific field study may be needed to assess such exposures.

- Sites with large numbers of creosoted pilings or other treated structures. While technically not a sediment cleanup issue, creosoted structures are known to leach significant amounts of PAHs into the water. Permits for construction and/or cleanup may require removal of creosoted structures and replacement (if needed) with more environmentally benign alternatives. Removal of creosoted structures is also a frequent habitat restoration activity and may be conducted in conjunction with site cleanup due to the need to remove structures for access to contaminated sediment.

- Waterbodies with natural or anthropogenic impairments unrelated to contaminated sediment (e.g., low dissolved oxygen, high temperatures). This is generally not considered a cleanup issue and is addressed under state water quality laws. However, it can impact conditions at the site and should be taken into account in the CSM.

- Sites with high potential for sediment redistribution. Many sediment sites are located in working waterfronts with frequent in-water activities. Ship and vessel traffic, such as ferries and barges, can disturb sediment and redistribute chemicals into the water column. This potential should be assessed during remedial design to ensure that the cleanup action alternative is protective and permanent.

During development of the CSM, identify whether any of the above conditions exist and determine an appropriate response in the RI/FS. These responses may include any of the following:

- Sequence activities at the site (e.g., upland cleanup, source control) to eliminate as many of these concerns as possible—ideally before sediment site characterization, but at least before cleanup.

- Identify any receptors (in sediment or water) that may be impacted by remaining conditions in sediment and ensure that these impacts are appropriately characterized. Some of these potential impacts may be characterized using traditional sediment sampling and testing protocols, which are modified to address water quality issues (e.g., not purging bioassay tests). Others may require specific sampling tasks, such as sampling porewater or using a passive sampler in sediment or near the sediment-water interface (Chapter 4, Section 4.2.4 and 4.5.4).

- Conditions that are unrelated to the site and cannot be controlled, such as ongoing sources or natural impairments, should be evaluated only to the extent that they substantially impact conditions at the site (and hence the CSM) or may impact cleanup alternatives. This evaluation can be limited to obvious concerns (i.e., waterbody impairments that limit the benthic community, or ongoing sources that may cause substantial recontamination).

- Sites with extensive contamination by petroleum products or organic wastes pose particular challenges, both during the RI and during cleanup. Special consideration should be given to health and safety of sampling and cleanup personnel; water quality impacts during sampling and cleanup; decontamination procedures; and added cost and practical challenges during cleanup. In some cases, comprehensive cleanup of such sites has proven difficult and extensive wood waste or petroleum-contaminated sediment remain in place underneath caps. In these cases, monitoring plans should be designed to ensure that water quality is protected in addition to sediment quality.

- Some of these impacts may be addressed through a preference for removal of wastes from waters of the state, to the extent feasible, or through removal of treated wood structures during site remediation or habitat restoration.

### 3.4.4. Feasibility study and remedial design

In addition to the goals of the RI, some sampling and data collection activities may be useful to support evaluation, selection, and design of cleanup actions (Chapter 12). Deciding when to conduct these field activities depends on when the information will be needed. If it will be important for evaluation and selection of cleanup action alternatives, the information should be collected at some point during the RI. If it is not needed to select the cleanup action alternative, but only for design or permitting, it can be carried out during the remedial design phase. Following are some activities that could be taken into account, depending on the size and complexity of the site and the cleanup action alternatives likely to be considered:

- High-resolution bathymetry is important to accurately determine the area and volume of sediment for capping, dredging, and remedial design. Bathymetry can also be important for habitat evaluation and restoration, determining human health exposure areas for intertidal sediment, and permitting. In areas that may experience seasonal or annual scour or deposition, it will be important to time these activities appropriately and possibly update bathymetry just prior to remedial design.

- Side-scan sonar or similar technology, typically used concurrent with high resolution bathymetry, is useful at many sites to identify debris or obstructions buried in or on top of sediment that may impede dredging, and to identify the locations of waste materials.

- Mapping of creosoted pilings; overwater structures; riprap; bulkheads; outfalls; shoreline and underwater utilities; and areas of significant underwater debris (e.g., logs or cables) is important to evaluate the feasibility of alternatives such as capping or dredging, and to evaluate the need to temporarily or permanently remove structures prior to cleanup. All of these features at a site affect the feasibility and cost of cleanup alternatives, and should be characterized prior to the FS.

- Mapping of sensitive habitat at the site, if any, is critical to evaluating the net adverse environmental impact of cleaning up these areas, as they may experience more severe impacts from dredging or capping.

- Vertical characterization of chemicals or wastes in sediment, typically done for areas with substantial waste deposits (e.g., wood waste) or when dredging is being considered, is important to determine the depth of contamination and evaluate alternative dredging scenarios. Analysis of the “Z-layer” (the layer of sediment that will then be exposed at the surface) is also recommended.

- Evaluation of the engineering properties of fill material to ensure the appropriateness of sediment and/or waste material as fill for construction projects or similar purposes may be necessary.

- Treatability or pilot studies may be needed to evaluate *in situ* sediment treatment alternatives such as use of activated carbon.

- Elutriate testing may be required in cases where sediment might be disturbed during cleanup actions, to determine whether suspended sediment may result in temporary water quality exceedances.

- Testing for disposal purposes may be necessary if sediment will be dredged and disposed, depending on the intended disposal location. Generally, this type of testing involves vertical and horizontal compositing and comparison to either in-water or upland disposal criteria.

- Assessing vulnerabilities to climate change (e.g. sea level rise, flooding, wildfire, and landslide) will be necessary to inform data collection and feasible remedial technologies and alternatives. For detailed guidance on addressing climate change vulnerabilities see Ecology 2017a.

**Figure 3-1.** RI/FS Work Plan outline and checklist

1. **Introduction**
   - ☐ Objectives of the remedial investigation/feasibility study
   - ☐ Regulatory framework
   - ☐ General site information
   - ☐ Legal description of the site
   - ☐ Document organization
2. **Site Information**
   - ☐ Site history
   - ☐ Summary of previous investigations, if any
   - ☐ Map of site in relation to surrounding area
   - ☐ Map of existing site conditions and features
3. **Conceptual Site Model and Data Gaps (see Section 3.3)**
   - ☐ Physical habitat features of the site (see Section 3.3.1)
   - ☐ Physical characteristics include physiography, meteorology, and hydrogeology
   - ☐ Past and present sources of contamination (see Section 3.3.2)
   - ☐ Known fate and transport pathways of contaminants (see Section 3.3.3)
   - ☐ Potentially exposed receptors and exposure scenarios for ecological and human populations (see Section 3.3.4)
   - ☐ Summary of available data on distribution of contaminants or toxicity (see Section 3.3.5)
   - ☐ Identification of contaminants of concern (see Section 3.3.6)
   - ☐ Delineation of potential sediment cleanup units or sediment management areas, if possible (see Section 3.3.7)
   - ☐ Identification of data gaps (see Section 3.3.8)
     - ☐ Information necessary to fill in missing pieces of the CSM to complete the remedial investigation
     - ☐ Information necessary to evaluate cleanup action alternatives as part of the feasibility study
4. **Field Investigations and Data Collection**
   - ☐ Overview of proposed field studies to fill data gaps (see Section 3.2.2 and Figure 3-2)
5. **Data Management and Evaluation**
   - ☐ Overview of data validation and quality assurance/quality control procedures
   - ☐ Data management and submittal to Ecology
   - ☐ Statistical methods used to evaluate the data
   - ☐ Data evaluation, graphing, mapping, and presentation methods
6. **Risk Assessment (Optional)**
   - ☐ Identification of receptors and exposure routes to be evaluated
   - ☐ Description of methods, equations, assumptions, and references

**Figure 3-1.** RI/FS Work Plan outline and checklist (continued)

- ☐ Methods used to present risks and identify CoCs

**7. Development of Proposed Cleanup Standards and Site Boundaries**

- ☐ Methods that will be used to develop proposed cleanup standards
- ☐ Methods used to establish site boundaries based on proposed cleanup standards

**8. Identification of Potential Sediment Management Areas**

- ☐ Preliminary evaluation of potential sediment management areas

**9. Evaluation of Remedies (see Chapter 12)**

- ☐ Identification and screening of available cleanup action technologies
- ☐ Identification and evaluation of cleanup action alternatives for each sediment management area
- ☐ Identification of a reasonable restoration timeframe (see Chapters 12 and 14)
- ☐ Selection of preferred alternatives and associated cleanup levels/points of compliance for each sediment management area

**10. Project Administration**

- ☐ Information on task management including roles of all involved parties (relevant agencies, contractors, subcontractors, and laboratories)

**11. Schedule**

- ☐ Timeline for all activities described in the RI/FS Work Plan , including PPP

**Appendix – Public Participation Plan (see Section 3.2.4)**

- ☐ Public notice and comment periods
- ☐ Locations where information about the site will be available to the public
- ☐ Methods that will be used to identify public concerns (meetings, questionnaires, and interviews)
- ☐ Participation requirements of other federal, state, or local laws and how they will be addressed
- ☐ Procedures for amending the plan

**Figure 3-2.** Sediment SAP outline and checklist

1. **Introduction**
   - ☐ Objectives of the field investigation
   - ☐ Regulatory framework
   - ☐ General site information
   - ☐ Project team and responsibilities
   - ☐ Schedule
   - ☐ Document organization

2. **Study Design (see Section 3.4)**
   - ☐ Summary of how tasks relate to the CSM and data gaps
   - ☐ Description of each sampling task
     - o Justification for sample placement (statistical or otherwise)
     - o Sample number and density
     - o Sampling locations (map and coordinate tables)
     - o Reference sampling locations (if necessary)
     - o Sample depth below sediment surface
     - o Target matrix at each location

3. **Sample Collection and Handling Methods (see Chapter 4)**
   - ☐ Sampling platform, positioning, and navigation
   - ☐ Sampling equipment and collection
   - ☐ Sample identification, containers, and labels
   - ☐ Sample storage and delivery
   - ☐ Field documentation including
     - ☐ Field notebooks and sample logbooks
     - ☐ Chain-of-custody procedures
   - ☐ Equipment decontamination
   - ☐ Waste disposal

4. **Laboratory analytical methods (see Chapter 5)**
   - ☐ Chemical analyses and target reporting limits
   - ☐ Biological testing
   - ☐ Corrective actions
   - ☐ Laboratory reporting

5. **Data presentation and reporting**
   - ☐ Presentation of sediment chemistry data
   - ☐ Presentation of biological test data
   - ☐ Discussion of data quality and whether DQOs were met
   - ☐ Record keeping and reporting procedures

**Figure 3-2.**Sediment SAP outline and checklist (continued)

**Appendix – Health and Safety Plan (see Section 3.2.3)**

- ☐ Description of tasks
- ☐ Key personnel and responsibilities
- ☐ Signature page
- ☐ Local emergency contact information
- ☐ Types of potential hazards
- ☐ Job safety analysis for each task (safety and health risks)
- ☐ Personal protective equipment
- ☐ Work zones
- ☐ Decontamination procedures
- ☐ Procedures for disposal of contaminated media and equipment
- ☐ Safe work practices
- ☐ Personal training requirements
- ☐ Medical surveillance program, if necessary
- ☐ Record keeping procedures

**Appendix - Quality assurance project plan**

- ☐ Data quality objectives
- ☐ Field and laboratory QA/QC for sediment chemistry
- ☐ Field and laboratory QA/QC for biological testing
- ☐ Data QA/QC and validation review procedures

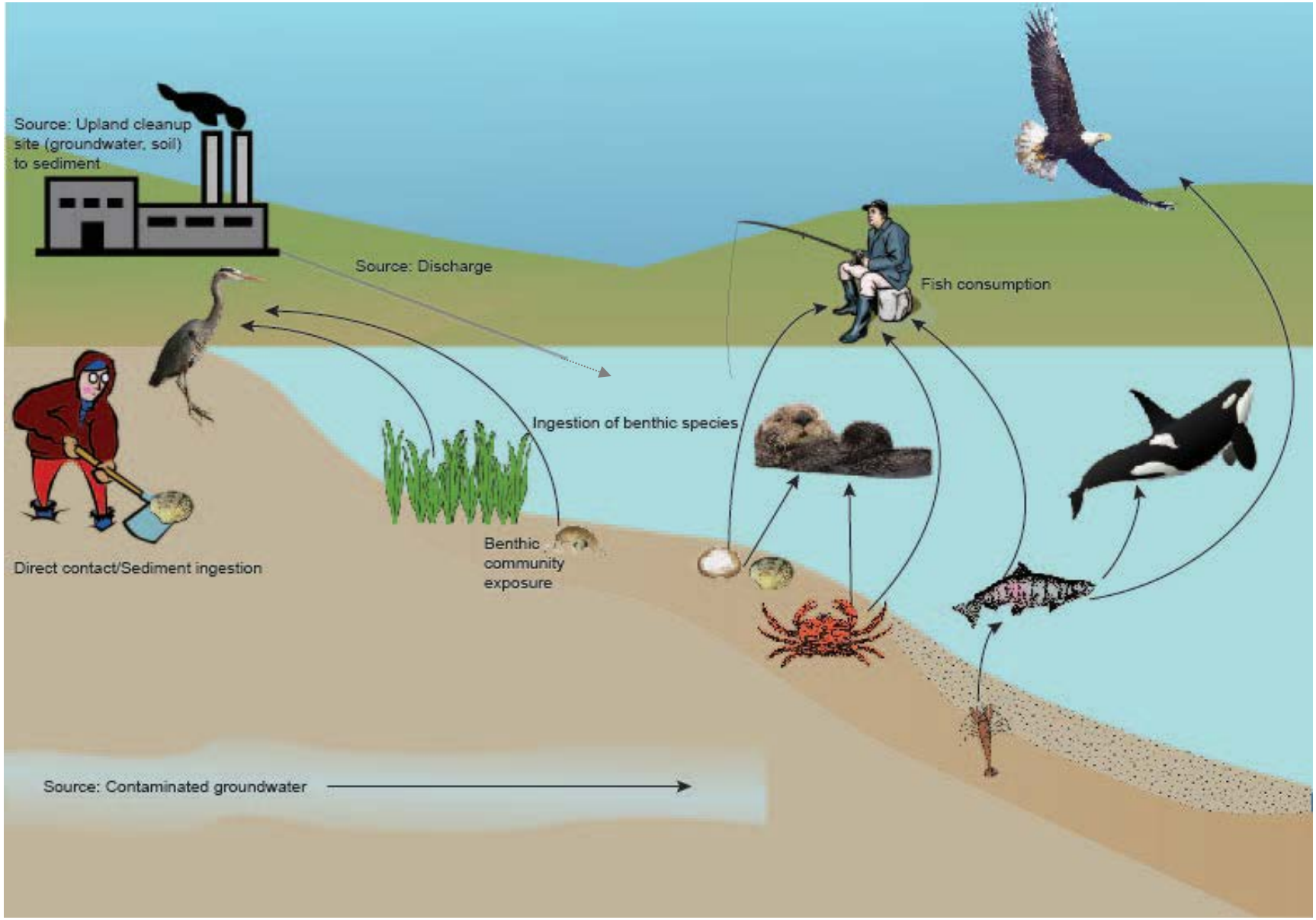



**Figure 3-3.** Example of a site CSM graphic figure for a sediment cleanup site.

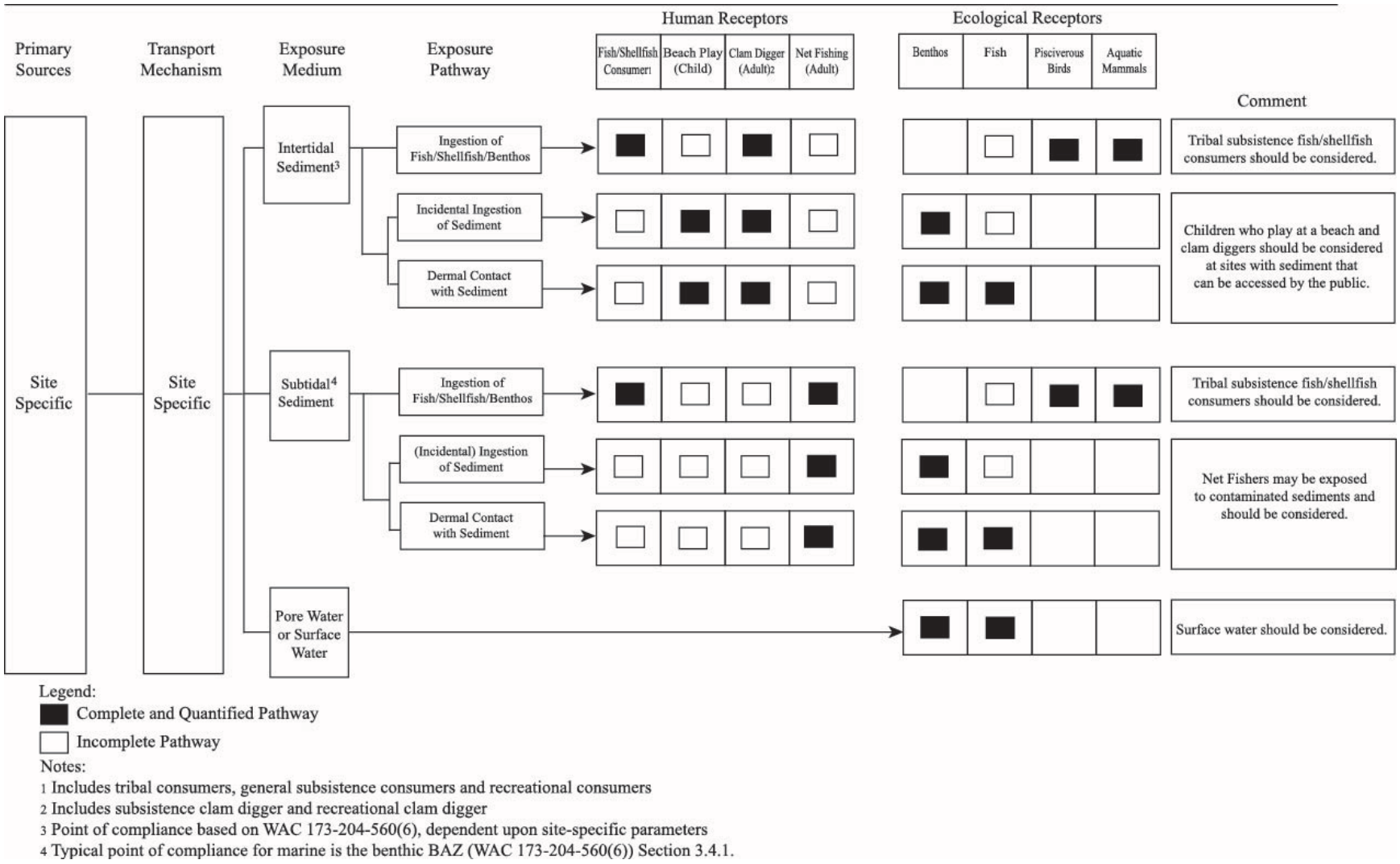



**Figure 3-4.** Example of a site CSM flow chart diagram for a sediment cleanup site.

# Chapter 4
# Field Sampling Methods and Selection of Analytical Parameters and Tests

## 4.1 Introduction

At this stage in the cleanup process, the RI Work Plan will be complete. Chapters 4 and 5 provide technical guidance for the sediment investigations that begin at this point.

Chapter 4 focuses on selecting analytical parameters and biological tests appropriate to the sediment investigation, and methods to conduct field sampling. Field sampling methods for source control purposes are also included in this chapter. However, specific information regarding placement of sampling stations for source control purposes are found in Appendix A.

Chapter 5 provides analytical and test methods for chemistry, bioassays, and bioaccumulation tests, as well as information on quality assurance and quality control (QA/QC), reporting, and record keeping. Additional technical information on sediment sampling and analysis procedures can be found in:

- The Puget Sound Estuary Program (PSEP) protocols, incorporated by reference into this guidance document where applicable. The PSEP protocols are available at: https://fortress.wa.gov/ecy/publications/SummaryPages/1509046.html.

- Appendix B of this guidance, which includes a compilation of relevant papers on technical updates to the PSEP protocols, and cleanup and DMMP dredging programs that were presented at SMARM.

The methods discussed in Chapters 4 and 5 include PSEP protocols, but also contain updates to these protocols that have been made through the SMARM process over the years, or based on best available science.

Additional information may be found on:

- Data interpretation and reporting in Chapter 6.
- Establishing cleanup standards in Chapters 7 – 11.
- Developing feasibility study reports and selecting cleanup actions in Chapter 12.
- Compliance and long-term monitoring in Chapter 13.

# 4.2 Selecting Analytical Parameters and Biological Tests

This section provides guidance on selecting appropriate study-specific parameters and laboratory analytical methods. In part, the study-specific parameters are determined in the RI/FS Workplan (Chapter 3). This section provides complementary but more detailed information on site-specific conditions that may impact selection of analytical parameters and biological tests. For sediment investigations that are not part of an RI, input from Ecology should be sought early in the process of designing the sediment investigation to ensure that appropriate parameters are selected.

## 4.2.1 Selection of chemical analytes

Sediment investigations generally involve measurement of sediment chemical concentrations. The list of analytes should include the SMS chemicals and conventional parameters (Chapter 8, Table 8-1), as well as any additional chemicals suspected to be present such as other bioaccumulative chemicals. The association of contaminants with a site may be due to current or historical activities at the site (e.g., upland source, log rafting, mining activities, waste disposal) or their presence in wastewater or stormwater. Examples of such contaminants are listed in Table 4-1. When there is reason to believe that any such potentially toxic contaminants may be present in the sediment at a site, they should also be measured.

## 4.2.2 Consideration of site-specific conditions

The SMS benthic criteria were developed using synoptic chemistry and biological data from a variety of water bodies in Washington and Oregon that represent eight of the nine eco-regions in Washington State. Sediment included in the marine and freshwater datasets were intended to represent a wide range of sediment types and water quality conditions. The resulting benthic chemical criteria are intended to protect the health of the benthic community. However, the criteria do not take into account all possible CoPCs, nor do they take into account all possible water bodies, sediment types, or unique water quality characteristics that may affect toxicity to the benthic community. In such cases, the SMS rule allows for some flexibility in site evaluations and data interpretation. This section presents examples of unusual site conditions that may require an alternative approach to assess toxicity to the benthic community.

1. Contaminants without SMS criteria. In some cases, there were insufficient data to develop benthic criteria for certain chemical classes (e.g., pesticides). If there is reason to believe that such chemical classes may be present in sediment, additional measures may be required to be protective of the benthic community or other trophic levels.

2. Bioaccumulative chemicals. The benthic criteria do not address bioaccumulative impacts to higher trophic level species or human health. If there are bioaccumulative chemicals of concern at the site, see Chapter 9.

3. Unusual aquatic habitats. While the SMS benthic chemical criteria were developed by incorporating data from a wide range of aquatic habitats encountered throughout the state, certain types of water bodies were not represented. These include bogs, ephemeral or seasonal wetlands and streams, and alpine wetlands and tarns. These aquatic systems can have unique substrates or geophysical properties that alter chemical availability, which potentially affects the ability of the SMS benthic chemical criteria to predict toxicity. Sediment associated with bogs and seasonal wetlands can have a high organic content, low dissolved oxygen, altered pH, and elevated levels of ammonia and sulfides. Alpine tarns may be susceptible to changes in pH from atmospheric sources, potentially altering the toxicity of certain metals. For these sites, bioassays are recommended.

4. Unusual water quality conditions. Particularly in freshwater environments, site water quality can influence the availability and toxicity of contaminants in sediment, which potentially affects the ability of the benthic chemical criteria to predict toxicity. Other water quality parameters affect the survival and fitness of benthic organisms and may affect responses of test organisms in the bioassays. If the site has unusual water quality conditions that are within ASTM/EPA acceptable ranges, biological tests can be adjusted to better match the site-specific conditions. Table 4-2 includes more information on sediment and water quality parameters. The following water quality parameters require additional consideration during screening studies and remedial investigations:

    a. Water hardness. Water hardness is a measure of the concentration of certain positively charged metal complexes (cations) that occur naturally. Common cations in freshwater include calcium and magnesium. Calcium and magnesium enter the surface waters by leaching from minerals within the aquifer. Calcium is commonly associated with calcite and gypsum. Magnesium is a mineral associated with dolomite.

        i. Water with high concentrations of cations is considered to be hard.

        ii. Water low in cations, such as rainwater, is considered to be soft.

        iii. Hardness is affected by a complex mixture of temperature, pH, and mineral concentrations, and is typically measured in milligrams per liter as calcium carbonate ($CaCO_3$).

        iv. Water hardness typically ranges from 25 mg/L to 400 mg/L $CaCO_3$ (40 CFR Part 131). Hard water is generally considered to be above 121-180 mg/L $CaCO_3$ and very hard water is $\geq$ 181 mg/L $CaCO_3$.

        v. Water hardness affects the biological availability and toxicity of metals. Toxicity decreases as hardness increases which can result in overestimating

the toxicity of metals in very hard water. In water bodies with very soft water, this may result in an underestimate of the toxicity of metals.

vi. Aquatic species have a tolerance range for water hardness. Concentrations of $CaCO_3$ outside the tolerance range for bioassay test species can affect the responses observed in bioassays.

b. pH. Similar to water hardness, pH is a water quality parameter that can affect availability and toxicity of metals. The pH is a measure of water acidity or basicity. Lower pH is associated with more acidic waters and higher pH is associated with more basic waters. Geologic formations can both increase pH (such as limestone) and decrease it (such as iron sulfides or peat bogs). Low pH is also associated with eutrophication, acid rain, and mining activities. Low pH has been associated with increased metals toxicity, particularly for aluminum. The pH range that is considered to be protective of fish in Washington State is 6.5 – 8.5 (WAC 173-201A-200) for freshwater bodies, and 6.5 – 9.0 for marine water bodies (WAC 173-201A-210).

c. Alkalinity. Alkalinity is a measure of the total amount of base present and provides an indication of how much acid (hydrogen ion) a waterbody can absorb or buffer before the pH is affected. The EPA recommends an alkalinity of > 20 mg/L $CaCO_3$ to maintain a pH that supports aquatic life. Water bodies with an alkalinity below 20 mg/L $CaCO_3$ are considered to be sensitive to acidification. While alkalinity may have a direct impact on the health of aquatic organisms, it does not directly affect the availability or toxicity of chemicals. Water hardness is a better measure to understand the predictive ability of the SMS chemical benthic criteria.

d. Dissolved oxygen. Dissolved oxygen (DO) is a measure of gaseous oxygen found in surface waters, typically expressed as mg/L. Certain water bodies may have either depressed DO or elevated DO concentrations above saturation. Depressed DO concentrations may be associated with natural or anthropogenic organic enrichment, or due to prolonged periods of water-column stratification. Chronic exposure to low dissolved concentrations may affect the health of aquatic life. Furthermore, seasonal changes to near-bottom DO concentrations can affect the depth of oxygenated sediment. The reducing conditions can influence parameters such as acid volatile sulfides (AVS), which subsequently affect the toxicity of metals. For freshwater bodies, acceptable ranges are 6.5 to 9.5 mg/L (WAC 173-201A-200(1)(c)) and 4 to 7 mg/L for marine water bodies (WAC 173-201A-210(1)(c)).

e. Temperature. In quiescent waters or during periods of low flow, water temperatures can increase particularly in the summer months. Temperatures can be altered by anthropogenic activities associated with effluent or alterations to water flow. In some cases, prolonged periods of increased temperatures can alter contaminant availability

or the survival, growth, or reproduction of some aquatic invertebrates. For freshwater bodies, acceptable ranges are 12-17.5 °C (WAC 173-201A-200(1)(c)) and 13-22° C for marine water bodies (WAC 173-201A-210(1)(c)).

f. Dissolved organic carbon. Humic and fulvic acids are organic constituents of soils. Certain soil types, such as peat, are rich in organic matter. When organic matter is dissolved in surface waters, it can form complexes with metals and other contaminants, changing their availability and toxicity to aquatic life. In particular, humic and fulvic acids can alter metals availability. Water bodies with high humic/fulvic acid content can reduce metals toxicity, with the chemical criteria potentially over-predicting toxicity.

5. Unusual sediment characteristics. Some water bodies have unique sediment characteristics that can affect the bioavailability of chemicals or have physical effects on biota, such as smothering adults or preventing larval development. Such physical effects may be due to naturally-occurring factors or anthropogenic sources, such as the accumulation of wood waste (Ecology 2013a) or slag.

a. Unusual organic carbon. TOC in sediment can vary seasonally and with depth. Organic carbon in sediment provides an adsorptive surface to bind contaminants, particularly those with high $K_{OW}$ values such as organic pesticides, PAHs, and organometallics. The bioavailability and toxicity of high $K_{OW}$ contaminants can be altered in sediment with very high TOC. TOC is frequently elevated in sediment impacted by wood waste (Ecology 2013a).

i. Sediment in certain freshwater habitats can have elevated TOC. This is particularly true of sediment in peat bogs, wetlands and streams with heavy vegetation, and ponds that experience seasonal algal blooms. While TOC in freshwater sediment can range from < 1% to approximately 15% (Sloan and Blakely 2009), a TOC > 3.5% could be considered unusual.

ii. TOC in marine sediment outside the range of 0.5 – 3.5% could be considered unusual. For example, wood waste impacted sites may have unusually high TOC above 3.5%. See section 6.3.3.1 for steps to take with unusual TOC.

b. Unusual organic carbon sources. The forms and phases of organic carbon in sediment vary and can include colloidal carbon, glass-like (hard) and rubbery (soft) particulate carbon, and soot carbon. The effect of these different forms on partitioning and availability of chemicals is complex. However, it is important to consider that, for sites where unusual forms of carbon are likely to be present (soot, coal tar, coal ash, and creosote), the availability of certain chemicals may be affected. Sediment with high woody content may require alternative estimates of organic carbon to understand

chemical availability. In addition, the type of carbon may cause adverse effects itself (e.g., pencil pitch, wood waste (Ecology 2013a) or black carbon from soot).

c. Unusual physical characteristics. Materials such as mining slag and tailings, paint chips, wood waste, and ferricrete can impact toxicity. Fine clays (in particular, the dense dusts from mining activities), slag, and wood pulp can collect as a cohesive or flocculent layer in depositional areas. This can alter surface textures and reduce sediment porosity and permeability. Such surfaces can reduce interstitial DO, creating a reducing layer below the surface and changing the availability of metals. Fine clays can also encase burrowing infauna by covering the sediment surface, while slag can result in physical trauma to benthic organisms.

d. Unusual contaminant profiles. Contaminant groups such as PAHs may include an array of subgroups of contaminants that have different availability and toxicity. See Appendix C for more information on bioassays to be used for sediment with UV exposed PAHs.

In many cases, the unusual conditions mentioned above affect the availability of contaminants of potential concern, thereby either increasing or decreasing toxicity. For such situations, the recommended alternative is to conduct biological toxicity tests (Table 4-3 and Table 4-4) concurrent with analysis of site sediment chemistry. The biological toxicity tests in the SMS rule should be used to develop cleanup levels for regulatory purposes. However, alternate biological tests may be appropriate to conduct site evaluations if conditions warrant (see Section 4.2.3). The standard sediment chemistry suite (Chapter 8, Table 8-1) may be expanded to cover those contaminants or characteristics that may be contributing to toxicity. Table 4-1 includes a list of some chemicals and their potential sources that are not included in the SMS benthic chemical criteria. In some cases, or when chemicals of concern without SMS criteria are at the site, site-specific conditions may require the selection of an alternative species or methods modification (Table 4-4). Such changes are subject to review and approval by Ecology.

To retain consistency with the SMS, the SMS biological criteria should be used with site sediment chemistry to develop site-specific chemical criteria. Ecology recommends use of the AET or FPM methods with the SMS biological criteria to develop site-specific chemical criteria for marine and freshwater sites, respectively. However, Ecology may consider other methods (such as logistic regression or the reference-envelope approach). Any of these methods require at least 30 synoptic chemical and biological sediment samples depending on the distribution of chemical concentrations, homogeneity of site conditions, and the numbers of hit and no-hit bioassay results.

## 4.2.3 Selection of biological toxicity tests

Biological testing may only be necessary if SMS chemical criteria are exceeded and biological confirmation is needed. However, biological testing may be warranted if: a) there is reason to believe that potentially toxic chemicals other than those with adopted SMS benthic chemical criteria may be present; or b) there are chemical or physical characteristics or interactions potentially contributing to toxicity (Section 4.2.2). In certain cases, biological testing may be conducted prior to or concurrent with chemical analyses, particularly if chemicals are expected to be in an unusual matrix that might affect their bioavailability. Either Ecology or the PLP may choose to have biological tests conducted in addition to chemistry.

Biological testing to assess existing sediment quality may include conducting bioassays or benthic community analyses. The applicable biological tests vary depending on whether the sediment environment is marine, estuarine, or freshwater.

### 4.2.3.1 Marine and estuarine biological tests

The five marine biological tests in the SMS are (Table 4-3 or Chapter 8, Table 8-2):

- Sediment toxicity tests (bioassays), which include acute and chronic tests; and
- A benthic community analysis test which is a chronic/sublethal test.

When marine biological tests are conducted, the SMS requires using at least:

- Two acute biological tests consisting of the amphipod acute test and one of the larval acute tests, and
- One chronic biological test.

The biological tests described in the SMS apply to marine sediment (i.e., those with interstitial salinities ≥ 25 parts per thousand [ppt]), and to low salinity estuarine sediment (i.e., those with interstitial salinities of 0.5 – 25 ppt) on a case-by-case basis. These biological tests include:

**Acute Effects Tests**

- Amphipod: A 10-day acute bioassay that assesses mortality of *Rhepoxynius abronius*, *Ampelisca abdita*, or *Eohaustorius estuarius*, are used based on interstitial water salinity ≥ 25 ppt and the percentage of sediment fines as shown in Figure 4-1. Among the three amphipod species (Table 4-3):
    - *E. estuarius and R. abronius* should be used if fines are < 60%.
    - *R. abronius* is known to be adversely affected by sediment with a high proportion of fines. Therefore, if the proportion of fines (i.e., particles having diameters < 62.5

μm) is ≥ 60%, *A. abdita* should be used because it is relatively tolerant of a wide range of sediment grain sizes.

- If the interstitial salinity of sediment is < 25 ppt, the choice of low salinity biological tests must be approved by Ecology in advance.

- If sediments with interstitial salinities between 15 and 24 ppt are being evaluated for dredging and disposal at a DMMP site, the PSEP (1995) protocols allow for upward adjustment of the interstitial salinity so that *R. abronius* can be used. However, this is not appropriate for the amphipod toxicity tests for cleanup purposes.

- Larval: Any one of several acute sediment toxicity tests that assess mortality and/or abnormality of larvae of the following organisms:

  - Pacific oyster, *Crassostrea gigas*
  - Blue mussel, *Mytilus galloprovincialis*
  - Purple sea urchin, *Strongylocentrotus purpuratus*
  - Green sea urchin, *Strongylocentrotus droebachiensis.*
  - Sand dollar, *Dendraster excentricus*.

  The primary factor affecting the selection of an appropriate species for the larval test is the time of year. It is generally desirable to select a species that is naturally spawning at the time of the year the biological test will be conducted. The natural spawning seasons for test species in the Puget Sound area are:

  - **Oyster** – summer
  - **Mussel** – late spring through early summer
  - **Sea urchin** – December through April
  - **Sand dollar** – April through October

  Although all of these species can be induced to spawn at other times of the year, this practice is not recommended since the larvae may then be subject to higher mortality.

  The PSEP (1995) protocols recommend against using the larval toxicity tests for sediment with interstitial salinities < 10 ppt because of the limited experience with the tests at these salinities. However, all of the larval toxicity tests can probably be used over a wide range of interstitial salinities (from full-strength seawater to < 1 ppt). This is because a small

volume of sediment is mixed with a much larger volume of seawater which, prior to testing, has a salinity of 28 ppt. Use of the larval toxicity tests for such low salinity sediment should therefore be discussed with Ecology and considered on a case-by-case basis.

In more recent years, oyster larvae have not been used frequently. They may also be adversely affected by small sediment grain sizes. Use of oyster larvae for sediments known to have a high proportion of silt- and clay-size particles is therefore not recommended (PSEP 1995). Instead, either a sea urchin or sand dollar test would be preferable. A resuspension protocol has been developed to address situations when sediment may have flocculent material such as wood fiber which is described in the 2013 SMARM paper *Bioassay endpoint refinements: Bivalve larval and Neanthes growth bioassays* (Appendix B, Bioassays section).

**Chronic Effects Tests**

- Juvenile polychaete: A 20-day sublethal sediment toxicity test that assesses decreases in biomass of the juvenile polychaete *Neanthes* species.

- Microtox® 100 percent sediment porewater extract: A 15-minute toxicity test that assesses decreased bioluminescence of the bacteria *Vibrio fischeri* (strain NRRL B-11177) when exposed to a pH/dissolved oxygen/salinity-adjusted 100 percent porewater extract of the sediment sample. For more information on marine Microtox® test, see Appendix C. The marine Microtox® porewater test only has an SCO-level criterion.

- Benthic macroinvertebrate abundance*:* This benthic community test assesses a statistically significant alteration (reduction of 50% or more) in the naturally-occurring abundances of three major taxa: Crustacea, Mollusca, and Polychaeta.

Among the chronic effects tests, the benthic community analysis requires more time for the collection of samples because five replicate grab samples from each station are necessary for this analysis (in addition to sediment samples collected for chemical and other biological tests). The benthic community analysis is also generally more expensive than any of the sediment toxicity tests because of the additional sample processing time in the field, and the cost of sorting and taxonomically identifying the samples.

The choice between the other two chronic tests may depend on how the data is used. The Microtox® test is quick, relatively inexpensive, unaffected by interstitial salinity or grain size characteristics, and available throughout the year. However, the SMS only has an SCO marine criterion for Microtox®. The SMS has both SCO and CSL criteria for the juvenile polychaete test but *Neanthes* species may be adversely affected by interstitial salinities < 20 ppt. Use of the

juvenile polychaete test for sediments having interstitial salinities < 20 ppt will only be approved by Ecology on a case-by-case basis.

#### 4.2.3.2 Freshwater biological tests

When freshwater biological tests are conducted, the SMS requires using at least:

- Three toxicity test endpoints using at least two species,
- Both acute and chronic tests, and
- At least one sublethal endpoint (e.g., growth).

The SMS freshwater biological tests and corresponding endpoints are below. Each of these freshwater sediment bioassay species is available year round.

**Acute Effects Tests**

| | | |
|---|---|---|
| • *Hyalella azteca* (US EPA, 2000) | 10-day mortality | ASTM E1706-05 (2010)/EPA Method 100.1 |
| • *Chironomus dilutus* (US EPA, 2000) | 10-day mortality | ASTM E1706-05 (2010)/EPA Method 100.2 |
| • *Chironomus dilutus* (US EPA, 2000) | 10-day growth | ASTM E1706-05 (2010)/EPA Method 100.2 |

**Chronic Effects Tests**

| | | |
|---|---|---|
| • *Hyalella azteca* | 28-day mortality | EPA Method 100.4 (US EPA, 2000) |
| • *Hyalella azteca* | 28-day growth | EPA Method 100.4 (US EPA, 2000) |
| • *Chironomus dilutus* | 20-day mortality | EPA Method 100.5 (US EPA, 2000) |
| • *Chironomus dilutus* | 20-day growth | EPA Method 100.5 (US EPA, 2000) |

The Microtox® test is not included in the SMS rule for freshwater, but can be used for investigation purposes, see Appendix C for more details. Unlike marine biological criteria, the freshwater biological criteria are based on a comparison to control treatments. This is due to the lack of established reference sites in Washington and the highly variable responses observed in reference sediment. Therefore, it is not necessary to collect reference sediment for freshwater bioassays. Comparison to reference treatments may be allowed on a case-by-case basis.

The SMS criteria were based on benthic toxicity tests considered to be protective of the benthic community and, to a certain extent, protective of other receptor groups that may interact with

sediment-borne contaminants. However, there may be some sites that have species of concern that will require alternative toxicity tests, such as:

- Mollusks (e.g., the freshwater mussel, *Anodonta californiensis* or the gastropod snail, *Fluminicola columbiana*).
- Amphibians (e.g., the frog, *Rana pipiens*).

In such cases, the SMS allows for the use of alternative test species, with approval from Ecology. The following list of alternative bioassays—most of which are summarized in Table 4-4—may be considered in addition to those in the SMS (listed above). While the SMS allows for the use of best available science, some of these methods are in different stages of development. Protocols for these alternative tests have not undergone the same degree of peer review and development as the SMS biological tests. In addition, interpretive criteria relative to cleanup decisions have not been developed for these alternative tests. Therefore, both the protocols and interpretive guidelines must be coordinated with and approved by Ecology.

*Amphibians*

- Frog Embryo Test: A 96-hour sediment test with survival and development endpoints of the frog, *Xenopus laevis*.

*Amphipods*

- *Hyalella azteca*: In addition to the 10-day acute and 28-day chronic sediment tests in the SMS, this amphipod can be exposed for 42 days for both survival and growth endpoints.
- *Diporeia* spp.: A 28-day chronic sediment test with survival and growth endpoints. *Diporeia* spp. is a freshwater amphipod found in a variety of substrate types.

*Annelid Worms*

- *Lumbriculus variegates*: A 10-day acute sediment with survival endpoint. This species can also be exposed for 28 days for an evaluation of bioaccumulation.
- *Tubifex tubifex*: A 10-day acute sediment with survival endpoint or a 28-day chronic sediment test with survival and reproductive endpoints.
- *Pristina* spp: A 10-day acute sediment with survival endpoint. *Pristina* spp. are small, delicate segmented worms that live in pond and stream sediments.

*Crustaceans*

- *Daphnia* spp. or *Ceriodaphnia* spp: A 7-day chronic sediment test with survival, growth and reproduction endpoints. These species can also be exposed to sediment elutriates or suspended particulate phases to evaluate survival and reproduction.

*Insects*

- *Chironomus* spp.: In addition to the 10-day acute and 20-day chronic tests, this species can also be exposed for 40 days in a life cycle test.

- *Hexagenia* spp.: A 21-day chronic sediment test with survival and growth endpoints.

*Mollusks*

- *Anodonta* spp.: A 10-day acute sediment test with a mortality and behavioral (gaping) endpoint.

### 4.2.4 Tools to evaluate bioavailability

There are a number of tools to assess the bioavailability of chemicals in sediment. These include 1) bioaccumulation testing (Section 4.2.5), 2) analyzing tissue chemistry in biota from the site (Section 4.2.5), and 3) measuring chemical concentrations in porewater (Section 4.5.4).

The concentration of chemicals in sediment porewater is an important factor influencing their bioavailability to aquatic biota. Hence, measurement of porewater chemical concentrations can be a useful tool to evaluate the bioavailability of chemicals in sediment. While the SMS requires the use of sediment concentrations to establish cleanup criteria (not porewater or tissue concentrations), this does not preclude the use of these tools for other purposes. Used as one line of evidence, each tool listed above cannot provide sufficient information on the bioavailability for all chemicals in all sediment types. However, in tandem with analysis of bulk sediment, these tools can be used in a weight of evidence approach to assist in:

- Screening bioaccumulative chemicals to identify chemicals of concern during an initial site evaluation or the RI (Chapter 3).
- Assessing the bioavailability of CoCs for risk assessments (Chapter 9 and Appendix E).
- Assessing the bioavailability or concentrations of CoCs, such as sulfides, that pose a risk to the benthic community.
- Determining if CoCs are bioavailable during compliance monitoring (Chapter 13).
- Selecting an appropriate remedial design (Chapter 12).
- Understanding if sediment-bound CoCs have potential to impact water quality (Chapter 3).

In addition, these tools are not sufficient to fully assess the toxicity of sediment bound contaminants to the benthic community. To do so, the SMS biological and chemical benthic criteria should be used (Chapter 8).

Section 4.5.4 provides a general description of peepers and solid phase micro-extraction fibers (SPMEs) and a brief description of deployment of these tools in the field.

### 4.2.5 Selection of bioaccumulation tests or direct measurements of site-specific tissue chemistry

Bioaccumulation testing or measurement of tissue concentrations is normally conducted using multiple species, which reduces uncertainty about the results and limits errors when interpreting the data. There are three basic methods that can be used to evaluate bioaccumulation potential by using tissue data:

- Laboratory bioaccumulation testing. Sediments from the site are collected and several species are exposed to the sediments under controlled laboratory conditions. At the end of the test, tissue concentrations are measured and compared to risk-based tissue concentrations (Chapter 9) or background tissue concentrations (Chapter 10), or PQL (Chapter 11) provided steady-state conditions are achieved or can be estimated. This is the most common approach used in dredging programs and can be used at cleanup sites, particularly if there is a concern that other sources (e.g., water or prey) may be contributing to tissue chemical concentrations.

  Two bioaccumulation tests are generally required with species from two different trophic niches representing a suspension/filter-feeding and a burrowing deposit-feeding organism. For marine sediment, a 28-day or 45-day bioaccumulation test is typically conducted with both an adult bivalve (*Macoma nasuta*) and an adult polychaete (*Nereis virens, Nepthys, or Arenicola marina*). A 45-day testing period is required for contaminants that may not come into equilibrium within 28 days, such as PCBs, TBT, DDTs, and dioxins/furans.

  For freshwater sediment, a test is conducted with the oligochaete (*Lumbriculus variegatus*) and a second species to be determined at the time of testing. Selection of additional approved species for freshwater bioaccumulation testing is in progress. This section will be updated as this work progresses.

- *In-situ* bioaccumulation testing. The test species organisms are placed in webbing or cages and exposed in the field to sediment at the site for a specified length of time. In situ bioaccumulation testing can help integrate toxicity and bioaccumulation testing because endpoints such as survival, growth, and reproduction have been developed for some bioaccumulation test species and can be measured in the same organisms. The

main advantage of this approach is the ability to characterize exposure and effects over space and time under the environmental conditions at the site. The main disadvantage is cost, although costs do not increase incrementally over time as they do with laboratory toxicity or bioaccumulation tests since daily maintenance in the field is not required. Other disadvantages include the potential for confounding factors in the field, the difficulty of locating suitable reference sites, and the lack of exposure to subsurface sediment.

- Tissue testing of field organisms. Fish and/or benthic infauna (frequently shellfish, crab, or bottom fish) may be collected directly from the site for tissue chemical analysis. The species are selected based on their site fidelity; representativeness of feeding guilds at the site; exposure and feeding strategies; and commercial, recreational, and cultural significance. Tissue concentrations are compared to human health or ecological risk-based concentrations, or to natural or regional background tissue concentrations. This approach is used primarily to evaluate the bioaccumulative effects of surface sediment at cleanup sites. For more information on study design, see Chapter 3 Section 3.4.2.

Laboratory bioaccumulation tests are most appropriate when a) the bioaccumulation potential of material proposed for dredging needs to be assessed; and b) concentrations are likely to be higher in the subsurface sediment than at the surface; and c) assessing site conditions during the RI and development of the FS. Because *in situ* tests and field organisms are primarily exposed to surface sediment, these approaches are more appropriate for evaluating sediment in place, such as assessing site conditions during remedial investigations or sediment proposed for natural recovery. The bioaccumulation testing approach should be selected to address all potential routes of exposure identified in the conceptual site model (see Chapter 3 Section 3.3).

## 4.3 Frequency and Timing of Sampling

This section provides guidance on the appropriate frequency and timing of sampling for sediment investigations.

### 4.3.1 Frequency of sampling

Certain types of sediment sampling may occur only once, while other types (such as compliance monitoring) may occur periodically. In remedial investigations, a single sampling event may suffice to determine the present state of sediment conditions. In situations where the initial sampling identifies a problem (e.g., exceedance of SMS criteria), further sediment sampling and analysis may be required to define the spatial extent of the problem or establish gradients that may be useful in interpreting the source of the problem. In other types of sediment investigations—where the goal is to establish whether there are temporal changes in sediment conditions (e.g., source control monitoring)—the selection of an appropriate sampling frequency depends on the expected rate of change of sediment conditions.

In relatively quiescent marine or estuarine environments away from large sources of sediments (such as river deltas), surface sediment is unlikely to change appreciably in a few years even if nearby sources of contaminants are eliminated. This slow rate of change can be due to:

- Slow natural rates of sedimentation;
- Bioturbation of sediment by organisms (which may mix relatively clean, newly deposited sediment with more contaminated sediment at greater depth below the sediment surface);
- The CoCs are not subject to degradation or are very slowly degraded in the environment.

Therefore, in marine or estuarine areas with very slow rates of sedimentation, a period of 5 to 10 years may be required for appreciable changes to occur in surface sediment conditions.

In freshwater environments, the rate of change in surface sediment conditions may also be relatively slow if there is little flow (such as lakes, reservoirs, or ponds). However, the rate of change may be very rapid in rivers or streams, especially when there are large seasonal fluctuations in flow. Sediment may be deposited near sources during periods of low flow, only to be swept away and re-deposited downstream during periods of high flow. Knowledge of the local hydrology is essential to determine the appropriate sampling frequency in freshwater environments subject to periodic variations in flow.

### 4.3.2 Timing of sampling

In many sediment investigations, the time of year when sampling is conducted is generally not an issue. However, factors that could influence the selection of an appropriate time of year may include the following:

- <u>Seasonal availability of appropriate biological test organisms</u>. As described in Section 4.2.3, certain test organisms are only available during certain times of the year so sampling will need to be scheduled accordingly. In addition, sampling to analyze biological effects (i.e., toxicity test) should be done when environmental conditions are at the most extreme as this is when benthic populations are at most risk. This would generally be at highest water temperatures and lowest dissolved oxygen, which is approximately between August 15 and September 30 (+/– 14 days).

- <u>Seasonal variations in sediment conventional contaminant concentrations</u>. If the purpose of the sampling is to characterize potential toxicity due to contaminants in locations where concentrations may fluctuate (e.g., conventionals such as ammonia or sulfides), sampling should be scheduled when concentrations are likely to be highest.

- <u>Normal seasonal variations in the abundance of the benthic community</u>.

    - Benthic macroinvertebrate assemblages are constantly changing. When sampling to conduct benthic community analyses, it is preferable to sample

when the population estimates are subject to the least natural variability. In Puget Sound, both the numbers of individuals per sample and the variability among stations are lowest in late winter or early spring, which makes that the best time of the year for sampling (PSEP, 1987). Sampling can certainly occur at other times of the year, but the higher natural variability makes it more difficult to discern differences among stations. It may be necessary, for example, to collect and analyze additional replicate samples to achieve the same statistical power.

- Regardless of the time of year selected for bioassay or benthic community analyses, it is essential that all samples being compared (e.g., site stations vs. reference stations; site stations vs. stations sampled historically) are collected at the same time of year. If multi-year temporal trends are of interest, sampling in successive years should be conducted during the same season.

- Periodic variations in the quantity or quality of a discharge. If the goal is to investigate potential effects of a point source, periodic variations in the quantity or quality of the discharge must be taken into account. For example, sediment in the vicinity of a wastewater discharge from a seasonal food processing plant should be sampled during or soon after periods of high food processing activity.

- Concurrent with tissue collection for bioaccumulation studies. Sediment and tissue samples to be paired for calculating bioaccumulation should be collected concurrently. In some cases, sediment collection will have to be timed to the foraging behavior of biota (Burkhard 2009).

- Tidal stage. In coastal areas, the stage of the tide (e.g., neap tide, spring tide) may influence selection of the time of sampling. This could be due to access restrictions to the site (e.g., a large sampling vessel might only have access during high spring tides, or personnel on foot might sample sediment during low spring tides). It may also be due to the effect of tidal currents on sediment (e.g., the strongest tidal currents occur during spring tides and might scour the sediment surface, while periods of neap tides might be relatively quiescent).

- River stage. For sediment sampling in rivers subject to pronounced seasonal variations in flow, it may be appropriate to sample during or near the end of low flow periods when sedimentation is more likely to occur. Periods of low flow may also be the optimal time for sampling if there is reason to believe upland contamination might be migrating to sediment through seeps. Alternatively, periods of high flow may scour away a veneer of relatively clean sediment, exposing more contaminated sediment deposited earlier. Drawdown of the water level behind dams for fish passage may also be an important consideration.

### 4.3.3 Phasing of sampling and analysis

In order to effectively assess sediments in any locale, synoptic (chemistry and biological) sediment data (i.e. data collected within a 2-3 months of one another) should be collected. Also, as described above, biological data generally sets the limit on the overall collection schedule. Because biological samples should be collected between August 15 and September 30, in order to collect synoptic data, it is strongly advised to collect chemistry samples at the same time (same sampling event) as the biological samples. This would allow cost savings, as only a single sediment sampling mobilization would be necessary. Be aware, however of the holding times for the biological sediment samples. Generally these holding times are limited to 8 weeks (see holding times and procedures). This therefore requires diligence by the lab to complete chemistry analysis within the holding time to decide if biological testing is necessary (i.e., if there are SCO chemistry exceedances).

In some cases, it may be necessary to analyze for chemistry and biology at different times or in stages (for example, analyzing sediment for chemistry first, then conducting biological tests if chemistry exceeds the SMS criteria). Depending on the chemical, biological tests results can be used to override chemistry results. It may be less time consuming and more economical to collect enough sediment volume during a single sampling event for both chemical and biological testing to prevent lost time and remobilization costs to resample if biological testing is later determined to be necessary. This strategy is only practical, however, if the chemical analyses are conducted and the results are evaluated within the maximum holding times for biological testing. Such a strategy is particularly valuable because both chemical analyses and biological tests can be conducted on subsamples of the same homogenized sediment sample, which helps interpret the data. If a separate field sampling effort must be conducted to collect sediment for biological testing, it is generally impossible to resample the exact locations and chemical analyses may need to be repeated concurrent with biological testing.

If separate field sampling events are necessary (one for chemistry and one for biological analysis), and in order to collect synoptic data, below are recommended options in order of preference:

- Option 1:
    - Sample in June and conduct chemistry analysis. Since biological testing is generally conducted on samples that exceed the SCO for chemistry, this will inform any subsequent biological testing.
    - Sample between August 15 and September 30 (+/- 14 days) for biological toxicity testing.
- Option 2:
    - Sample between August 15 and September 30 (+/- 14 days) for biological toxicity testing. Then

- Sample in late November for chemistry analysis.

In cases where there are no SMS numeric chemical benthic criteria for the site CoCs, Ecology recommends conducting biological toxicity testing first or concurrently with sediment chemistry to provide a direct assessment of toxicity. Biological testing may also be recommended if there is reason to believe that chemicals may be present in a less bioavailable form (e.g., metals in sandblast grit, slag, or paint chips).

### 4.3.4 Schedule

Each sampling and analysis plan should include a schedule showing when each element of the sediment investigation will be completed, along with a brief rationale of the frequency, timing, and phasing (if any) of sampling and analyses.

Elements to be scheduled include:

- Field mobilization
- Field sampling
- Field demobilization
- Shipment of samples to laboratories
- Maximum holding times
- Initiation and completion of chemical analyses
- Initiation and completion of biological testing
- Initiation and completion of data validation
- Submittal of data to Ecology's Environmental Information Management System database (EIM)
- Submittal of the draft and final data report to Ecology

## 4.4 Sampling Locations

This section provides guidance on: a) how to locate stations relative to known or suspected contaminant sources or contaminated areas; b) selecting appropriate water depths for sampling stations; and c) selecting the appropriate sediment depth interval to be sampled. This section also contains information about other factors to consider when selecting appropriate sampling station locations.

The selection of appropriate sampling station locations depends on which study is underway: an initial investigation or a sediment cleanup investigation. For example, an initial investigation (such as initial site investigation or due diligence [property transfer] investigation where sediment contamination is suspected) will determine whether there is sediment contamination. A sediment cleanup investigation, for example, will determine if the existence but not the spatial extent of sediment contamination has already been documented. For information on the appropriate selection of sampling locations for NPDES permit monitoring, see Appendix A.

### 4.4.1 Initial investigations

For initial investigations where there is no prior information on sediment quality conditions, the appropriate number and locations of sampling stations will depend largely on site characteristics. Because clusters of potential concern are defined in the SMS on the basis of sediment conditions at a minimum of three sampling stations, it is necessary to locate at least three stations in any discrete area for which a decision is to be made (Chapter 2). If the area is large or complex, more than three sampling stations will be necessary to adequately identify station clusters of potential concern. In most cases, available site information will provide an indication of areas that should be targeted for sediment sampling. The following guidelines should then be used to select appropriate sampling locations:

- If there are areas of known or suspected upland soil contamination, some sampling stations should be placed adjacent to the shoreline—either evenly-spaced or focused on areas adjacent to upland areas with high soil contamination.

- Sampling stations should be placed in the vicinity of current or historic point source discharges, including wastewater outfalls, storm drains, combined sewer overflows, oil/water separators, or ditches carrying runoff. If those point sources are located in an area of high flow (e.g., in rivers), it may be necessary to sample instead at the nearest area(s) where sediment deposition is likely to occur.

- Sampling stations should be placed in the vicinity of loading docks, particularly if pipelines carrying oil or other products were or are present. The sampling stations should be placed along the length of the dock where the pipelines were or are present, with some stations placed as close as possible to manifold or loading areas on the dock or at the shoreline.

- If there are areas along the shoreline where boats were refueled, sandblasted, or maintained, sampling stations should be placed offshore of those areas.

- Where groundwater is known or suspected to be contaminated, sampling stations should be placed in any areas (usually intertidal or shallow subtidal) where groundwater may be discharged to the waterbody (i.e., seeps).

- Sampling stations should be placed in any areas where it is known or suspected that wastes were discharged, spilled, or otherwise released.

- In leased areas and/or if upstream or general area-wide contamination is suspected, sampling stations should be placed along the property boundaries.

- If biological testing is to be conducted, one or more reference stations should also be sampled to match the sediment grain size of the site sediment. If benthic community analysis is to be conducted, water depths, grain size, percent TOC, and other physical attributes at reference area and site stations should be similar.

- Sampling stations should be placed in depositional areas and/or areas shown to have accumulated sediment over time (e.g., where bathymetric surveys show net accumulation over time).

- Sampling stations should be placed in areas where there are natural resources such as shellfish and eelgrass beds.

- Areas where humans or wildlife may be exposed (beach or clamming areas) should be characterized.

### 4.4.2 Remedial investigations

For investigations where available data information indicates that the sediment is contaminated, the appropriate number and locations of sampling stations should be selected to address the following objectives:

- Stations should be placed in any areas suggested for an initial investigation, if those areas have not been previously sampled.

- In cases where an initial investigation has occurred, stations should be placed to determine the spatial boundaries of the area where the SCO and CSL criteria are exceeded. Stations should be placed closely enough together to provide a reasonably accurate estimate of the area(s) that might need to be considered for active remediation (e.g., dredging or capping).

- Additional stations may be useful to identify gradients of contamination or sources of contaminants. Differentiation among various sources is important to determine whether the sources overlap or are separate, to establish if source control is sufficient to proceed with cleanup, and to identify multiple PLPs.

- If cleanup action alternatives include dredging, sediment cores are necessary to calculate the volume of contaminated sediment. Core samples may also be collected and dated to estimate sediment deposition rates, if a natural recovery evaluation or an evaluation of the potential for recontamination is needed. Sediment traps may be used for the same purpose, but require additional steps for deployment, retrieval, and an extended period of time in the field to collect sediment. Analysis of both lead-210 and cesium-137 is recommended to interpret core dating results. Cores collected for dating and to evaluate the depth of contamination normally have different compositing intervals and analyses and generally cannot be used for both purposes.

- For stream and river systems, station frequency and locations should be sufficient to detect downstream gradients from a suspected source or from previously sampled stations that are contaminated. This can be achieved by dividing the study region into linear segments with sample transects located systematically across each segment. Up-gradient samples should be collected to define the extent of the affected area or to capture any other potential release points.

- For pond and small lake sediments, samples should be biased towards adjacent inflow/outflow areas and topographically low/deep areas where sediment is likely to accumulate. If there is no basis for developing a sampling grid, a random sampling design is recommended.

In general, it is recommended that each station be specifically located to accomplish one or more of the above objectives. The purpose of each station should be described in the sampling and analysis plan or work plan. This will help minimize the number of samples needed and ensure the objectives of sampling are clearly understood.

### 4.4.3 Incremental Sampling Methodology

In some cases it may be appropriate to characterize a sediment area with composite sampling rather than discrete samples. This section briefly describes an incremental sampling methodology (ISM) that may be appropriate for sediment in some cases. Updates will be provided as this approach is further refined.

Multiple increment sampling (MIS) is a specific methodology originally developed for the sampling and analysis of munitions residues in soil, but has been expanded to soils in general. A large number of discrete soil samples from a defined area are composited to calculate the true mean concentration for an area known as a “decision unit.” MIS involves both field and laboratory subsampling and compositing, generally through the following steps:

1) Divide field area into 30–50 grids.
2) Collect equal volumes from each grid. The final volume may contain 1–5 kg of material.

3) In the laboratory, sieve the material (typically with a #10 [2-mm] mesh size), which is then milled or ground.
4) Spread out sieved material and divide into 30–50 grids.
5) Take less than 1 g from each grid. Extract the final composite (10–30 g) in its entirety and analyze.
6) If another composite is needed for additional analysis or archival, repeat step 5.

National guidance for MIS as it applies sediment is not yet available, although detailed guidance for soil has been developed (ITRC 2012). Because MIS applies to soil, this type of sampling for sediment is referred to as ISM in SCUM, with minor laboratory modifications for sediment. A number of states and agencies have adjusted this approach for sediment and used it successfully to obtain a representative mean concentration for an area (e.g., HDOH 2011; MFA 2013; OEPA 2007, 2009; ODEQ 2012). ISM can also reduce analytical costs by compositing multiple subsamples into a single sample for analysis that is representative of a large area, although field sampling and laboratory sample preparation may be more time-consuming due to the large number of subsamples composited in the field and laboratory.

Central to the concept of ISM is the identification of decision units based on the CSM for the site (Chapter 3 Section 3.3). A decision unit is the smallest volume of sediment for which a separate decision of some kind will be made. During the FS or compliance monitoring, a decision unit could be consistent with a sediment management area (Chapters 3 Section 3.3.7, 12 and 13).

Ecology may consider use of ISM for evaluating sediment management areas that are expected to be relatively homogenous, including areas that have been actively remediated or areas where natural recovery is expected to occur. See Chapter 13, Section 13.6.1 for guidance on using ISM for compliance monitoring. Decision units should be contiguous and selected to minimize the heterogeneity of the sediment. Multiple decision units may be needed within a site and should correspond to areas already identified in the CSM, such as exposure areas or sediment management areas. The final decision units and sampling design should be included in the SAP.

Ecology will not allow ISM for the following purposes:

- During the RI, especially during the early phases due to the need to characterize spatial gradients and benthic effects.
- To determine compliance with the benthic criteria, which must be on a point-by-point basis.
- Sampling to determine source control effectiveness.

Additional uses of ISM will be considered on a site-specific basis.

See ITRC (2012) for the most recent guidance on sampling design. In general, grid designs are used with a minimum of 30 subsamples, but more may be needed depending on the expected

heterogeneity of the sediment, the estimated mean and variance, and how close the mean is expected to be to the cleanup level. The same volume of sediment should be taken from each subsample to ensure equal representation throughout the decision unit. Any depth can be targeted, but all subsamples within a composite must be collected from the same depth interval. The depth interval should normally correspond with the depth of compliance for the type of exposure area being sampled, or a deeper depth being managed separately (e.g., a dredging horizon).

Frequently, several ISM samples are collected within one decision unit to obtain an estimate of the variance on the mean. It may be necessary to archive sediment from each subsample to conduct individual analysis. It may be appropriate to analyze the individual subsamples in addition to the composite material to monitor sample homogeneity. It may also be appropriate to analyze them if the chemical concentration in the composite exceeds the cleanup level, which can occur due to a few subsamples or a small area within the sampling grid.

The ISM laboratory steps that include drying and milling or grinding should not be done for sediment. Instead, wet sieving is recommended.

ISM is not recommended when:

- The sediment contains a high percentage of clay or other materials that would prevent homogenization.
- The sediment contains fill, wood waste, or other non-native material.
- The target analytes should not be composited due to their volatility (e.g., VOCs, sulfides, or ammonia).
- Sediment concentrations are expected to be highly heterogeneous or have strong spatial gradients that should be monitored over time (e.g., for source control).

### 4.4.4 Water depth

The depth of water at each sampling station is important to consider and document. After locating sampling stations (e.g., at the point of discharge from an outfall or in an area of suspected sediment contamination), additional stations should be positioned nearby at similar depth(s) for comparison, because currents typically flow along contours of equal depth rather than across them. Reference stations for benthic community analyses should also be at a similar depth to site stations because the benthic community can be stratified by depth. However, similar depths are not necessary for bioassay tests.

It may not always be possible to locate stations at similar depth(s). For example, site stations in a grid pattern may need to be placed at different depths. Also, transects designed to investigate potential gradients between two sources may include stations at different depths if the sources are at different depths. Therefore, some flexibility in this general guideline may be necessary.

### 4.4.5 Sampling depth interval

Sediment investigations are generally focused on assessing the condition of sediment where there may be a pathway to the benthic community, higher trophic levels, or humans. However, contamination of sediment at depths below the biologically active zone is generally not as great a concern unless there is a risk of exposure to humans or aquatic life. For example, if vessels in the area have the potential to redistribute contaminated sediment from below the biologically active zone, then characterization below this zone may be necessary.

Past studies in Puget Sound have demonstrated that the majority of marine benthic macroinvertebrates are generally found within the uppermost 10 cm of the sediment. However, some important commercial and subsistence shellfish species (such as geoduck) may be found at deeper depths. In the absence of such species, sampling of the uppermost 10 cm of sediment for comparison with the SMS criteria is generally recommended. The biologically active zone in freshwater sediment is highly site-specific, and will need to be determined on a site-specific basis as part of the remedial investigation. For further information on the biologically active zones for marine and freshwater sediment, see Chapter 3 Section 3.4.1.

Sediments that are being characterized for protection of human health can be composited over a depth deeper than the biologically active zone to assess risk from intertidal activities such as shellfish collection and beach play. However, this depth should be established on a site-specific basis, depending on the exposure pathways being evaluated. In summary, Ecology may require, or the PLP may request, establishment of a different biologically active zone depending on the species, exposure routes, and site conditions. See Chapters 3 (Section 3.4.2) and 7 for further information on establishing the appropriate point of compliance post-remediation.

In some cases, monitoring data may be used to interpret temporal changes in sediment conditions. Such cases may include ambient monitoring programs or monitoring to determine the effectiveness of source control as part of the cleanup action. In such cases, it is appropriate to limit the sampling to the uppermost 2 cm of sediment, which would represent the most recent sediment deposition. If deeper sediment samples were collected and analyzed, older sediment would be included which would make detecting temporal changes more difficult. See Chapter 13 for further details on monitoring.

The targeted depth of sediment to be sampled may influence the selection of appropriate sampling station locations, because sediment grain size may vary spatially and affect the ability to collect samples from the targeted depth with the available sampling gear. The targeted depth of sediment to be sampled will also influence the selection of the most appropriate sampling gear (see Section 4.5.2).

In sediment cleanup investigations, it will often be important to characterize sediment conditions below the biologically active zone in order to estimate the volume of sediment that will

potentially require remediation. In general, it will be necessary to sample the sediment over the entire depth of suspected contamination and just below the depth of contamination in order to predict the condition of surface sediment if the overburden were removed. When assessing the depth of sediment that may be contaminated, factors to consider include:

- The depth of the sediment layer potentially subject to anthropogenic influences (e.g., the depth of sediment accumulated, such as the maximum dredged depth within a navigation channel or berth).
- The depth of sediment potentially affected by historical activities, recent activities, or ongoing activities.
- Local sedimentation rates.
- The potential for disturbance or exposure of the sediment, either through intentional (e.g., maintenance or cleanup dredging), unintentional (e.g., propeller scour, log-raft grounding), or natural (e.g., erosion) means.
- The pathway for introducing the sediment contaminants (e.g., a one-time spill, a long-term discharge, groundwater intrusion).

### 4.4.6 Other factors

Several additional factors may need to be considered to select appropriate sampling station locations. Reference sediment for bioassay testing should be collected from areas where grain size, particularly the percent fines fraction, is similar to site sediment. For evaluations of benthic community analyses, reference sediment should be collected from areas where the sediment grain size, organic carbon content, and water depth are similar to site sediment. Information on the depth, sediment grain size, organic content, and contaminant concentrations of selected Puget Sound reference areas is available in PSEP (1991). Ecology recommends using reference sediment stations from those areas for Puget Sound.

The SMS freshwater bioassay tests are compared against laboratory negative control sediment because recommended freshwater reference areas have not been identified. However, Ecology may approve the use of freshwater reference stations on a case-by-case basis. These reference stations should be selected to match site stations' sediment characteristics as closely as possible, and placed as far as practical from known or suspected contaminant sources. A process for selection of freshwater reference sites is described in the 2008 SMARM paper *Reference Areas for Freshwater Bioassays* (see Appendix B, Bioassays section).

Depending on the purpose of the sediment investigation, it may be prudent to avoid locating sampling stations within areas that have recently been dredged, capped, or otherwise affected by construction activities.

Factors such as bottom slope, currents, vessel traffic, and debris or obstructions on the sediment bed may affect the ability to collect sediment samples and should be considered when selecting appropriate sampling station locations. In some cases, such factors may preclude sampling within an area of interest. In other cases, careful planning of the timing of sampling may allow access to locations during periods of slack currents or reduced vessel traffic.

## 4.5 Field Sampling Methods

This section provides guidance on selecting appropriate field sampling methods for sediment investigations. Included is information on station positioning methods; sampling equipment; decontamination procedures; sample compositing; sample containers and labels; field documentation; and disposal of contaminated sediment.

### 4.5.1 Station positioning

Station locations should generally be accurate to within ± 3 meters. The sampling location should be referenced to the actual deployment location of the sampler using GPS or a similar system. For hard-to-reach areas (e.g., under piers or other structures that may be out of line-of-sight), distances can be measured using tape or other means from known surveyed points or structures.

Station locations should be reported a) in latitude and longitude (to the nearest hundredth of a second); or b) in state plane coordinates as the Washington State Plane North or South Zone with a datum of NAD 83 HARN in units of U.S. survey feet.

### 4.5.2 Sampling equipment

The primary goal of sediment sampling is to collect a sample that accurately represents *in situ* conditions. The sampling equipment selected will depend on the study objectives; the numbers and types of analyses required; the available sampling vessel; weather conditions; the type(s) of sediment being collected; and the sampling depth.

There are two general types of sediment samplers that are recommended:

- Surface sediment samplers. Collection of surface sediment samples is usually required for physical, chemical, and biological analyses.

- Subsurface sediment corers. Sediment corers are most often used for chemical analyses in subsurface sediment, and for bulk characterization of sediment when evaluating dredging and disposal options. Sediment corers can provide samples and profiles of subsurface sediment in which *in situ* conditions are preserved. The surface layer may be disturbed by some types of corers:

    - Immediately prior to impact by the water being pushed ahead by the corer.

  - By distortion caused by compaction of the sediment during collection.

- Although rotary drilling methods are capable of collecting long sediment cores, even in areas with consolidated sediment, they are rarely used in sediment investigations because of the greater cost of a drilling rig.

The advantages and disadvantages of various sediment samplers are summarized in Table 4-5. More in-depth information on sediment samplers can be found in a) Baudo 1990, b) Burton 1992, c) Mudroch and MacKnight 1991, d) APHA 1989, e) USEPA 2003a, and f) ASTM 2002. An overview of the two general types of sediment samplers is presented in the following sections.

#### 4.5.2.1 Surface Sediment Samplers

Surface sediment samplers are usually designed as a box with a set of jaws or a rotating bucket that takes a wedge-shaped bite out of the surface sediment. These samplers can collect small or large sample volumes and are effective for a wide range of surface sediment types. They are easy to use, and the smaller grab samplers allow hand deployment and retrieval from a small boat. Grab samplers generally do not disturb the surface sediment significantly unless they over-penetrate. Penetration depths of grab samplers can be highly variable, depending on sampler design and sediment composition. Disadvantages of the grab sampler include uncertainty of the depth of sediment penetration, and the loss of sample integrity when the sampler is retrieved and opened. Box corers, which consist of a metal box with a closing mechanism to seal the bottom of the core, overcome these disadvantages but are generally heavier and require a winch and a larger sampling vessel.

When selecting a surface sediment sampler, the method of retrieval, the type of sediment, the required sample volume, and the strength of currents at the site should be considered.

#### 4.5.2.2 Subsurface Sediment Corers

Sediment coring is done by inserting a cylindrical tube into the sediment, closing the top of the tube, and withdrawing a sediment core. Subsurface sediment corers differ greatly in size and complexity. Small push corers and small gravity corers can be operated by hand and used from a small boat. Larger and more complicated corers such as piston corers, vibra-corers, and impact corers require a lifting boom, a winch, larger sampling vessels, and more field crew.

Problems in sediment coring are often associated with inadequate sediment penetration, core distortion, or inadequate core retention during corer retrieval. Heavy weights or vibrations applied to the core tube can improve penetration in dense sediment. Various types of core “catchers” installed at the lower end of the core tube can prevent sample loss in unconsolidated sediment. However, these catchers can also impede penetration in compacted sediment as well as disrupt surface sediment. Corer deployment can also be difficult under certain conditions. It may be

necessary to 3-way anchor the sampling vessel to maintain a steady position while the corer penetrates the sediment. Trying to core in a strong current or wind, even with the vessel properly anchored, can result in the corer penetrating the sediment at an angle or core tubes being bent during retrieval.

### 4.5.3 Recommended sampling equipment and procedures

In shallow water that is inaccessible to the bigger vessels needed to deploy large grab samplers or sediment corers, collection of sediment samples is generally done with hand-held sediment corers or small grab samplers that can be operated by hand. In deeper water accessible to large sampling vessels with power winches, the most commonly used grab sampler is the modified 0.1-$m^2$ Van Veen grab sampler. This grab sampler achieves good penetration (generally 10 – 20 cm in soft sediment) with minimal disturbance of the sediment surface, and is recommended for collecting shallow surficial sediment (e.g., 0 – 10 cm). Recommended procedures for using sediment grab samplers are described in detail in the PSEP protocols (PSEP, 1986).

Sediment samples collected with a grab sampler should be carefully inspected to ensure that the following acceptability criteria are met:

- The sampler is not over-filled so the sediment surface is not pressed against the top of the sampler.
- Overlying water is present (indicates minimal leakage).
- The overlying water is not excessively turbid (indicates minimal sample disturbance).
- The sediment surface is relatively flat (indicates minimal disturbance or winnowing).
- The necessary penetration depth is achieved (e.g., several centimeters more than the targeted sample depth).

If a sediment sample does not meet all of these criteria, it should be rejected.

In coarse, sandy sediments the Van Veen grab may not yield sufficient penetration if the goal is to sample the upper 10 cm. In that case, it may be necessary to employ a power grab, which is heavier than a Van Veen and has a hydraulic closure that makes it capable of penetrating harder substrates. Hydraulic power grabs, however, require a specially outfitted vessel for deployment.

If the goal is to collect longer sediment cores or penetrate hard substrate, Ecology recommends either vibracorers or impact corers.

### 4.5.4 Porewater sampling

Sediment porewater concentrations are often used as a measure of the bioavailability chemicals. In some investigations, it may be necessary to sample porewater in addition to bulk sediment. When collecting porewater samples, it is important to only sample the interstitial water and avoid any overlying water.

At subtidal sampling stations, methods for collecting porewater are the same as those for collecting bulk sediment. Only grabs where overlying water is present should be retained, as these grabs indicate no leakage. The overlying water should be siphoned off and the sediment should be placed in the sample container (typically 1 liter) prior to homogenization. If sulfides and/or ammonia are to be analyzed, the sample container should contain no headspace to minimize oxidation. Once the samples arrive at the laboratory, each sample will be centrifuged to separate the porewater and sediment.

In the intertidal zone and in some cases in the subtidal zone, other options are available for porewater sampling using passive samplers. These are detailed in EPA's guidance (USEPA 2017) on passive samplers and examples are described in this section. "Peepers" are containers filled with distilled, deoxygenated water and have lids equipped with permeable mesh membranes. Peepers are generally buried in the sediment for a two-week deployment period to allow water concentrations inside the peepers reach equilibrium with the porewater. However, the time to reach equilibrium is a function of the type of chemicals in the sediment, sediment type, peeper volume, and mesh pore size (EPA 2001). Positioning of the peepers should be marked on a hand-held GPS and flagged to ensure their recovery. Once retrieved, the peeper container's exterior should be cleaned, and the lid should be replaced or the permeable membrane sealed to prevent exposure to oxygen.

Another option for *in situ* collection of porewater chemicals are solid phase microextraction (SPME) fibers (Maruya 2010). SPME fibers are small pieces of gas chromatography columns that absorb dissolved semi-volatile organic chemicals in porewater. SPME fibers may be a suitable method for analytes that require a volume of water that is too large to be obtained by other methods. Prior to deployment, SPME fibers must be placed in a protective, yet permeable housing made of a material such as glass fiber filters. Positioning of SPME fibers matches that of peepers. SVOC concentrations between the SPME fibers and porewater typically reach equilibrium between 30 and 60 days. Once recovered, SPME fibers are sent to the analytical laboratory for extraction. In many cases, SPME fibers can be reused after laboratory conditioning with a solvent rinse (Maruya 2010).

### 4.5.5 Decontamination procedures

Procedures for decontaminating field sampling equipment are briefly described in PSEP (1997c), but some of the recommended procedures are out of date (including solvent rinses for most

sampling efforts). In general, decontamination procedures for field sampling equipment should include scrubbing the equipment with a brush and phosphate-free detergent solution, followed by a rinse with a) clean site water (for marine or estuarine sediment); or b) deionized water (for freshwater sediment). At sites with high levels of contamination, particularly oil and grease, a solvent rinse may still be necessary. If needed, the equipment should undergo standard decontamination followed by a solvent rinse (acetone or hexane) and a final rinse with site water or deionized water. If a solvent rinse is necessary, the used solvent should be retained in an appropriate vessel and correctly disposed.

Decontamination should always be conducted between stations. It is generally not necessary to decontaminate sampling equipment between collections of composite sediment samples from a single station, but equipment should be decontaminated when using incremental sampling of composite sediment samples (Section 4.4.3).

Even when using field decontamination procedures, other precautions should be taken to minimize sample contamination. For example, sediment for chemical analyses should be collected away from the surfaces of the sampling device, thus minimizing the possibility of contaminating a sample with any residues left on the sampling device from earlier sampling. If information about the level of contamination is known, the potential for cross-contamination can be reduced by sampling the lower concentration areas first. Note that most sampling gear is lowered through the water column before collecting the sediment sample, so the surface of the sampling device may come in contact with potentially contaminated water overlying the sediment surface.

### 4.5.6 Sample compositing

Sample compositing may be necessary during discrete sampling when the sampling device contains insufficient sediment volume for the required analysis. Ideally, a single cast of the sampling device at each station should be sufficient to obtain the appropriate volume for analysis. In practice, it is often necessary to collect more than one cast if larger volumes of sediment are required. In such cases, multiple casts of the sampling device should be made at the same station and target depth, taking care to sample as close as possible to other casts at that station. Sediment from each cast of the sampling device should be combined, after removal of unrepresentative material (e.g., woody debris, shells, rocks), and homogenized to a uniform appearance by stirring. Subsamples should then be taken from this composite sediment sample for chemical analyses, physical analyses, and bioassay testing.

The same volume of sediment should be taken from each cast to ensure equal representation and the total should be sufficient to meet the required final sample volume. Accumulated sediment from the subsamples should be stored in stainless steel bowls and covered with aluminum foil between casts.

There are two cases when sediment collected for analysis should not be composited and/or homogenized:

- When sampling for potentially volatile chemicals. Sediment samples collected for the analysis of potentially volatile chemicals (e.g., total sulfides, volatile organic compounds) should be taken from the sampling device immediately after retrieval and placed in appropriate sample containers prior to homogenization and subsampling for other analyses.

- When sampling for benthic community analyses. Sediment samples collected for benthic community analyses should be handled as separate and distinct replicates rather than homogenized. Sediment required for chemical analyses, physical analyses, or toxicity testing should be collected in one or more casts of the sampling device separate from those used for sampling benthic macroinvertebrates at that station.

### 4.5.7 Sediment volumes, sample containers, and labels

Different amounts of sediment are required for different types of analyses (Table 4-6). When designing a sediment investigation, the total amount of sediment required from a given station should be calculated based on the types of required analyses. The total amount of sediment will impact selection of the appropriate field sampling equipment, the time required to collect the samples, and the appropriately–sized field equipment (e.g., bowls for homogenizing the sediment). Allowance should be made for a) collecting additional sediment for field duplicate samples; b) laboratory QA/QC samples; c) repeated analyses in the case of laboratory error or failure of a bioassay test; and d) archiving of sediment samples for future analyses. It may be necessary to collect twice the volume of sediment required for bioassay tests and archive half of them if reanalysis will be needed. If a broad spectrum of chemical and biological analyses is required, the total volume of sediment may be 10 L or more.

Depending on the depth of sediments, this total amount will require multiple casts at each station.

The appropriate types of sample containers depend on what analyses will be conducted (Table 4-6). If the same laboratory will perform multiple analyses, it is not necessary for each type of analysis to have a separate sediment sample jar. Two or more sediment subsamples from the same station may be combined in a single sample jar as long as the required container types are the same (Table 4-6) and the sample preservation methods and maximum holding times are compatible (Table 4-7). The analytical laboratory should be consulted for guidance on which subsamples are appropriate to combine in the same jar. In most cases, the analytical laboratory should be responsible for providing the sample jars and ensuring the jars have been cleaned and prepared in accordance with methods described in the PSEP protocols (PSEP, 1997c).

Self-adhesive labels should be attached to the outside of every sediment sample container. Each sample should be labeled in waterproof ink with the following information:

- Sample identification name or number
- Site or project name
- Station number
- Sampling date and time
- Sampling personnel
- Preservative (if appropriate)
- Benthic macroinvertebrate samples that have been sieved and preserved with formalin should be placed in sample containers and labeled as above.

### 4.5.8 Field documentation

To ensure proper record keeping, most firms have standardized forms for recording field activities. It is the responsibility of the chief scientist to ensure that all necessary forms are completed accurately and that all pertinent information is recorded. Although the content of such forms may vary, a recommended list of appropriate forms is as follows:

- Field log. General information such as the names of the field crew, arrival and departure dates and times, weather, and other miscellaneous observations should be recorded in a field log.

- Station/sample log. Each gear deployment event should be recorded on a station log sheet. One or more station/sample log sheets may be completed for each station where sediment sampling is conducted. The station name; date; time; gear and cast number; water depth; and location coordinates should be recorded on each log sheet. Penetration depth; sediment type; sediment color; sediment odor; presence of any organisms and obvious evidence of contamination (e.g., sheen, wood waste, oil droplets, sandblast grit, paint chips); sample type; sample identifier; and unique sample number should be recorded. If any materials such as woody debris, shells, or rocks are removed prior to homogenizing the sample, the type of material and approximate quantity should be noted. Any deviations from the sampling and analysis plan necessary based on field conditions should be noted.

- Chain-of-custody form. See Section 4.6.2.

### 4.5.9 Disposal of contaminated sediments

It is generally considered acceptable practice to return excess sediments (collected but not needed for analysis) to the water at the station where they were collected. However, sediments with visible evidence of contamination (e.g., oily droplets, sheen, paint chips, sandblast grit, other wastes) should not be returned to the water. Instead they should be retained in a watertight drum on board the vessel for appropriate disposal onshore. In some cases, field sediment may be brought to shore for compositing and subsampling, and it may not be practical to return any excess sediments to the station where they were collected. In such cases, the excess sediments should also

be retained for appropriate disposal onshore. Decisions regarding the appropriate disposal of excess sediments may depend on the chemistry results. Sediments are rarely contaminated to an extent that would require special handling and disposal as dangerous or hazardous wastes, but provisions must be made for appropriate disposal if that were the case.

## 4.6 Sample Handling Procedures

This section provides guidance on procedures designed to ensure sample integrity between field collection and laboratory analyses. It also discusses sample storage requirements, chain-of-custody procedures, and delivery of the samples to analytical laboratories. The best analytical methods and procedures can fail and yield incorrect data if samples are improperly handled and prepared.

### 4.6.1 Sample storage requirements

Appropriate methods for sample preservation (e.g., freezing, refrigerating, fixation) and sample storage (e.g., maximum holding time) depend on the type of analyses (e.g., chemical/physical analyses, bioassay testing, benthic community analyses).

#### 4.6.1.1 Chemical/physical analyses

Sediment samples for chemical/physical analyses should be transported to the analytical laboratory on ice at 4 °C. Upon receipt at the laboratory, storage temperature and maximum holding time will be determined based on the analyses to be performed. In some cases, the requirements may vary, depending on how long it will be before the laboratory expects to analyze the samples. Required storage temperature and maximum holding time are presented in Table 4-7. Sediment samples may be archived for later analysis by freezing and storing at -18 °C. Samples to be analyzed for grain size, ammonia, total sulfides and volatile organic compounds should not be frozen. Allowance for expansion of the sample should be made to prevent breakage of the sample bottles upon freezing. The archived samples may be thawed within the maximum holding times listed in Table 4-7 and analyzed for the appropriate analytes.

#### 4.6.1.2 Bioassay testing

Sediment samples intended for bioassay testing should be transported to the toxicology laboratory on ice at 4 °C. The samples should be held in the laboratory in the dark at 4 °C and should not be frozen. There are special cases where freezing a sediment sample prior to conducting bioassays may be appropriate to eliminate indigenous species that may interfere bioassay test results. In these cases, Ecology must approve of such plans before the sample is frozen. According to the PSEP (1995) toxicity test guidelines, all toxicity tests should be initiated as soon as possible (ideally within 2 weeks of collecting the samples in the field). Maximum holding times are important when conducting chemical analyses prior to bioassay testing. This tiered approach is used by the DMMP to evaluate dredged sediments for

unconfined, open-water disposal in Puget Sound. The DMMP allows sediment samples to be held at 4 °C in the dark in a nitrogen atmosphere up to 8 weeks prior to bioassay testing. Because the results of recent studies evaluating the effects of sediment holding time on sediment toxicity have been variable, it is prudent to store sediments for as short a time as possible after field collection. If there are no other compelling reasons otherwise (such as the tiered testing schedule under the DMMP), a maximum holding time of 2 weeks is recommended, and based on the analyst's best professional judgment. If logistical constraints mandate a holding time longer than 2 weeks, the DMMP sample storage requirements should be followed.

Regardless of which holding time is used, it is essential that the holding time and conditions be reported along with the bioassay test results.

#### 4.6.1.3 Benthic macroinvertebrate community analyses

Sediment samples to be analyzed for benthic community analyses should generally be sieved and fixed in the field for the reasons described in the PSEP (1987) protocols. If sieving must be delayed, it is possible to fix the sediment samples in their entirety and sieve at a later time, but the precautions described in the PSEP (1987) protocols should be followed. Fixation of the material retained on the sieve can be done by adding formalin. A vital stain may be added to help sort the samples in the laboratory and a relaxant (e.g., magnesium chloride) may be used to decrease breakage of the organisms and facilitate taxonomic identification. The samples should remain exposed to formalin for a minimum of 24 hours (to ensure adequate fixation) and a maximum of 7 – 10 days (to reduce the risk of decalcifying mollusks and echinoderms). Thereafter, the samples should be thoroughly rinsed and transferred to a 70% solution of ethanol for storage until taxonomic sorting and identification.

### 4.6.2 Chain-of-custody procedures

Documenting the chain-of-custody between sample collection and arrival at the analytical laboratory is necessary. Each sample container should be recorded on a chain-of-custody form at the end of each sampling day. The chain-of-custody form should be completed in duplicate or triplicate and include the sample collection date and time, the project, and the chief scientist's name. It is the chief scientist's responsibility to ensure that these forms are accurately completed and signed at the time of sample transfer. One copy of the form should be placed in a waterproof bag and attached to the inside of each sample cooler. The chief scientist should keep one copy of the form. In the event that sediment subsamples are sent to different laboratories (e.g., chemistry laboratory, toxicology laboratory), separate chain-of-custody forms should be prepared for each laboratory and each sample cooler. The sample cooler should be sealed with chain-of-custody tape and kept in a secure location when not in the presence of the chief scientist or assigned crew.

### 4.6.3 Delivery of samples to analytical laboratories

Individual sample bottles should be sealed with tape to prevent leakage, and glass bottles should be wrapped with a shock absorbent material (e.g., plastic bubble wrap) to prevent breakage during shipment. The sample bottles should then be placed in individual plastic bags and packed in an ice chest or other suitable container with bubble wrap, vermiculite, or other packing material to prevent shifting of contents during transport. Until the samples are delivered to the laboratory, they should be held at 4°C using ice sealed in plastic bags to prevent contamination from melt water. If any of the collected samples are considered hazardous materials, the sample packaging and shipping procedures should follow U.S. Department of Transportation regulations specified in 49 CFR 173.6 and 49 CFR 173.24. Every shipping container should be clearly labeled with all pertinent information: name of project; time and date container was sealed; person sealing the container; name, address, and telephone number of the party sending the samples; and name, address, and telephone number of the analytical laboratory. One copy of the chain-of-custody form should be placed in a waterproof bag and sealed inside the lid of the container. A chain-of-custody seal should be placed on the outside of the container before shipment or transfer to the laboratory.

To ensure timely delivery of samples to the analytical laboratories, couriers or overnight express delivery services are typically employed. The Sampling and Analysis Plan should describe the method of delivery needed to ensure that the laboratory receives the samples within 24 hours of being sealed. Upon receipt at the laboratory, the chain-of-custody seal should be broken, the condition of the samples should be noted and recorded, and the chain-of-custody form should be signed by laboratory personnel. The samples should be promptly placed in appropriate storage facilities, where proper temperature, atmosphere, and light conditions are maintained until the samples can be analyzed.

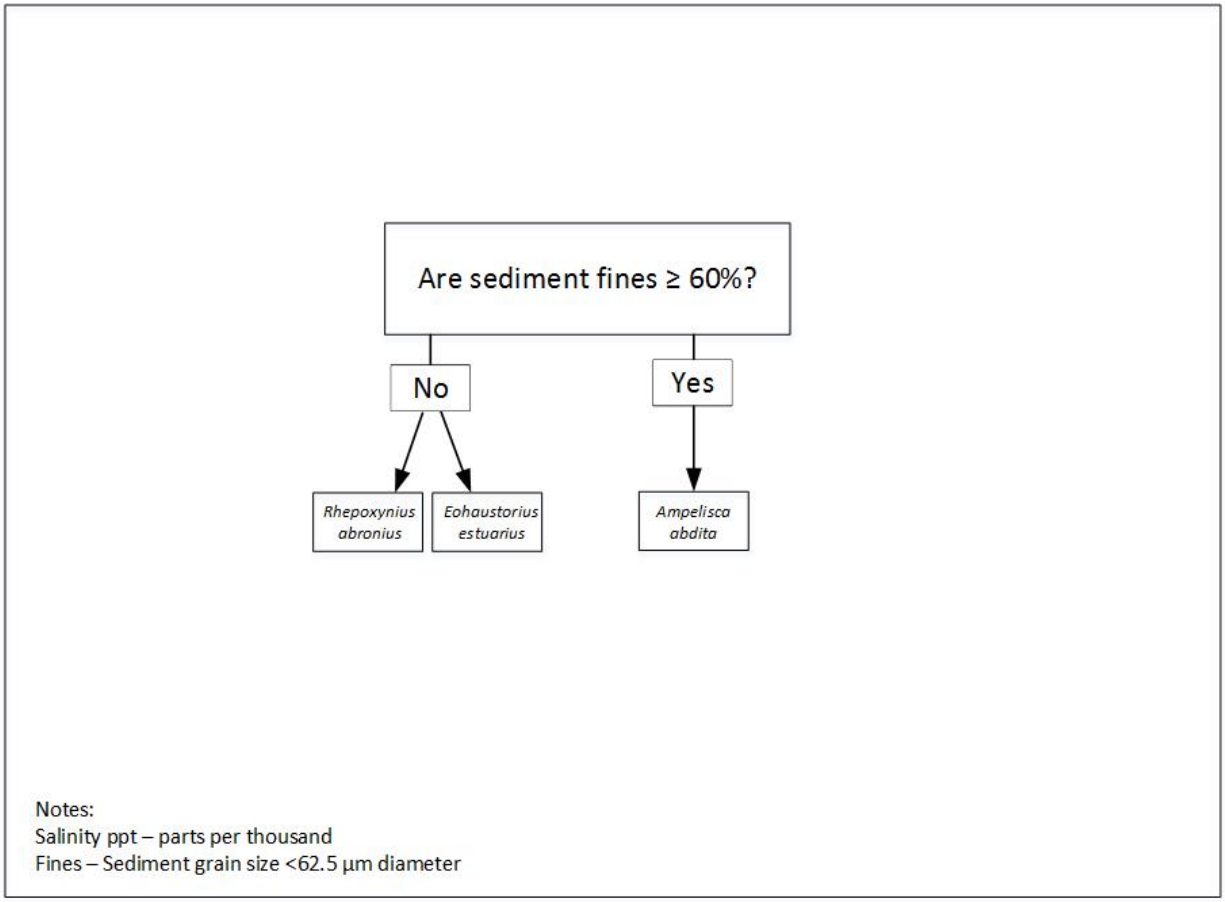



**Figure 4-1.** Selection of appropriate amphipod species for marine/estuarine toxicity tests.

**Table 4-1.** Chemicals that may be analyzed on a site-specific basis.

| Chemical Class | Example Individual Chemicals | Associated Sources |
|---|---|---|
| Ammonia | | Associated with stormwater/CSOs, fish processing plants, and aquaculture. |
| Other toxic metals | Metals not on the standard CoC list (e.g., beryllium) | Associated with mining wastes and metal plating operations. |
| Organotins | e.g. Tributyltin, dibutyltin, monobutyltin | Historical use as antifouling paint in marine waters; potentially associated with shipyards, dry docks, and marinas. |
| Pesticides/herbicides | Pesticides not included in the standard CoC list (e.g., glyphosate, pyrethrins) | Associated with agriculture, aquaculture, or agricultural chemical companies. |
| PCB congeners | Group of 209 individual PCB congeners; dioxin-like PCB congeners particularly of concern | Globally distributed; original sources include production of chlorinated pesticides, transformers, and as additives in some paints/caulks. |
| Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs) | Focus on the 17 congeners with 2,3,7,8-tetrachloro-dibenzo-p-dioxin (2,3,7,8-TCDD) activity | Associated with the presence of PCBs, 1,4,5-T, or pentachlorophenol; pulp and paper mills using chlorination; combustion such as waste incinerators, cement kilns, hog fuel burners, or structural fires; metals smelting; or refining/processing/burning of coal, wood and petroleum products in the presence of salt. |
| Wood waste | | Associated with log rafting and pulp and paper mills. |
| Semi- and Volatile organic compounds (SVOCs/VOCs) | Petroleum compounds not included in standard analyses (e.g., benzene, toluene, ethylbenzene, xylenes) | Typically related to cross-media transport from upland sites or ongoing sources of petroleum contamination. |
| Guaiacols and resin acids | | Byproducts of wood waste decay processes. |
| Volatile organic compounds (VOCs) | e.g., Trichloroethane, tetracloroethane | Used as solvents and in chemical manufacturing operations. |
| Radioactive substances | e.g., Uranium, plutonium, $^{14}C$, cobalt | Associated with nuclear power plants, nuclear processing plants, or medical wastes. |
| Explosives compounds | e.g., TNT, RDX, HMX | Associated with military installations or munitions loading areas. |

**Table 4-2.** Conventional sediment and water quality parameters applicable to sediment.

| **Conventional Sediment Variable** | **Use** |
|---|---|
| Total organic carbon (TOC) | • Presence of eutrophic and/or low dissolved oxygen conditions<br>• Normalization of the concentrations of nonionizable organic compounds<br>• Identification of appropriate reference sediments for biological tests (on a case-by-case basis)<br>• Understanding contaminant availability and toxicity |
| Sediment grain size | • Interpretation of sediment toxicity test data<br>• Wet sieving in the field for real-time matching of site and reference sediment percent fines when conducting bioassays<br>• Evaluation of sediment transport and deposition<br>• Evaluation of cleanup action alternatives<br>• Identification of appropriate reference sediments for biological tests (on a case-by-case basis) |
| Total volatile solids | • Evaluation of eutrophic and/or low dissolved oxygen conditions<br>• Measure of wood waste (Ecology, 2013a) in sediments |
| Total solids | • Expression of chemical concentrations on a dry-weight basis |
| Ammonia | • Interpretation of sediment toxicity test data and/or other deleterious substances<br>• Associated with stormwater/CSOs, fish processing plants and aquaculture |
| Total sulfides | • Identification of anoxic sediments<br>• Interpretation of bioassays |
| **Water Quality Measure** | **Porewater** |
| Temperature (°C) | • Understanding of contaminant availability and toxicity |
| Dissolved oxygen (mg/L or %) | • Presence of eutrophic or organically enriched conditions |
| pH (pH units) | • Understanding of contaminant availability and toxicity |
| Alkalinity | • Understanding of contaminant availability and toxicity |
| Hardness (mg/L $CaCO_3$) | • Understanding of contaminant availability and toxicity |
| Conductivity (µS/cm) | • Identification of ionic chemistry<br>• Understanding of contaminant availability and toxicity |
| Nutrients | • Indication of organic loading and potential for eutrophication and ammonia or sulfide enrichment |
| Dissolved organic carbon | • Understanding of contaminant availability and toxicity |

**Table 4-3.** Marine and low-salinity estuarine sediment toxicity tests.

| Toxicity Test | Test Species | Test Duration | Primary Endpoints | Interstitial Salinity (ppt) |
|---|---|---|---|---|
| **Acute Effects Tests** | | | | |
| Amphipod | *Rhepoxynius abronius* [b] | 10 days | Mortality | ≥ 25[c] |
| | *Ampelisca abdita* [b] | 10 days | Mortality | 20–35 |
| | *Eohaustorius estuarius* [b] | 10 days | Mortality | ≤ 32 |
| Larval | Oyster (*Crassostrea gigas*)[d] | 48–60 hours | Abnormality Mortality | ≥ 10[h,i] |
| | Mussel (*Mytilus galloprovincialis*)[e] | 48–60 hours | Abnormality Mortality | ≥ 10[i] |
| | Sand dollar (*Dendraster excentricus*) | 48–96 hours | Abnormality Mortality | ≥ 10[i] |
| | Sea urchin (*Strongylocentrotus purpuratus* or *S. droebachiensis*) | 48–96 hours | Abnormality Mortality | ≥ 10[i] |
| **Chronic Effects Tests** | | | | |
| Juvenile polychaete | *Neanthes* sp. | 20 days | Biomass | ≥ 20[f] |
| Microtox® (100 percent sediment porewater extract) | *Vibrio fischeri*[g] | 15 minutes | Luminescence | Not Applicable |

a, *In situ* test sediments should have interstitial salinities corresponding to the guidelines, except as noted. The use of any of these tests for low salinity sediments (interstitial salinities < 25 ppt) must be approved by Ecology on a case-by-case basis.

b, *Rhepoxynius abronius* is known to be adversely affected by sediments having ≥ 60% fine sediments (< 62.5 µm diameter). To test sediments having ≥ 60% fines, use *Ampelisca abdita*.

c, For assessments of sediments for dredging and DMMP disposal, upward adjustment of interstitial salinities between 15 and 24 ppt is possible, but for interstitial salinities < 25 ppt, use of *Ampelisca abdita* or *Eohaustorius estuarius* is preferred (see PSEP, 1995 for further details).

d, *C. gigas* larvae may be adversely affected by small sediment grain sizes. Use of *C. gigas* larvae for sediments known to have a high proportion of silt- and clay-size particles is therefore not recommended (PSEP, 1995).

e, PSEP (1995) and the SMS refer only to the use of *Mytilus edulis* in this test. However, it may be more accurate to refer to the test organisms used as members of the *Mytilus edulis* sibling species complex. Taxonomic studies of west coast mussels (McDonald and Koehn, 1988; McDonald et al., 1991; Geller et al., 1993) indicate that the mussels in Washington State are either *M. trossulus* (a more northerly species) or *M. galloprovincialis* (a more southerly species). The mussel species being used by most

biological laboratories in the Pacific Northwest is *M. galloprovincialis*. *M. edulis* does not occur locally and is therefore unlikely to be used in toxicity tests. This does not constitute a change in test organisms, but an acknowledgment that the organisms may have been previously misidentified.

f, Neanthes sp. may be adversely affected by interstitial salinities < 20 ppt. Use of the test for sediments having interstitial salinities < 20 ppt must be approved by Ecology on a case-by-case basis.

g, Formerly known as *Photobacterium phosphoreum.*

h, Oyster larvae may be adversely affected by small sediment grain sizes. Use of oyster larvae for sediments known to have a high proportion of silt- and clay-size particles is therefore not recommended (PSEP, 1995). Instead, either a sea urchin or sand dollar test would be preferable.

i, The PSEP (1995) protocols recommend against using the larval toxicity tests for sediments with interstitial salinities < 10 ppt because of the limited experience with the tests at these salinities. However, all of the larval toxicity tests can probably be used over a wide range of interstitial salinities (from full-strength seawater to < 1 ppt) because a small volume of sediments is mixed with a much larger volume of seawater, which has a salinity of 28 ppt, prior to testing. Use of the larval toxicity tests for such low salinity sediments should therefore be discussed with Ecology and considered on a case-by-case basis.

**Table 4-4.** Freshwater bioassay tests adopted in the SMS rule and additional tests.

| Tool/Test Species | Method | Measurement Endpoints | Reference | Acute/ Chronic/ Chronic Surrogate | Ease of Use | Repeat-ability | Protocol Status |
|---|---|---|---|---|---|---|---|
| **Sediment Benthic Tests** | | | | | | | |
| *Hyalella azteca*[a] | 10-day | Survival | b, c, d | A | 1 | 1 | 3 |
| *Chironomus spp*[a] *Midge* | 10-day | survival, growth | b, c, d | A | 1 | 1 | 3 |
| *Hyalella azteca*[a] | 28-day | survival, growth | d | C | 2 | 2 | 3 |
| *Chironomus spp*[a] *Midge* | 20-day | survival, growth | d | C | 1 | 2 | 3 |
| *Lumbriculus variegatus* | 10-day | Survival | b | A | 1 | 1 | 2 |
| *Tubifex tubifex* | 10-day | Survival | b | A | 1 | 1 | 2 |
| *Pristina spp.* (naidia oligochaete) | 10-day | Survival | b | A | 1 | ? | 2 |
| *Hexagenia spp.* (mayfly larvae) | 10-day | Survival | b | A | 1 | ? | 2 |
| *Anodonta spp*. (freshwater mussel) | 10-day | Survival | b | A | 1 | ? | 2 |
| *Hyalella azteca* | 42-day | survival, growth | d | C | 2 | 2 | 3 |
| *Chironomus spp Midge* | 40-day | life cycle | c, d | C | 1 | 2 | 3 |
| *Chironomus riparius* | 10 to 30-day | survival, growth, head capsule width, emergence | c | C | 2 | 2 | 3 |
| *Hexagenia spp*- Mayfly | 21- day | survival, growth | c | C | | | 3 |
| *Daphnia/Ceriodaphnia* | 7-day | survival, growth, reproduction | c | C | 1 | 1 | 3 |
| *Diporeia spp- Amphipod* | 28-day | survival and behavior | c | C | | | 2 |
| *Tubifex tubifex* | 28-day | survival and reproduction | c | C | | | 2 |
| **Water-column Tests** | | | | | | | |
| Cladocerans (*Daphnia, Ceriodaphnia)* | 96-h | Survival | b | A | 1 | 1 | 3 |
| Fish, *freshwater (Pimephales, Lepomis, Onchyrynchus, Ictalurus)* | 96-h | Survival | b | A | 1 | 1 | 3 |
| Cladocerans (*Daphnia, Ceriodaphnia)* | 7-day | Survival and reproduction | c | C | 1 | 1 | 3 |
| Microtox | 15-min | Bioluminescence | Appendix C | CS | 3 | 1 | 3 |

a, Biological tests adopted in the SMS rule (shaded grey).
b, USEPA/USACE (1998a)
c, ASTM (2010)
d, USEPA (2000)

**Table 4-5.** Advantages and disadvantages of sediment samplers.

| Type of Sampler | Advantages | Disadvantages |
|---|---|---|
| **Surface Sediment Samplers** | | |
| Van Veen or Young grab* | Useful in deep water and on most substrates. Young grab coated with inert polymer. Large sediment volume obtained. May be subsampled through lid. | Incomplete jaw closure possible. Young grab is expensive. Both may require a winch. |
| Ponar grab* | Commonly used. Large volume of sediment obtained. Adequate on most substrates. Weight allows use in deep waters. Good sediment penetration. | Incomplete jaw closure occurs occasionally. Heavy and requires a winch. |
| Petite Ponar grab* | Similar in design to the Ponar grab, but smaller and more easily handled from a small boat. Can be deployed by hand without a winch in shallow water. | Small volume. Incomplete jaw closure occurs occasionally. May require winch in deeper water. |
| Ekman or box dredge* | Relatively large volume of sediment may be obtained. May be subsampled through lid. Lid design reduces loss of surficial sediments as compared to many dredges. Usable in moderately compacted sediments of varying grain sizes. | Incomplete jaw closure occurs in coarse-grain sediments or with large debris. Sediment integrity disrupted. |
| Power grab* | Relatively large sediment volume. Able to penetrate and retrieve sediments high in sand, gravel, and small cobble. | Requires hydraulic cable equal to the water depth to operate. Must be deployed from a specialized vessel. |
| Petersen grab* | Large sediment volume obtained from most substrates in deep waters. | Incomplete jaw closure may occur. May require winch. |
| Orange-peel grab* | Large sediment volume obtained from most substrates. Efficient closure. | Requires winch. |
| Shipek grab | Adequate on most substrates. | Small volume. Loss of fine surface sediments and sediment integrity. |
| **Sediment Corers** | | |
| Vibracorer | Samples deep sediment for historical analyses. Samples consolidated sediment. | Expensive and requires winch and A-frame. Outer core integrity slightly disrupted. |
| Impact corer | Samples deep sediment for historical analyses. Samples consolidated sediment. | Large impact corers may be expensive and require specialized sampling vessel. Outer core integrity slightly disrupted. |

**Table 4-5** (continued)**.** Advantages and disadvantages of sediment samplers.

| Type of Sampler | Advantages | Disadvantages |
|---|---|---|
| **Sediment Corers** | | |
| Box corer | Maintains sediment layering of large volume of sediment. Fine surface sediments retained relatively well. Quantitative sampling allowed. Excellent control of depth of penetration. | Size and weight require power winch; difficult to handle and transport. Some box corers may not be suitable for sampling very coarse sediments. |
| Hand and gravity corers | Maintain sediment layering of the inner core. Fine surface sediments retained by hand corer. Replicate samples efficiently obtained. Removable liners. Inert liners may be used. Quantitative sampling allowed. | Small sample volume. Gravity corer may result in loss of fine surficial sediments. Liner removal required for repetitive sampling. Not suitable in coarse-grain or consolidated sediments. |
| Piston corer | Samples deep sediment for historical analyses. Samples consolidated sediments. | Expensive and requires winch and A-frame. Outer core integrity slightly disrupted. |

**Source:** Adapted from Burton (1992).

***** A downside of all grab samplers is the potential loss of fine surface sediments and sediment integrity during sampling.

**Table 4-6.** Minimum sediment sample sizes and acceptable containers for physical/chemical analyses and sediment toxicity tests.

| Sample Type | Minimum Sample Size[a] | Container Type[b] |
|---|---|---|
| **Physical/Chemical Analyses** | | |
| Grain size | 100–150 g | P,G |
| Total solids | 50 g | P,G |
| Total volatile solids | 50 g | P,G |
| Total organic carbon | 25 g | P,G |
| Ammonia | 25 g | P,G |
| Total sulfides | 50 g | P,G[c] |
| Acid volatile sulfides | 50 g | G[c] |
| Oil and grease | 100 g | G |
| Metals (except mercury) | 50 g | P,G |
| Mercury | 1 g | P,G |
| Methyl Mercury | 100 g | G, T[c] |
| Organotins | 100 g | G (for bulk sediment) Pc, T (for interstitial water) |
| Volatile organic compounds | 50 g | G,T |
| Semivolatile organic compounds | 50–100 g | G |
| Pesticides and PCBs | 50–100 g | G,T |
| **Biological Toxicity Tests** | | |
| **Marine** | | |
| Amphipod (*Rhepoxynius abronius, Ampelisca abdita*, or *Eohaustorius estuarius*) | 0.25 L per replicate (1.25 L per station) | G |
| Bivalve larvae (*Crassostrea gigas, Mytilus* sp.) | 200 g (wet weight) per station | G |
| Echinoderm larvae (*Strongylocentrotus purpuratus, Strongylocentrotus droebachiensis,* or *Dendraster excentricus*) | 200 g (wet weight) per station | G |
| Juvenile polychaete (*Neanthes* sp.) | 0.25 L per replicate (1.25 L per station) | G |
| Microtox® 100% porewater | 0.5 L per station | G |
| **Freshwater** | | |
| Amphipod (*Hyalella azteca*) | 0.1 L per replicate (0.8 L per station) | G |
| Midge (*Chironomus tentans*) | 0.1 L per replicate (0.8 L per station) | G |
| Frog embryo *(Xenopus laevis)* | 45 g (dry weight) per station | G |
| Microtox® 100% porewater | 0.5 L per station | G |

It is recommended that adequate sample volume is collected and properly archived to duplicate the tests or analyses in case they must be repeated.

a, Recommended minimum field sample sizes (wet weight basis) for one laboratory analysis. If additional laboratory analyses are required (e.g., laboratory replicates, allowance for having to repeat

an analysis), the field sample size should be increased accordingly. For some chemical analyses, smaller sample sizes may be used if comparable sensitivity can be obtained by adjusting instrumentation, extract volume, or other factors of the analysis.

b, P - linear polyethylene; G - borosilicate glass; Pc – Polycarbonate; T - polytetrafluorethylene (PTFE, Teflon®)-lined cap.

c, No headspace or air pockets should remain. If such samples are frozen in glass containers, breakage of the container is likely to occur.

**Table 4-7.** Storage temperatures and maximum holding times for physical/chemical analyses and sediment toxicity tests.

| Sample Type | Sample Preservation Technique | Maximum Holding Time |
|---|---|---|
| Grain size | Cool, 4 °C | 6 months |
| Total solids | Cool, 4 °C<br>Freeze, -18 °C | 14 days<br>6 months |
| Total volatile solids | Cool, 4 °C<br>Freeze, -18 °C | 14 days<br>6 months |
| Total organic carbon | Cool, 4 °C<br>Freeze, -18 °C | 14 days<br>6 months |
| Ammonia | Cool, 4 °C | 7 days |
| Total sulfides | Cool, 4 °C, zero headspace required (a 250 ml sample for 5 ml of 2 N zinc acetate) | 7 days |
| Acid Volatile Sulfides | Cool, 4 °C, zero headspace required | 14 days |
| Oil and grease | Cool, 4 °C<br>Freeze, -18 °C | 28 days<br>6 months |
| Metals (except mercury) | Cool, 4 °C<br>Freeze, -18 °C | 6 months<br>2 years |
| Mercury | Freeze, -18 °C | 28 days |
| Methyl Mercury | Freeze, -18 °C | 8 days |
| Organotins<br><br><br><br><br>After extraction | Cool, 4 °C<br>Freeze, -18 °C<br>(for interstitial water analysis, extract water prior to freezing)<br><br>Cool, 4 °C | 14 days<br>1 year<br><br><br>40 days |
| Semivolatile organic compounds, pesticides, PCBs, PCDD/PCDF<br><br>After extraction | Cool, 4 °C<br>Freeze, -18 °C<br><br>Cool, 4 °C | 14 days<br>1 year<br><br>40 days |
| Volatile organic compounds | Cool, 4 °C, zero headspace required | 14 days |
| Sediment toxicity tests | Cool, 4 °C<br>Cool, 4 °C, nitrogen atmosphere | 2 weeks[a]<br>8 weeks[a] |

PCB - polychlorinated biphenyl
PCDD - polychlorinated dibenzo-p-dioxin
PCDF - polychlorinated dibenzofuran

a, The PSEP (1995) protocols recommend a maximum holding time of 2 weeks, but recognize that it may be necessary under certain circumstances to extend the holding time to accommodate a tiered testing strategy in which chemical analyses are conducted prior to toxicity testing. The DMMP, for example, allows sediments to be stored in the dark in a nitrogen atmosphere at 4 °C for up to 8 weeks. The 8-week holding time applies to reference and to test sediments which should be collected at the same time.

# Chapter 5
# Chemical Analyses, Biological Testing, and Quality Assurance/Quality Control

This chapter provides guidance on conducting chemical analyses, bioassay testing, and bioaccumulation testing for sediment investigations. These methods incorporate PSEP Protocols, which can be found at: https://fortress.wa.gov/ecy/publications/SummaryPages/1509046.html.

The methods also include updates to the PSEP protocols that were adopted through the SMARM process (Appendix B) or based on best available science.

## 5.1 Chemistry Analytical Methods

This section discusses analytical methods for sediment chemical analysis. Different preparation methods may have varying extraction and cleanup efficiencies. In order to compare data over time, it is critical to use consistent extraction and cleanup methods for a project. Additionally, when a sample has low total solids content, it may be necessary to adjust the preparation method to achieve lower PQLs. This can include special handling of the sample such as decanting overlaying water, centrifugation to remove water, or freeze drying.

### 5.1.1 Sediment Chemistry

The recommended sample preparation, cleanup, and analytical methods are summarized in Table 5-1. Specific issues associated with analysis of conventional sediment parameters, metals, and organics are discussed below. PQLs should be at or below applicable standards to meet the study goals (Table 8-1 for benthic criteria, Table 10-1 for natural background values, and Table 11-1 for PQLs).

#### 5.1.1.1 Conventional Sediment Parameters

PSEP 1986 guidelines are recommended for analysis of the conventional sediment parameters: ammonia, total sulfides, total volatile solids, and grain size. However, the EPA analytical method (USEPA 1986) is recommended for analysis of Total Organic Carbon (TOC), which is described in the 2002 SMARM clarification paper *Recommended Methods for Measuring TOC in Sediments* (Appendix B, Sampling and Testing Requirements Issue Papers Section ).

#### 5.1.1.2 Metals

The PSEP 1997a methods are recommended for analysis of metals. In special cases, alternative methods for analysis of organometallics (arsenic, mercury) may be necessary, which will be decided on a case-by-case basis.

To determine metal concentrations in sediment samples, the metals must be extracted prior to quantitative analysis. PSEP 1997a recommends strong acid digestion, which is acceptable for most applications except mercury. Total acid digestion is generally not recommended because it releases metals that are part of the mineral-bound matrix and requires the use of aqua regia or perchloric acid which have health and safety concerns. Strong acid digestion procedures include:

- Method 3050B: Acid Digestion of Sediment, Sludges, and Soil (USEPA 1986). This is a strong acid digestion method using nitric acid and hydrogen peroxide.
- Method 3051: Microwave Assisted Acid Digestion of Sediment, Sludges, and Soil (USEPA1986). This is a strong acid digestion method using nitric acid and hydrogen peroxide but is faster than Method 3050B and requires less acid.

#### 5.1.1.3 Organics

PSEP 1997b guidelines are recommended for the analysis of organic chemicals. Selected ion monitoring may improve the sensitivity of Method 8270D (USEPA 1996) and is recommended when PQLs must be low or when TOC levels elevate PQLs above the SMS benthic criteria. Alternative analytical methods that meet quality assurance (QA) requirements may be approved by Ecology on a case-by-case, with preference given for accredited methods. For example, when hexachlorobenzene or hexachlorobutadiene are analyzed by EPA method 8270D, they often have PQLs above the SMS criteria. However, these chemicals can be analyzed by EPA method 8081B which has lower PQLs (Appendix D).

***TOC and Practical Quantitation Limits***

When analyzing organic chemicals, it is important to achieve sufficiently low PQLs. This is particularly important when analyzing for bioaccumulative chemicals with very low risk-based criteria or samples with low TOC. Achieving the recommended PQLs identified in Appendix D will allow comparison with the SMS benthic chemical criteria for sediment with a normal range of TOC (0.5 – 3.5%) and PQL-based (sum TEQ) cleanup levels for bioaccumulatives. However, for sediment with low TOC (e.g., $\leq$ 0.5%), the TOC-normalized quantitation limits for certain chemicals may be above the SMS benthic criteria, which are TOC-normalized. See Section 5.1.1.4 for further information on PQLs.

Organic chemicals must be extracted into a solvent before cleanup and analysis can begin. Extraction methods for extractable, non-volatile organic chemicals include:

- Method 3540C: Soxhlet extraction (USEPA 2007a).
- Method 3550C: Sonication extraction (commonly referred to as ultrasonic extraction) (USEPA 2007a).
- Method 3545A: Pressurized fluid extraction (also called accelerated solvent extraction) (USEPA 2007a).
- Method 3546: Microwave assisted solvent extraction (USEPA 2007a).

Soxhlet and sonication extraction are the most commonly used laboratory extraction procedures. While sonication is somewhat faster, both procedures have comparable extraction efficiency.

Pressurized fluid extraction is less commonly used for sediment extraction. The procedure uses elevated temperature and pressure to extract organic chemicals. It is faster and uses less solvent than soxhlet extraction. The major drawback is poor extraction efficiency for samples that contain moderate to high moisture levels. This method may be impacted by super saturation when extracting highly contaminated material.

Microwave extraction is performed in a sealed container at lower temperatures and pressure than pressurized fluid extraction. This method may be impacted by super saturation when extracting highly contaminated material.

Because of the differences in extraction efficiencies, care should be taken to ensure that consistent methods are used throughout the project.

#### 5.1.1.4 Detection Limits

Achieving adequate analytical detection limits to support decision making is critical. For the SMS benthic chemicals (those not driven by human risk-based values), detection limits must be adequate to determine if the benthic criteria have been met. For bioaccumulative chemicals (those driven by risk to humans or higher trophic levels), it is critical that the lowest consistently achievable detection limits are achieved during the RI process. After the RI is complete and cleanup levels have been established, PQLs must be at or below any PQL-based cleanup levels (Chapter 11, Table 11-1).

Laboratories have varying definitions of reporting limits that are not necessarily consistent with the SMS definition. Ecology plans to work with local labs, and will consider new guidance that may be published by the EPA, to determine if future updates to the SMS definition are warranted. In the meantime, Ecology will use the following definitions.

***Definition of PQL***

The PQL is defined in WAC 173-204-505(15) as:

> *The lowest concentration that can be reliably measured within specified limits of precision, accuracy, representativeness, completeness, and comparability during routine laboratory operating conditions, using department approved methods. When the limit for an analytical method is higher than the concentrations based on protection of human health or the environment, the department may require the use of another method to lower the practical quantitation limit.*

In practice, the PQL generally corresponds to the lowest instrument calibration standard that meets all method-defined requirements, such as the lower limit of quantitation (LLOQ) for SW-846 methods. This concentration is adjusted to include the a) sample size (mass or volume); b) final sample extraction volume; c) cleanup method (if any); and d) the volume of sample extract introduced into the instrument. To establish a PQL-based SCO and CSL, follow the recommended approach in Chapter 11.

Ecology recognizes that the PQL, method reporting limit (MRL), and LLOQ are generally the same concept (i.e., PQL ≈ MRL ≈ LLOQ). Ecology will accept reporting of the LLOQ (SW-846 method) and recognizes that EPA SW-846 no longer includes method detection limits (MDL). However, since this is a requirement in MTCA, reporting of the MDL is also required.

***Definition of Method Detection Limit***

Although terminology varies, the MDL according to 40 CFR 136, Appendix B is: "The minimum concentration of a substance that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero." This is essentially the lower bound of what can be identified as "present but not necessarily accurate" (J-qualified data).

Methods for estimating MDLs typically involve:

- Measuring the variability of instrument response to replicate analysis of a low-concentration, spiked sample (either clean sand or a sample-specific matrix), or

- Evaluating the signal to noise ratio for each analyte on a sample-specific basis.

The MDL accounts for false positives (i.e., one percent false positive rate). MDLs are laboratory and instrument-specific, can vary over time, and are typically updated on an annual basis by the laboratories. Achieving low MDLs is important for various reasons, including avoiding non-detected results for surface weighted averages or background determinations.

***Achieving Low PQLs***

When analyzing organic chemicals, it is important to achieve sufficiently low PQLs. This is particularly important when analyzing for bioaccumulative chemicals with very low risk-based criteria or samples with low TOC. Achieving the recommended PQLs in Appendix D will allow comparison with the SMS benthic chemical criteria for sediment with a normal range of TOC (0.5 – 3.5%). However, for sediment with low TOC (e.g., ≤ 0.5%), the TOC-normalized quantitation limits for certain chemicals may be above the SMS benthic criteria, which is TOC-normalized.

In these cases, the analytical laboratory should contact the project manager to identify steps to lower PQLs. It is unacceptable for the laboratory to report high PQLs after holding times are exceeded, which precludes reanalysis. If the reported PQLs are above the SMS benthic criteria after TOC normalization the sample should be reanalyzed with sample preparation and analysis modifications. If cleanup levels are based on a PQL (sum TEQ; Chapter 11, Table 11-1) these PQLs must be met. If they are not, it may be necessary to determine which congener does not meet the PQL or reanalysis may be appropriate.

Depending on the matrix and analyte, these modifications can include:

- Correcting for matrix interferences through appropriate clean-up procedures (Table 5-1).
- Increasing the sample mass.
- Reducing the final extract volume.
- Use of higher instrument injection volume.
- For samples with low total solids, modifications can also include:
    - Freeze drying
    - Air drying
    - Decanting
    - Centrifugation

In some cases, it may not be possible to achieve sufficiently low PQLs even with modified methods. Assuming the sample detection limit is lower than the SMS benthic criteria, the data validator should examine the raw data—focusing on the ion chromatogram, quantitation report, and mass spectra—to determine if the compound is actually present. When low TOC (less than 0.5%) unavoidably causes SMS criteria exceedances, Ecology may allow case-by-case comparison of the dry-weight test sediment to the Apparent Effects Threshold values (Chapter 8 Table 8-1). For further information on TOC analysis and normalization, see Chapter 4 Section 4.2.2(5) or Michelsen 1992.

There are special cases when not meeting the specified PQL is acceptable. For example, elevated PQLs may not be an issue when all data is above the PQL or below established natural

or regional background values. As discussed above, matrix interference or low solids may impact the ability to achieve appropriate PQLs. In this case, if the non-detect data associated with elevated PQLs interferes with appropriate statistical analysis, specialized sample preparation or analytical methodologies may be necessary to lower the PQLs. Any alterations in standard methodologies should be approved by the Ecology project manager.

A number of bioaccumulative chemicals such as polychlorinated dioxins/furans (PCDD/PCDF) and PCBs are known to have risk-based concentrations below PQLs. Therefore, it is important to obtain and report the lowest possible PQLs and method detection limits for bioaccumulative chemicals. Data should be reported to the detection limit and qualified appropriately.

## 5.1.2 Tissue chemistry

In this section, specific issues associated with tissue chemistry analysis are discussed. Recommended tissue sample preparation, cleanup, and analytical methods are summarized in Table 5-2. PQLs for metals and bioaccumulative chemicals of concern are provided in Table 11-1.

### 5.1.2.1 Tissue types

The decision to analyze whole body or muscle tissue should be made during development of the RI workplan. This decision depends on whether results will be used to address risks to humans or aquatic life. When human health is involved, potential consumers must be identified since eating habits vary. If the project is located within a tribal usual and accustomed fishing area, the appropriate tribe(s) should be consulted to understand the types of fish they consume. Based on that information, consider analyzing the following:

- Fish tissue:
  - Fillets (muscle)
  - Whole body
  - With or without skin

- Crab tissue:
  - Whole body
  - Crabmeat and hepatopancreas (crab butter)
  - Determination of percent of each by weight

- Shellfish (clam, mussel, geoduck) tissue:
  - Whole body
  - Removal of the gutball
  - Removal of siphon skin

A sufficient number of organisms should be collected to ensure an adequate sample mass for QC analysis and to achieve required PQLs. Clams and geoducks should be rinsed with site water and then depurated by storing in aerated site seawater for 24 hours to flush sediment from the viscera and gutball before sample preparation.

Tissue dissection and clam shucking should be performed using a decontaminated, high-quality ceramic or stainless steel scalpel or knife. Samples should be homogenized in a blender or tissue grinder, placed in individually labeled sample containers, and immediately placed in a freezer.

#### 5.1.2.2 Tissue compositing

Multiple organisms are typically composited to reduce individual variability and statistical relevance. Care should be taken to composite tissues sampled from appropriate areas. For example, it is inappropriate to composite tissue samples that are:

- Taken from different sediment areas but with dissimilar chemical concentrations.
- Taken from organisms with different mobility and home range, such as crab and relatively sessile clams.

The following should also be considered when compositing samples:

- Minimum of five organisms. Typically, it is necessary to composite a minimum of five organisms to meet analytical chemistry requirements.

- Sampling time of year. The reproductive status of the organism can change lipid content, which can impact bioaccumulation rates.

- Gender of the organisms. Crab and fish may have gender-based differences in bioaccumulation rates.

#### 5.1.2.3 Tissue chemistry analysis

Tissue extraction and chemical analysis procedures are the same as for sediment, except that tissue results are typically reported on a wet-weight basis.

Lipids analysis should be performed using the Bligh-Dyer method (Bligh-Dyer 1959), since bioaccumulative chemicals tend to concentrate in lipids. Although data is typically reported in wet weight, lipid data may be used to address variability between samples or sampling events.

PAH analysis should be performed on a project- and species-specific basis. While PAHs are readily taken up by fish and crab, they are usually not detected at high enough concentrations in tissue since the parent chemicals are rapidly metabolized. Therefore, it is generally not

recommended to analyze fish or crab tissue for PAHs. However, it is appropriate to analyze other species such as bivalves for PAHs, since they have limited ability to metabolize PAHs.

## 5.2 Bioassay Testing

PSEP (1995 as amended through SMARM, see Appendix B) includes guidelines for conducting the amphipod, larval, and juvenile Polychaete tests for marine sediment. The PSEP guidelines are recommended except for the following modifications:

- Microtox® test. Guidelines for conducting Microtox® 100% sediment porewater extract test for marine, estuarine, and freshwater sediments are in Appendix C.

- Larval test. PSEP refers to the use of *Mytilus edulis* in the mussel larval test. However *M. galloprovincialis* is the species routinely used for the larval test by biological laboratories in the Pacific Northwest. Where sediments may have flocculent material such as wood fiber, a re-suspension protocol has been developed to address this which is described in the 2013 SMARM paper *Bioassay endpoint refinements: Bivalve larval and Neanthes growth bioassays* (see Appendix B Bioassays Section).

- Freshwater tests. Guidelines for conducting freshwater sediment toxicity tests for *Hyalella azteca* and *Chironomus tentans* can be found in the ASTM (2010).

- PAH Toxicity. The toxicity of certain PAHs in sediment can be significantly increased if those PAHs are exposed to UV light (Ahrens and Hickey 2002). Toxicity tests for sediment collected in shallow water or the intertidal area should be carefully designed following the recommendations in Appendix C.

- Alternative tests. On a case-by-case basis, alternative marine and freshwater sediment toxicity tests may be approved by Ecology for sediment investigations. Chapter 4, Sections 4.2.2, 4.2.3 and Table 4-4 includes more detail on the types of environments where these alternative toxicity tests may be appropriately used and the different types of tests.

## 5.3 Bioaccumulation Testing

### 5.3.1 Laboratory bioaccumulation testing

Information on bioaccumulation tests for freshwater and marine sediments can be found in The Ocean Testing Manual (USEPA/USACE 1991) and the Inland Testing Manual (USEPA/USACE 1998a). A normal test exposure duration of 28 days is recommended before tissue chemical analysis is conducted. However, for some chemicals with a high $K_{ow}$ (e.g., PCBs, PCDD/PCDF,

TBT, and DDT), an exposure duration up to 45 days may be necessary to reach equilibrium between the sediment and tissue of the test species (see Appendix B Bioaccumulation Testing Section). Alternatively, the tissue residue measured at the end of the 28-day test could be adjusted upward by extrapolation (i.e., estimating the proportion of the final steady state concentration that would be reached in 28 days). This extrapolation of measured tissue concentrations to steady-state concentrations for high $K_{ow}$ chemicals should be conducted using chemical-specific information from published studies, and prior to using the data to judge sediment suitability. In these cases, it is recommended to discuss the data with Ecology and determine an appropriate study design.

PSEP 1997 (a,b) is recommended for tissue digestion and tissue chemical analysis for metals and organic chemicals.

### 5.3.2 In situ bioaccumulation testing

ASTM (2001, 2010b) protocols are recommended for bioaccumulation testing using *in situ* caged bivalves to assess bioaccumulation potential and associated biological effects in marine, estuarine, and freshwater species. *In situ* test organisms other than bivalves are also available, and these methods are evolving in both marine and freshwater environments. For a complete discussion of available marine and freshwater species, see Appendix B of RSET 2009. For marine species, the species indigenous to the Pacific Northwest and appropriate for estuarine or marine environments include:

- Mussels: *Mytilus trossulus, M. californianus, M. galloprovincialis, M. edulis*.
- Oysters: *Crassostrea gigas, Ostrea lurida.*
- Clams: *Macoma balthica, Protothaca staminea, Venerupis japonica*.

See ASTM 2001and 2010b for a complete list of marine and estuarine species, their geographic distributions, and salinity tolerances.

For freshwater species, three groups of organisms are recommended (Salazar and Salazar 1998):

- Bivalves: *Corbicula fluminea*. This species is recommended because it has been used extensively in laboratory testing, field monitoring, and in situ assessments of both toxicity and bioaccumulation potential. However, it should not be used in areas where it has not yet been introduced.
- Gastropods: This may be recommended for areas where threatened, endangered, or candidate species of snails are present. *Lumbriculus variegatus* (an oligochaete) has been suggested by several agencies as a potential species since it will reach steady state more

rapidly (28 days may be sufficient). However, it can be difficult to obtain sufficient tissue volume for both tissue chemical and lipid analyses due to their small biomass.

- Decapods (crayfish).

As discussed above, with some chemicals (mercury, DDT, TBT, PCBs, and PCDD/PCDF), an extended exposure duration up to 45 days to reach steady state may be necessary as described in the 2009 SMARM paper *Bioaccumulation protocol clarifications* Appendix B Bioaccumulation Testing Section. However, there is insufficient data to determine how long *Corbicula* takes to reach steady state. If the standard 28-day period is used, correction factors should be developed to estimate eventual steady state tissue concentrations. Either a gastropod or freshwater crayfish can be used as a second choice species.

### 5.3.3 Collection of field organisms

Recommended guidelines for collection and processing of tissue samples can be found in PSEP (1997c). Guidelines for analysis of metals and organics in tissue samples can be found in PSEP (1997a, b).

## 5.4 Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) procedures are discussed in detail in other publications (e.g., PSEP and ASTM protocols). The following subsections summarize QA/QC requirements that should be part of each sediment sampling and analysis plan, and include references to pertinent source documents for more detailed information.

### 5.4.1 Laboratory accreditation

Ecology has a laboratory accreditation program designed to ensure that certain performance standards are met. Only accredited laboratories should be used for sediment cleanup investigations (WAC 173-340). When data will be used for regulatory purposes, laboratories must be accredited for the methods specific to the environmental media. For example, laboratories that are accredited within the "Solids and Chemical Materials" matrix category should be used for the sediment project-specific analytical methods. Laboratory accreditation requirements are specified in Accreditation of Environmental Laboratories (WAC 173-50) and Ecology's publication, *Procedure Manual for the Environmental Laboratory Accreditation Program*. A current list of accredited laboratories can be accessed at the following websites:

- http://www.ecy.wa.gov/programs/eap/labs/lab-accreditation.html
- https://fortress.wa.gov/ecy/laboratorysearch/

Method accreditation requirements for the analysis of chemicals without SMS criteria (e.g., organic debris, resin acids, guaiacols) will be determined by Ecology on a case-by-case basis.

### 5.4.2 Data quality objectives

Data quality objectives are the quantitative and qualitative terms used to describe how good the data needs to be in order to meet the project's objectives. Typical data quality objectives include precision, accuracy, representativeness, comparability and completeness:

- Precision is evaluated using the Relative Percent Difference values between the duplicate sample results. Precision may be calculated using the following equation:

  $$\text{Relative Percent Difference} = [(\text{ABS}\ (R1 - R2)) / ((R1 + R2) / 2)] \times 100$$

  Where:
  ABS = Absolute difference between values (meaning no negative values)
  MS = Matrix Spike
  MSD = Matrix Spike Duplicate
  R1 = Measured concentration for MS or duplicate #1
  R2 = Measured concentration for MSD or duplicate #2

- Accuracy is evaluated using the percent recovery of the target analyte in spiked samples and, where applicable, the percent recovery of surrogates in all samples and QC samples. Accuracy may be calculated using the following equation:

  $$\text{Percent Recovery} = [(SSR - SR) / SA] \times 100$$

  Where:
  SSR = Spiked sample result
  SR = Sample result
  SA = Spike added

- Representativeness is the degree to which data accurately represents a particular characteristic of the environmental matrix being tested. Representativeness of samples is ensured by adhering to standard field sampling protocols, standard laboratory protocols, and an adequate number of samples.

- Comparability is the measurement of the confidence in comparing the results of one sampling event with the results of another that were achieved by using the same matrix, sample location, sampling techniques, and analytical methodologies.

- Completeness is the percentage of valid results compared to the total number of samples taken for each parameter. Percent completeness may be calculated using the following equation:

  Percent Completeness = [(Number of valid results) / (Number of samples taken)] x 100

### 5.4.3 Sediment chemistry

The applicable QA/QC procedures are summarized in:

- Table 5-3 for analyses of organic chemicals.
- Table 5-4 for analyses of metals.
- Table 5-5 for analyses of conventional sediment parameters.
- Table 5-6, Table 5-7, and Table 5-8 for analyses of dioxins/furans.

When not specified by the analytical method, control limits should be laboratory- and instrument- specific, and are typically established using laboratory control charts. Control limits different from those in Table 5-3 through Table 5-8 must be approved by Ecology and developed with the laboratory.

The laboratory is responsible for monitoring the analysis, identifying the analytical problems, and taking corrective actions prior to the expiration of sample holding times. The laboratory should communicate any problems to the project manager during the analysis. When reasonable corrective actions do not result in bringing QC sample results within control limits, data may need to be qualified depending on the specific project requirements documented in the SAP.

### 5.4.4 Tissue chemistry

Tissue analysis follows the same QA/QC procedures as for sediment. Control limits for tissue chemistry may differ from sediment chemistry and those specified in Table 5-1 through Table 5-6. Control limits should be specified in project planning documents when appropriate. Project-specific control limits must be developed in consultation with the laboratory.

The laboratory is responsible for monitoring the analysis, identifying the analytical problems and taking corrective actions before the expiration of sample holding times. The laboratory should communicate analytical problems to the project manager during the analysis. When reasonable corrective actions do not bring QC sample results within control limits, data may need to be qualified depending on the specific project requirements documented in the SAP.

## 5.4.5 Marine and estuarine sediment toxicity test conditions

The recommended QA/QC requirements for biological tests (bioassays and benthic community analyses) are in the following protocols for each type of test: a) PSEP 1987, 1995, b) ASTM 2010a, 2010b, c) USEPA 1994, d) Nebeker et al. 1984, and e) Microbics Corporation 1992.

### 5.4.5.1 Bioassays

For marine bioassay tests, particular attention should be paid to:

- Water quality conditions. Ensuring that water quality conditions remain within acceptable limits during the test procedure is important. Otherwise, it can contribute to observed toxicity and confound the actual toxicity results.

- Temperature, salinity, dissolved oxygen. The control limits that apply to most marine bioassay tests for temperature, salinity, and dissolved oxygen are listed in Table 5-9.

- pH. Control limits for Microtox® are listed in Table 5-9. See Appendix C for specific protocols for conducting the Microtox® test. pH should be measured for all bioassay tests to help interpret test results.

- Sulfides and ammonia.
    - Monitoring sulfides and ammonia concentrations in the test chambers is required for marine bioassays when it is suspected they may be contributing to toxicity.

    - Sulfides and ammonia results can be used to help interpret test results.

    - Conducting bioassays using purged sediment to remove or decrease sulfide and/or ammonia concentrations should only be done side-by-side with non-purged sediment bioassays so that results can be compared. The use of purged bioassays may be helpful in interpreting results if toxicity is due to ammonia, sulfides, or another factor, but should not be used to replace the unmodified test results. The purpose of this comparison is to inform the appropriate remedial alternative for the cleanup. See Appendix J for further details on conducting bioassays with naturally-occurring chemicals.

- Positive/negative controls and reference sediment. Bioassays must be conducted using negative and positive controls as well as reference sediment. The SMS performance standards for control and reference sediment are summarized in Table 5-9. The difference in percent fines in reference and test sediment should not exceed 20%.

#### 5.4.5.2 Benthic community analysis

The recommended QA/QC requirements for benthic community analyses are described in the PSEP (1987) protocols. They generally focus on the completeness of sample sorting and accuracy of taxonomic identification.

The SMS includes performance standards for reference sediment in Puget Sound:

- For Parts III and IV of the rule, WAC 173-204-315(2)(c) applies.
- For Part V of the rule, WAC 173-204-562(3)(e) applies. See Chapter 8, Table 8-2 or Table 5-9 and Table 5-10 for more information.

The reference sediment should be from an area removed from significant sources of contaminants and have the following characteristics:

- The taxonomic richness of benthic macroinvertebrates and the abundances of higher taxonomic groups should reflect seasonality and natural physical-chemical conditions (e.g., grain-size composition of sediment; interstitial salinity of sediment; water depth). The reference area should not be obviously impacted by contaminants.
- Normally abundant species that are known to be sensitive to chemical toxicity should be present.
- Normally rare species that are known to be tolerant of chemical toxicity should be rare or absent.
- The abundances of normally rare species that control community structure through physical modification of the sediment should be similar to the test sediment site.

### 5.4.6 Freshwater sediment toxicity test conditions

The recommended QA/QC requirements for freshwater bioassay tests are the most recently updated ASTM International protocols. For freshwater bioassay tests, particular attention should be paid to:

- Water quality conditions. Ensuring that water quality conditions remain within acceptable limits during the test procedure is important. Otherwise it can contribute to observed toxicity and confound the actual toxicity results.
- Temperature and dissolved oxygen. The control limits for temperature and dissolved oxygen are listed in Table 5-10.

- pH. Control limits for Microtox® are listed in Table 5-9. See Appendix C for specific protocols for conducting the Microtox® test. Control limits for other bioassays should be measured at the start of the test. The pH of the overlying water of the test bioassay should equal (+ / - 0.2) the pH of the receiving water or the overlying water where the samples have been taken. pH should be measured during the test as well, because the information is helpful when interpreting results.

- Sulfides and ammonia. Monitoring sulfides and ammonia concentrations in the test chambers may be appropriate for freshwater bioassays when it is suspected they may be contributing to toxicity. Sulfides and ammonia results can be used to help interpret test results.

- Positive and negative controls. Bioassays must be conducted using negative and positive controls. The SMS performance standards for control sediment are summarized in Table 5-10.

## 5.5 Quality Assurance Review

The PLP or permittee is responsible for the QA review of data generated in any sediment investigation for regulatory purposes. There are two levels of QA review applicable for sediment data, referred to as QA1 (approximately equivalent to EPA Levels I & II) and QA2 (approximately equivalent to EPA Levels III & IV) (PTI 1989a, b). The analytical elements evaluated under each level of review are identified in Table 5-3 through Table 5-8.

### 5.5.1 QA1 review

A QA1 review represents a level of QA review acceptable for most sediment investigations conducted for cleanup. It is also used to determine the suitability of dredged material for unconfined, open-water disposal at a DMMP site (PTI 1989a). A chemistry data review at this level includes an evaluation of:

- Field collection and handling
- Completeness
- Data presentation
- Reporting limits (the PQL shall not be greater than the SQS/SCO)
- Acceptability of test results for:
    - Method blanks
    - Certified reference materials
    - Analytical replicates
    - Laboratory control samples (blank spikes)
    - Matrix spikes and surrogate recoveries.

A QA1 review can be performed using summary laboratory sample and QC results. A complete data package with all raw data is recommended (but not required) so that QC exceedance can be evaluated if necessary.

A QA1 review of bioassay data includes similar field and reporting elements, as well as an evaluation of the acceptability of test results for positive controls, negative controls, reference sediment, replicates, and experimental conditions (i.e., temperatures, salinity, pH, dissolved oxygen). Detailed guidance on QA1 review procedures is provided in PTI 1989a and on the EPA website for EPA Level I and II review procedures.

### 5.5.2 QA2 review

A QA2 review represents a more vigorous level of QA review, and is appropriate for sediment data that are to be used for the development of AET values and SMS criteria. A QA2 review is also recommended in cases where the data may be used in litigation. At this level, a chemistry data review is conducted to examine the complete analytical process, including:

- Calculation of instrument and method detection limits
- PQLs
- Final dilution volumes
- Sample sizes
- Wet-to-dry ratios
- Quantification of calibration compounds
- Quantification of all analytes detected in blanks and environmental samples, including examination of chromatograms and mass spectra.

Additionally, a complete laboratory data package with all raw data, instrument output, and laboratory bench sheets and notes must be submitted. Detail on QA2 review procedures is provided in PTI 1989b and on the EPA website for EPA Level III and IV review procedures.

## 5.6 Electronic Data Submittal and Record-Keeping

Ecology requires that all sediment chemistry, tissue chemistry, and bioassay data be submitted electronically to Ecology's Environmental Information Management System database (EIM). Information for online EIM data submittal and details on data qualifiers for chemical and bioassay data can be found at: http://www.ecy.wa.gov/eim/submitdata.htm. EIM has general fields that must be completed for all data, as well as sediment-specific fields for all sediment data. Guidance on data submittal can be found at: http://www.ecy.wa.gov/eim/helpDocs.htm.

Record keeping provisions should be included in SAPs consistent with the SMS (WAC 173-204-610). The PLP or permittee must retain copies of the following for at least 10 years from the date of issuance of an a) permit, administrative order, consent decree, or other administrative document; or b) site delisting:

- Final and Ecology-approved SAP;
- Field records that document any departures from the SAP and/or QA project plan; and
- Analytical results, including laboratory reports, summary tables, and data reports.

**Table 5-1.** Sediment chemistry recommended analytical methods.

| Parameter | Preparation Method | Analytical Method |
|---|---|---|
| **Metals (mg/kg)** | | |
| Antimony | EPA 6010/6020[a]/3050B | EPA 6010/6020 |
| Arsenic | EPA 6010/6020/3050B | EPA 6010/6020 |
| Cadmium | EPA 6010/6020/3050B | EPA 6010/6020 |
| Chromium | EPA 6010/6020/3050B | EPA 6010/6020 |
| Copper | EPA 6010/6020/3050B | EPA 6010/6020 |
| Lead | EPA 6010/6020/3050B | EPA 6010/6020 |
| Mercury | EPA 7471 | EPA 7471 |
| Nickel | EPA 6010/6020/3050B | EPA 6010/6020 |
| Silver | EPA 6010/6020/3050B | EPA 6010/6020 |
| Zinc | EPA 6010/6020/3050B | EPA 6010/6020 |
| **Polycyclic Aromatic Hydrocarbons (PAHs) (µg/kg)** | | |
| **Low-molecular weight PAHs (LPAHs)[b]** | | |
| Naphthalene | EPA 3550-mod[c,d] | EPA 8270 |
| Acenaphthylene | EPA 3550-mod[c,d] | EPA 8270 |
| Acenaphthene | EPA 3550-mod[c,d] | EPA 8270 |
| Fluorene | EPA 3550-mod[c,d] | EPA 8270 |
| Phenanthrene | EPA 3550-mod[c,d] | EPA 8270 |
| Anthracene | EPA 3550-mod[c,d] | EPA 8270 |
| 2-Methylnaphthalene | EPA 3550-mod[c] | EPA 8270 |
| **High-molecular weight PAHs (HPAHs) (µg/kg)[b]** | | |
| Fluoranthene | EPA 3550-mod[c,d] | EPA 8270 |
| Pyrene | EPA 3550-mod[c,d] | EPA 8270 |
| Benzo(a)anthracene | EPA 3550-mod[c,d] | EPA 8270 |
| Chrysene | EPA 3550-mod[c,d] | EPA 8270 |
| Benzofluoranthenes[f] | EPA 3550-mod[c,d] | EPA 8270 |
| Benzo(a)pyrene | EPA 3550-mod[c,d] | EPA 8270 |
| Indeno(1,2,3-c,d)pyrene | EPA 3550-mod[c,d] | EPA 8270 |
| Dibenzo(a,h)anthracene | EPA 3550-mod[c,d] | EPA 8270 |
| Benzo(g,h,i)perylene | EPA 3550-mod[c,d] | EPA 8270 |
| **Chlorinated Hydrocarbons (µg/kg)[b]** | | |
| 1,4-Dichlorobenzene | EPA 3550-mod[c,d] | EPA 8270 |
| 1,2-Dichlorobenzene | EPA 3550-mod[c] | EPA 8270 |
| 1,2,4-Trichlorobenzene | EPA 3550-mod[c] | EPA 8270 |
| Hexachlorobenzene | EPA 3550-mod[c,d] /3540 | EPA 8270/8081 |

**Table 5-1** (continued). Sediment chemistry recommended analytical methods.

| Parameter | Preparation Method | Analytical Method |
|---|---|---|
| **Phthalates[b]** | | |
| Dimethyl phthalate | EPA 3550-mod[c,d] | EPA 8270 |
| Diethyl phthalate | EPA 3550-mod[c,d] | EPA 8270 |
| Di-n-butyl phthalate | EPA 3550-mod[c,d] | EPA 8270 |
| Butyl benzyl phthalate | EPA 3550-mod[c,d] | EPA 8270 |
| Bis(2-ethylhexyl)phthalate | EPA 3550-mod[c,d] | EPA 8270 |
| Di-n-octyl phthalate | EPA 3550-mod[c,d] | EPA 8270 |
| **Phenols[b]** | | |
| Phenol | EPA 3550-mod[c,d] | EPA 8151/8270 |
| 2 Methylphenol | EPA 3550-mod[c,d] | EPA 8151/8270 |
| 4 Methylphenol[f] | EPA 3550-mod[c,d] | EPA 8151/8270 |
| 2,4-Dimethylphenol | EPA 3550-mod[c,d] | EPA 8151/8270 |
| Pentachlorophenol | EPA 3550-mod[c,d] | EPA 8151/8270 |
| **Miscellaneous Extractables[b]** | | |
| Benzyl alcohol | EPA 3550-mod[c] | EPA 8151/8270 |
| Benzoic acid | EPA 3550-mod[c] | EPA 8151/8270 |
| Dibenzofuran | EPA 3550-mod[c] | EPA 8270 |
| Hexachloroethane | EPA 3550-mod[c] | EPA 8270 |
| Hexachlorobutadiene | EPA 3550mod[c,d]/3540 | EPA 8270/8081 |
| N-Nitrosodiphenylamine | EPA 3550-mod[c] | EPA 8270 |
| **Pesticides/Polychlorinated biphenyls (PCBs)** | | |
| DDE (p,p'-, o,p'-) | EPA 3540/3550-mod | EPA 8081 |
| DDD (p,p'-, o,p'-) | EPA 3540/3550-mod | EPA 8081 |
| DDT (p,p'-, o,p'-) | EPA 3540/3550-mod | EPA 8081 |
| Aldrin | EPA 3540/3550-mod | EPA 8081 |
| Chlordane compounds[g] | EPA 3540/3550-mod | EPA 8081 |
| Dieldrin | EPA 3540/3550-mod | EPA 8081 |
| Heptachlor | EPA 3540/3550-mod | EPA 8081 |
| Lindane | EPA 3540/3550-mod | EPA 8081 |
| Total Polychlorinated biphenyls Aroclors/Congeners | EPA 3540[d,h]/3550-mod | EPA 8082/1668 |

**Table 5-1** (continued). Sediment chemistry recommended analytical methods.

| Parameter | Preparation Method | Analytical Method |
|---|---|---|
| **Conventional Sediment Variables** | | |
| Ammonia (bulk) | j | Plumb (1981) |
| Grain size[i] | j | PSEP, 1986 / ASTM D-422 |
| Total solids | j | PSEP, 1986 |
| Total organic carbon (TOC) | j | 9060 |
| Total volatile solids (TVS) | j | PSEP, 1986 |
| Total sulfides | j | Plumb (1981) /9034/9030B |
| **Chemicals of Special Occurrence** | | |
| **Tributyltin (TBT)** | | |
| TBT in porewater | Krone 1989 | Krone 1989 |
| TBT in sediment | Krone 1989 | Krone 1989 |
| **Total Petroleum Hydrocarbons (TPH)** | | |
| TPH-diesel | EPA 3630/3665 | NWTPH-Dx |
| TPH-residual | EPA 3630/3665 | NWTPH-Dx |
| **Dioxins/ Furans** | | |
| Sum TEQ | EPA 8290/1613 | EPA 8290/1613 |
| **Polychlorinated biphenyls** | | |
| Sum TEQ | EPA 1668 | EPA 1668[k] |

a, Includes hydrochloric acid digestion per EPA 3050-B.

b, Selected ion monitoring may improve the sensitivity of EPA Method 8270 and is recommended in cases when detection limits must be lowered to human health criteria levels or when TOC levels elevate detection limits above ecological criteria levels. See PSEP organics chapter, Appendix B, Guidance for Selected Ion Monitoring (1997b).

c, EPA Method 3550 is modified to add matrix spikes <u>before</u> the dehydration step.

d, If sulfur is present in the samples (as is common in most marine sediment), cleanup procedures specified by EPA SW-846 Method 3660B should be used.

e, Total benzofluoranthenes represent the sum of the b, j, and k isomers. Some laboratories report total benzofluoranthenes concentration rather than concentrations of individual isomers since isomers may not be able to be separated.

f, In some instances 3-methylphenol and 4-methylphenol may not be able to be separated. In this case methylphenol may be reported as the sum of the 3-methyl and 4-methylphenol isomers.

g**,** Chlordane compounds include cis-chlordane, trans-chlordane, cis-nonachlor, trans-nonachlor, and oxychlordane. In samples with interference from PCBs, the SQLs for cis- and trans-nonachlor and oxychlordane may be elevated.

h, All PCB extracts should be subjected to sulfuric acid/permanganate cleanup as specified by EPA SW-846 Method 3665A.

i, Sternberg, D. (2006). *Reporting of sediment-bound contaminants: standardization of sieving and analytical procedures*. DMMP/SMS clarification paper on converting phi, mm, or microns to the standard "gravel, sand, silt, clay" groups. See Appendix B.

j, Sample preparation methods for sediment conventional analyses are described in the analytical methods.

k, Selection of PCB analytical method can be determined on a project-specific basis. EPA Method 1668 is currently recommended.

**Table 5-2.** Tissue chemistry recommended analytical methods.

| Parameter | Preparation Method | Analytical Method |
|---|---|---|
| **Conventionals (%)** | | |
| Lipids | Bligh/Dyer | Bligh/Dyer |
| **Metals** | | |
| Arsenic | EPA 3050B/ PSEP | EPA 6010/6020/7010 |
| Cadmium | EPA 3050B/ PSEP | EPA 6010/6020/7010 |
| Lead | EPA 3050B/ PSEP | EPA 6010/6020/7010 |
| Mercury | EPA 7471 | EPA 7471 |
| Selenium | EPA 3050B/ PSEP | EPA 6010/6020/7010 |
| **Polycyclic Aromatic Hydrocarbons** | | |
| Fluoranthene | 3540C, 3541 or 3550B | EPA 8270-SIM/8270 |
| Pyrene | 3540C, 3541 or 3550B | EPA 8270-SIM/8270 |
| **Miscellaneous Semivolatiles** | | |
| Hexachlorobenzene | 3540C, 3541 or 3550B | EPA |
| Pentachlorophenol | 3540C, 3541 or 3550B | EPA 8270-SIM/8270 |
| Pentachlorophenol | 3540C, 3541 or 3550B | EPA 8151 |
| **Chlorinated Pesticides** | | |
| DDE (p,p'-, o,p'-) | 3540C, 3541 or 3550B | EPA 8081 |
| DDD (p,p'-, o,p'-) | 3540C, 3541 or 3550B | EPA 8081 |
| DDT (p,p'-, o,p'-) | 3540C, 3541 or 3550B | EPA 8081 |
| Chlordane compounds[a] | 3540C, 3541 or 3550B | EPA 8081 |
| Dieldrin | 3540C, 3541 or 3550B | EPA 8081 |
| Endosulfans | 3540C, 3541 or 3550B | EPA 8081 |
| Lindane | 3540C, 3541 or 3550B | EPA 8081 |
| Methoxychlor | 3540C, 3541 or 3550B | EPA 8081 |
| **Polychlorinated Biphenyls[b]** | | |
| PCB Aroclors | EPA 3540 | EPA 8082 |
| PCB Congeners | EPA 1668 | EPA 1668 |
| **Dioxins/Furans[c]** | | |
| 2,3,7,8 - TCDD | 2,3,7,8 - TCDD | 2,3,7,8 – TCDD |
| Dioxins/Furans (other) | EPA 8290/1613 | EPA 8290/1613 |
| **Organotins[c]** | | |
| EPA 3550B or NMFS | EPA 3550B or NMFS | EPA 3550B or NMFS |

a, Chlordane compounds include cis-chlordane, trans-chlordane, cis-nonachlor, trans-nonachlor, and oxychlordane. In samples with interference from PCBs, the quantitation limits for cis- and trans-nonachlor and oxychlordane may be elevated.

b, Selection of PCB analytical method will be determined on a project-specific basis.

c, Dioxins/furans and tributyltin are chemicals of special occurrence; analysis of these constituents will be determined on a project-specific basis.

**Table 5-3.** Quality control procedures for organic analyses.

| Quality Control Procedure | Frequency | Control Limit | Corrective Action |
|---|---|---|---|
| **Instrument Quality Assurance/ Quality Control** | | | |
| Initial Calibration[a] | Before sample analysis and when continuing calibration does not meet method requirements. See reference method(s) in Table 5-1. | See reference method(s) in Table 5-1 | Laboratory to recalibrate and reanalyze affect samples |
| Continuing Calibration[a] | Method-specific. See reference method(s) in Table 5-1 | Method – specific. See reference method(s) in Table 5-1 | Laboratory to recalibrate if correlation coefficient or response factor does not meet requirements |
| **Method Quality Assurance/Quality Control** | | | |
| Holding Times[a,b] | All samples. | See Chapter 4 | Laboratory to qualify results if holding times are exceeded. Data validator will use professional judgment to qualify results as estimated or reject data. |
| Method Detection Limits (MDL) [a,b] | Update method detection limit studies annually. | See reference method(s) in Table 5-1. | Revise detection limits. |
| Method Blanks[a,b] | One per sample batch or every 20 samples, whichever is more frequent, or when there is a change in reagents. | Analyte concentration ≤ PQL. Control limits are not applicable if sample concentrations are < MDL. | Laboratory to eliminate or greatly reduce laboratory contamination due to glassware, or reagents, or analytical system. Re-extract and reanalyze affected samples. |
| Analytical Laboratory Duplicates [a,b] and Matrix Spike Duplicates [a,b] | One duplicate analysis with every sample batch or every 20 samples, whichever is more frequent. Use analytical replicates when samples are expected to contain target analytes, otherwise use matrix spike duplicates | Compound and matrix specific. Use intra-laboratory control chart results if sufficient data are available to generate control charts. Otherwise use analytical method default criteria. | Laboratory to re-extract and reanalyze samples to qualify the data if sample homogeneity problems are suspected and the project manager is consulted. Otherwise, see Matrix Spikes corrective action below. |
| Matrix Spikes[a,b] | One per sample batch or every 20 samples, whichever is more frequent. Spiked with the same analytes at the same concentration as the laboratory control sample. | Compound and matrix specific, recovery should not exceed method or performance -based intra-laboratory control chart limits. | If results are outside the limits, re-evaluate data to find source(s) of difference (i.e., matrix effect or analytical error). If it is an analytical error that cannot be corrected (i.e., calculation error), samples should be re-extracted. Outliers should be noted in the Case Narrative. |
| Surrogate Spikes[a,b] | Added to every organics sample as specified in analytical protocol. | Compound specific, recovery should not exceed the control limits specified in the method or performance-based intra-laboratory control limits. | Follow corrective actions specified in analytical method. |
| Laboratory Control Samples[a,b] | One per analytical batch or every 20 samples, whichever is more frequent. | Compound specific, recovery should not exceed performance-based intra-laboratory control limits. | Laboratory to correct problem to verify the analysis can be performed in a clean matrix with acceptable precision and recovery; then re-extract and reanalyze affected samples. |
| Certified or Standard Reference Material [a,b] | Project specific requirement or at project manager's discretion. | Compound specific, recovery should be within accepted control or advisory limits. | Laboratory to re-extract and reanalyze samples if analytical problems suspected, or to qualify the data after consultation. |

**Table 5-3** (continued). Quality control procedures for organic analyses.

| Quality Control Procedure | Frequency | Control Limit | Corrective Action |
|---|---|---|---|
| **Field Quality Assurance/Quality Control** | | | |
| Field Duplicates | At project manager's discretion | Project, matrix, and compound specific | Modify field sample homogenization procedures. |
| Field Blanks | At project manager's discretion | Analyte concentration ≤ PQL | Compare to method blank results to rule out laboratory contamination.<br><br>Modify sample collection and equipment decontamination procedures.<br><br>Quality associated data. |

a, Subject to QA2 review
b, Subject to QA1 review

**Table 5-4.** Quality control procedures for metals analyses.

| Quality Control Procedure | Frequency | Control Limit | Corrective Action |
|---|---|---|---|
| **Instrument Quality Assurance/Quality Control** | | | |
| Initial Calibration[a] | Daily. | Correlation coefficient ≥0.995. | Laboratory to optimize and recalibrate the instrument and reanalyze any affected samples. |
| Initial Calibration Verification[a] | Immediately after initial calibration. | 90-110% recovery for ICP-AES, ICP-MS and GFAA (80-120% for Mercury), or method based. | Laboratory to resolve discrepancy prior to sample analysis. |
| Continuing Calibration Verification[a] | After every 10 samples or every 2 hours, whichever is more frequent, and after the last sample. | 90-110% recovery for ICP-AES and GFAA, 85-115% for ICP-MS (80-120% for mercury). | Laboratory to recalibrate and reanalyze affected samples. |
| Initial and Continuing Calibration Blanks[a] | Immediately after initial calibration, then 10% of samples or every 2 hours, whichever is more frequent, and after the last sample. | Analyte concentration ≤ PQL. | Laboratory to recalibrate and reanalyze affected samples |
| ICP Interelement Interference Check Samples[a] | At the beginning and end of each analytical sequence or twice per 8-hour shift, whichever is more frequent. | 80-120% of the true value. | Laboratory to correct problem, recalibrate, and reanalyze affected samples. |
| **Method Quality Assurance/Quality Control** | | | |
| Holding Times[a,b] | All samples. | See Chapter 4. | Laboratory to qualify results if holding times are exceeded. Data validator will use professional judgment to qualify results as estimated or to reject data. |
| Method Detection Limits[a,b] | Update method detection limit studies annually. | See reference method(s) in Table 5-1. | Revise detection limits. |
| Method Blanks[a,b] | With every sample batch or every 20 samples, whichever is more frequent. | Analyte concentration ≤ PQL. Control limits are not applicable if sample concentrations are < MDL | Laboratory to re-digest and reanalyze samples. |
| Analytical (Laboratory) Duplicates[a,b] or Matrix Spike Duplicates[a,b] | One duplicate analysis with every sample batch or every 20 samples, whichever is more frequent; Use analytical replicates when samples are expected to contain target analytes. Use matrix spike replicates when samples are not expected to contain target analytes. | Analyte and matrix specific. Use intra-laboratory control chart limits if sufficient data are available to generate control charts; otherwise use analytical method default criteria. | Laboratory to re-digest and reanalyze samples if analytical problems are suspected, or to qualify the data if sample homogeneity problems are suspected and the project manager is consulted. |
| Matrix Spikes[a,b] | With every sample batch or every 20 samples, whichever is more frequent. | 75-125% recovery applied when the sample concentration is ≤4 times the spiked concentration for a particular analyte. | Laboratory may be able to correct or minimize problem, or qualify and accept data. |

**Table 5-4** (continued). Quality control procedures for metals analyses.

| Quality Control Procedure | Frequency | Control Limit | Corrective Action |
|---|---|---|---|
| Laboratory Control Samples[a,b] | With every sample batch or every 20 samples, whichever is more frequent. | 80 - 120% recovery, or performance based intra-laboratory control limits, whichever is lower. | Laboratory to correct problem to verify the analysis can be performed in a clean matrix with acceptable precision and recovery; then reanalyze affected samples. |
| Certified or Standard Reference Material[a,b] | Project specific requirement or at project manager's discretion. | Compound specific, recovery should be within accepted control or advisory limits. | Laboratory to re-digest and reanalyze samples if analytical problems suspected, or to qualify the data after the project manager is consulted. |
| **Field Quality Assurance/Quality Control** | | | |
| Field Duplicates | At project manager's discretion | Project, matrix, and analyte specific. | Modify field sample homogenization procedures. |
| Field Blanks | At project manager's discretion. | Analyte concentration ≤ PQL. | Compare to method blank results to rule out laboratory contamination; modify sample collection and equipment decontamination procedures. |

Notes:

GFAA - graphite furnace atomic absorption
ICP-MS - inductively coupled plasma/mass spectrometry
ICP-AES - inductively coupled plasma/atomic emission spectrometry

Instrument and method QA/QC to monitor the performance of the instrument and sample preparation procedures are the responsibility of the analytical laboratory.

When an instrument or method control limit is exceeded, the laboratory is responsible for correcting the problem and reanalyzing the samples.

Instrument and method QA/QC results reported in the final data package should always meet control limits with a very small number of exceptions that apply to difficult analytes as specified by EPA CLP.

If instrument and method QA/QC procedures meet control limits, laboratory procedures are deemed to be adequate.

Matrix and field QA/QC procedures monitor matrix effects, field procedures, and variability.

Although poor analytical procedures may also result in poor spike recovery or duplicate results, the laboratory is not held responsible for meeting control limits for these QA/QC samples.

Except in the possible case of unreasonably large exceedances, any reanalysis will be performed at the request and expense of the project manager.

a, Subject to QA2 review.
b, Subject to QA1 review.

**Table 5-5.** Quality control procedures for conventional analyses.

| Suggested Control Limit | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Analyte** | **Initial Calibration** | **Continuing Calibration** | **Calibration Blanks** | **Laboratory Control Samples** | **Matrix Spikes** | **Laboratory Duplicates** | **Method Blank** |
| Ammonia | Correlation coefficient ≥0.995 | 90 -110% recovery | Analyte concentration ≤ PQL | 80 -120% recovery | 75 -125% recovery | 20% RSD | Analyte concentration ≤ PQL |
| Grain size | Not applicable | Not applicable | Not applicable | Not applicable | Not applicable | 20% RSD | Not applicable |
| Total organic carbon | Correlation coefficient ≥ 0.995 | 90-110% recovery | Analyte concentration ≤ PQL | 80-120% recovery | 75-125% recovery | 20% RSD | Analyte concentration ≤ PQL |
| Total sulfides | Correlation coefficient ≥ 0.990 | 85 -115% recovery | Not applicable | 65 -135% recovery | 65 -135% recovery | 20% RSD | Analyte concentration ≤ PQL |
| Total Volatile Solids | Not applicable | Not applicable | Not applicable | Not applicable | Not applicable | 20% RSD | Analyte concentration ≤ PQL |
| Total solids | Not applicable | Not applicable | Not applicable | Not applicable | Not applicable | 20% RSD | Analyte concentration ≤ PQL |

RSD - relative standard deviation

EPA and PSEP control limits are not available for conventional analytes.

The control limits provided above are suggested limits only. They are based on EPA control limits for metals analyses (see Table 5-2), and an attempt has been made to take into consideration the expected analytical accuracy using PSEP methodology.

Corrective action to be taken when control limits are exceeded is left to the Project Manager's discretion.

The corrective action indicated for metals in Table 5-4 may be applied to conventional analytes.

When applicable, the QA/QC procedures indicated in this table should be completed at the same frequency as for metals analyses (see Table 5-4*).*

**Table 5-6.** Reporting limits for PCDD/PCDFs.

| Dioxins and Furans | Reporting Limit[a] (ng/kg Dry Weight) |
|---|---|
| PCDD | |
| 2,3,7,8-TCDD | 1.0 |
| 1,2,3,7,8-PeCDD | 1.0 |
| 1,2,3,4,7,8-HxCDD | 2.5 |
| 1,2,3,6,7,8-HxCDD | 2.5 |
| 1,2,3,7,8,9-HxCDD | 2.5 |
| 1,2,3,4,6,7,8-HpCDD | 2.5 |
| OCDD | 5.0 |
| PCDF | |
| 2,3,7,8-TCDF | 1.0 |
| 1,2,3,7,8-PeCDF | 2.5 |
| 2,3,4,7,8-PeCDF | 1.0 |
| 1,2,3,4,7,8-HxCDF | 2.5 |
| 1,2,3,6,7,8-HxCDF | 2.5 |
| 1,2,3,7,8,9-HxCDF | 2.5 |
| 2,3,4,6,7,8-HxCDF | 2.5 |
| 1,2,3,4,6,7,8-HpCDF | 2.5 |
| 1,2,3,6,7,8,9-HpCDF | 2.5 |
| OCDF | 5.0 |

a, Reporting limits are one-half those listed in EPA Method 1613B. Most laboratories can include this low-level calibration standard for a small additional cost.

**Table 5-7.** Quality control procedures for PCDD/PCDF analyses.

| QC Check | Minimum Frequency | Acceptance Criteria | Laboratory Corrective Action |
|---|---|---|---|
| Ongoing Precision and Recovery | 1 per analytical batch (< 20 samples) | Recovery within acceptance criteria in Table 5-6 | 1. Check calculation.<br>2. Re-extract and reanalyze batch. |
| Stable-isotope-labeled compounds | Spiked into each sample for every target analyte | Recovery within limits in Table 5-6 | 1. Check calculations.<br>2. Qualify all associated results as estimated. |
| | | Ion abundance ratios must be within criteria in Table 9 of method 1613B | 1. Reanalyze specific samples.<br>2. Reject all affected results outside the criteria.<br>3. Alternatively, use of secondary ions that meet appropriate theoretical criteria is allowed if interferences are suspect. This alternative must be approved by Ecology. |
| Sample target analyte Ion abundance ratios | All detected analytes for all samples | Ion abundance ratios must be within criteria in Table 9 of method 1613B | Laboratory to qualify results “K” or “EMPC” (estimated maximum concentration). |
| Method blank | One per analytical batch (<20 samples) | Detection ≤ minimum level in Table 2 of Method 1613B | 1. If the method blank results are greater than the reporting limit, halt analysis, find the source of contamination, and reanalyze batch.<br>2. Report project samples as non-detected for results ≤ to the reported method blank values. |
| GC/MS Tune | At the beginning of each 12 hour shift; must start and end each analytical sequence | > 10,000 resolving power @ m/z304.9825. Exact mass of 380.9760 within 5 ppm of theoretical values. | 1. Re-analyze affected samples.<br>2. Reject all data not meeting method 1613B requirements. |
| Initial Calibration | Initially and when continuing calibration fails | Five point curve for all analytes. TSD must meet Table 4 requirements for all target compounds and labeled compounds. Signal to noise ratio (S/N) >10. Ion abundance (IA) ratios within method specified limits. | |
| Window Defining/Column Performance Mix | Before every initial and continuing calibration | Valley < 25% for all peaks near 2378-TCDD/F peaks. | |
| Continuing Calibration | Must start and end each analytical sequence | % must meet Table 4 limits for target compounds & labeled compounds. S/N >10. IA ratios within method specified limits. | |

**Table 5-7** (continued). Quality control procedures for PCDD/PCDF analyses.

| QC Check | Minimum Frequency | Acceptance Criteria | Laboratory Corrective Action |
|---|---|---|---|
| Confirmation of 2,3,7,8-TCDF | For all primary column detections of 2,3,7,8-TCDF | Confirmation presence of 2,3,7,8-TCDF in accordance with method 1613B requirements. | Failure to verify presence of 2,3,7,8-TCDF by second column confirmation or use of an alternative primary column that meets resolution criteria requires qualification of associated 2,3,7,8-TCDF results as non-detected at the associated value |
| Sample data not achieving target reporting limits or method performance in presence of possibly interfering compounds | Not applicable | Not applicable | Rather than simply diluting an extract to reduce interferences, the lab should perform additional cleanup techniques identified in the method to insure minimal matrix effects and background interference.<br><br>Thereafter, the lab can dilute the extract.<br><br>If reanalysis is required, the laboratory shall report both initial and re-analysis results. |
| Sediment Reference Material | One per analytical project | Results must be within 20% of the 95% confidence interval | 1. Extraction and analysis should be evaluated by the lab and re-analysis performed of the entire sample batch once performance criteria can be met.<br>2. If analysis accompanies several batches with acceptable RM results, then the laboratory can narrate possible reason for RM outliers. |

If re-analysis is required, the laboratory shall report initial and re-analysis results.

**Table 5-8.** Quality control acceptance criteria for PCDD/PCDF analyses.

| Congener | Test Concentration ng/mL[a] | IPR[b] | | OPR[c] Recovery (%) | I-CAL[d] RSD% | CAL/VER[e] Recovery (%) | Labeled Compound Sample % Recovery |
|---|---|---|---|---|---|---|---|
| | | RSD (%) | Recovery (%) | | | | |
| **Native Compound** | | | | | | | |
| 2,3,7,8 -TCDD | 10 | 28 | 83 - 129 | 67 - 158 | 20 | 78 - 129 | - |
| 2,3,7,8 -TCDF | 10 | 20 | 87 - 137 | 75 - 158 | 20 | 84 - 120 | - |
| 1,2,3,7,8 - PeCDD | 50 | 15 | 76 - 132 | 70 - 142 | 20 | 78 - 130 | - |
| 1,2,3,7,8 - PeCDF | 50 | 15 | 86 - 124 | 80 - 134 | 20 | 82 - 120 | - |
| 2,3,4,7,8 - PeCDF | 50 | 17 | 72 - 150 | 68 - 160 | 20 | 82 - 122 | |
| 1,2,3,4,7,8 - HxCDD | 50 | 19 | 78 - 152 | 70 - 164 | 20 | 78 - 128 | - |
| 1,2,3,6,7,8 - HxCDD | 50 | 15 | 84 - 124 | 76 - 134 | 20 | 78 - 128 | - |
| 1,2,3,7,8,9 - HxCDD | 50 | 22 | 74 - 142 | 64 - 162 | 20 | 82 - 122 | - |
| 1,2,3,4,7,8 - HxCDF | 50 | 17 | 82 - 118 | 72 - 134 | 20 | 90 - 112 | - |
| 1,2,3,6.7.8 - HxCDF | 50 | 13 | 92 - 120 | 84 - 130 | 20 | 88 - 114 | - |
| 1,2,3,7,8,9 - HxCDF | 50 | 13 | 84 - 122 | 78 - 130 | 20 | 90 - 112 | - |
| 2,3,4,6,7,8 - HxCDF | 50 | 15 | 74 - 148 | 70 - 156 | 20 | 88 - 114 | - |
| 1,2,3,4,6,7,8 - HpCDD | 50 | 15 | 76 - 130 | 70 - 140 | 20 | 86 - 116 | - |
| 1,2,3,4,6,7,8 - HpCDF | 50 | 13 | 90 - 112 | 82 - 122 | 20 | 90 - 110 | - |
| 1,2,3,4,7,8,9 - HpCDF | 50 | 16 | 86 - 126 | 78 - 136 | 20 | 86 - 116 | - |
| OCDD | 100 | 19 | 89 - 127 | 78 - 144 | 20 | 79 - 126 | - |
| OCDF | 100 | 27 | 74 - 146 | 63 - 170 | 20 | 63 - 159 | - |
| **Labeled Compounds** | | | | | | | |
| $^{13}C_{12}$ - 2,3,7,8 - TCDD | 100 | 37 | 28 - 134 | 20 - 175 | 35 | 82 - 121 | 25 - 164 |
| $^{13}C_{12}$ - 2,3,7,8 - TCDF | 100 | 35 | 31 - 113 | 22 - 152 | 35 | 71 - 140 | 24 - 169 |
| $^{13}C_{12}$ - 1,2,3,7,8 - PeCDD | 100 | 39 | 27 - 184 | 21 - 227 | 35 | 62 - 160 | 25 - 181 |
| $^{13}C_{12}$ - 1,2,3,7,8 - PeCDF | 100 | 34 | 27 - 156 | 21 - 192 | 35 | 76 - 130 | 24 - 185 |
| $^{13}C_{12}$ - ,2,3,4,7,8 - PeCDF | 100 | 38 | 16 - 279 | 13 - 328 | 35 | 77 - 130 | 21 - 178 |
| $^{13}C_{12}$-1,2,3,4,7,8 - HxCDD | 100 | 41 | 29 - 147 | 21 - 193 | 35 | 85 - 117 | 32 – 141 |
| $^{13}C_{12}$-1,2,3,6,7,8 - HxCDD | 100 | 38 | 34 - 122 | 25 - 163 | 35 | 85 - 118 | 28 – 130 |
| $^{13}C_{12}$-1,2,3,4,7,8 - HxCDF | 100 | 43 | 27 - 152 | 19 - 202 | 35 | 76 - 131 | 26 – 152 |
| $^{13}C_{12}$-1,2,3,6,7,8 - HxCDF | 100 | 35 | 30 - 122 | 21 - 159 | 35 | 70 - 143 | 26 – 123 |
| $^{13}C_{12}$-1,2,3,7,8,9 - HxCDF | 100 | 40 | 24 - 157 | 17 - 205 | 35 | 74 - 135 | 29 – 147 |
| $^{13}C_{12}$-2,3,4,6,7,8 - HxCDF | 100 | 37 | 29 - 136 | 22 - 176 | 35 | 73 - 137 | 28 – 136 |
| $^{13}C_{12}$-1,2,3,4,6,7,8 -HpCDD | 100 | 35 | 34 - 129 | 26 - 166 | 35 | 72 - 138 | 23 – 140 |
| $^{13}C_{12}$-1,2,3,4,6,7,8 -HpCDF | 100 | 41 | 32 - 110 | 21 - 158 | 35 | 78 - 129 | 28 – 143 |
| $^{13}C_{12}$-1,2,3,4,7,8,9 -HpCDF | 100 | 40 | 28 - 141 | 20 - 186 | 35 | 77 - 129 | 26 – 138 |
| $^{13}C_{12}$-OCDD | 200 | 48 | 20 - 138 | 13 - 198 | 35 | 48 - 207 | 17 – 157 |
| **Standard** | | | | | | | |
| $^{37}C_{14}$-2,3,7,8 - TCDD | 10 | 36 | 39 - 154 | 31 - 191 | 35 | 79 - 127 | 35 – 197 |

a, QC Acceptance criteria for IPR, OPR, and samples based on a 20 µL extract final volume
b, IPR: Initial Precision and Recovery demonstration
c, OPR: Ongoing Precision and Recovery test run with every batch of samples
d, Initial Calibration
e, CAL/VER: Calibration Verification test run at least every 12 hours

**Table 5-9.** Marine and estuarine sediment toxicity test conditions.

| Biological Test Endpoint | | Performance Standard | | Control Samples | | | Control Limits | | | Water Quality Monitoring Frequency | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Control | Ref. | - Control | + Control | Ref. | Temp. °C | Salinity (ppt) | DO % Saturation | Temp. Salinity DO pH | Sulfides Ammonia |
| **Amphipod** | | | | | | | | | | | |
| **10-Day mortality** | ***Rhepoxynius abronius*** | $M_C \leq$ 10% | $M_R \leq$ 25% | Clean sediment | Ref. toxicant in seawater | Yes | 15 +/- 1 | 28 +/- 1 | NA | Daily | Start/end |
| | ***Ampelisca abdita*** | | | | | | 20 +/- 1 | 28 +/- 1 | | | |
| | ***Eohaustorius estuarius*** | | | | | | 15 +/- 1 | Ambient | | | |
| **Larval** | | | | | | | | | | | |
| **Bivalve or echinoderm abnormality / mortality** | **Oyster[a]** | $N_C$ / I $\geq$ 0.70 | $N_R$ / $N_C$ $\geq$ 0.65 | Clean seawater | Ref. toxicant in seawater | Yes | 20 +/-1 | 28 +/-1 | | Daily | Start/end |
| | **Mussel[b]** | | | | | | 16 +/-1 | | | | |
| | **Sand dollar[c]** | | | | | | 15 +/-1 | | | | |
| | **Sea urchin[d]** | | | | | | 15 +/-1 | | | | |
| **Juvenile Polychaete** | | | | | | | | | | | |
| ***Neanthes* 20-day growth** | | $M_C \leq$ 10% *and* $MIG_C \geq$ 0.38 mg/ind/day AFDW | $MIG_R$ / $MIG_C \geq$ 0.80 | Clean sediment | Ref. toxicant in seawater | Yes | 20 +/-1 | 28 +/- 2 | N/A | Every third day | Start/end (optional) |
| **Microtox** | | | | | | | | | | | |
| **Microtox decreased luminescence** | | See Appendix C | Case-by-case | Deionized or distilled water. See Appendix C to adjust salinity. | Ref. toxicant | Yes | 15 | See Appendix C | 50 - 100 | *7.9 ≤ pH ≤ 8.2* | N/A |

AFDW = Ash Free Dry Weight; C = Control; F = Final; I = Initial count; M = Mortality; mg/ind/day = milligrams per individual per day; MIG = Mean Individual Growth Rate; N = Normal Survivorship expressed as actual counts in mg/ind/day; R or Ref. = Reference;

a, Pacific oyster - *Crassostrea gigas*

b, Blue mussel – *Mytilus galloprovincialis*

c, Sand dollar – *Dendraster excentricus*

d, Sea urchin – *Strongylocentrotus purpuratus (purple sea urchin) or Strongylocentrotus droebachiensis (green sea urchin)*

**Table 5-10.** Freshwater sediment toxicity test conditions.

| Biological Test Endpoint | Performance Standard | | Control Samples | | Control Limits | | Water Quality Monitoring Frequency | |
|---|---|---|---|---|---|---|---|---|
| | Control[a] | Reference[b] | Negative | Positive | Temp[c] °C | DO[d] | Temp/DO | Hardness Alkalinity Conductivity Sulfides Ammonia |
| ***Hyalella azteca*** | | | | | | | | |
| **10-Day mortality** | $M_C \leq 20\%$ | $M_R \leq 25\%$ | Clean sediment | Reference toxicant in freshwater | 23 +/- 1 | 40 -100 | Daily | pH = Daily<br>Others at start/end of test |
| **28-Day mortality** | $M_C \leq 20\%$ | $M_R \leq 30\%$ | | | | | | |
| **28-Day growth** | $MIG_C \geq 0.15$ mg/individual | $MIG_R \geq 0.15$ mg/individual | | | | | | |
| ***Chironomus dilutus*** | | | | | | | | |
| **10-Day mortality** | $M_C \leq 30\%$ | $M_R \leq 30\%$ | Clean sediment | Reference toxicant in freshwater | 23 +/- 1 | 40 -100 | Daily | pH = Daily<br>Others at start/end of test |
| **10-Day growth** | $MIG_C \geq 0.48$ mg/individual | $MIG_R/MIGc \geq 0.8$ | | | | | | |
| **20-Day mortality** | $M_C \leq 32\%$ | $M_R \leq 35\%$ | | | | | | |
| **20-Day growth** | $MIG_C \geq 0.60$ mg/individual[d] | $MIG_R/MIGc \geq 0.8$ | | | | | | |
| **Microtox** | | | | | | | | |
| See Appendix C | | | | | | | | |

DO = Dissolved oxygen; M = Mortality; C = Control; R = Reference; F = Final; MIG = Mean Individual Growth at time final; mg = milligrams.

a, These tests and parameters were developed based on the most updated American Society for Testing and Materials (ASTM International) protocols.

b, Reference performance standards are provided for sites where Ecology has approved a freshwater reference sediment site(s) and reference results will be substituted for control in comparing test sediment to criteria.

c, Water bath or exposure chamber temperature should be continuously monitored. The daily mean temperature should be within + \ - 1 °C of the desired temperature. The instantaneous temperature should be within + \ - 3 °C of the desire temperature.

d, Percent saturation

*This page left intentionally blank.*

# Chapter 6
# Data Interpretation and Remedial Investigation Report

## 6.1 Introduction

This section provides guidance on preparation of the RI Report, including the contents of the report; methods for summing, graphing, and displaying data; updating the conceptual site model; identifying final CoCs; identifying cleanup levels for the CoCs through comparison of risk-based, background, and PQL-based concentrations; and identifying site boundaries and preliminary sediment management areas and/or sediment cleanup units.

For simple sites, a focused RI Report may be appropriate, which will reduce the categories of data and level of detail. Those items that could be streamlined for a simple site are noted throughout this chapter. A site may be considered simple where (as a whole or in combination):

- There are only a few CoCs.
- Chemical distribution and exposure pathways are not complex.
- The physical and hydraulic features of the site are straightforward.
- The site is small or isolated.
- A permanent cleanup action alternative is implementable and the PLP is willing to perform the cleanup.

Each simple site should be evaluated for the streamlining options that apply to it. This is not a complete list of what type of site could be considered simple for streamlining the RI Report. Ecology will consider other features on a site-specific basis.

## 6.2 Remedial Investigation Report

After the RI is completed, the results must be submitted in an RI Report. *Categories of data that may be streamlined (or are not necessary) for simple sites, or that may not be applicable to all sites, are noted in italics.* The RI Report should include the following (WAC 173-204-550(6)):

- <u>Introduction and general site information (Chapter 3)</u>. Much of the information in this section may repeat information that is found in the RI Work Plan, but the RI Report should be a stand-alone document for public review.

- Introduction. The introduction should state the objectives of the investigation and include general site information such as the site name; name, address, and phone number of the project coordinator; and a legal description of the site.

- Site information. This should include:

    - A summary of available information for the site, such as site history and past and present sources of contamination to the site (including a list of owners and operators of sources); and

    - A map of existing site conditions showing the site location; surface and subsurface topography; surface and subsurface structures; utility lines (if known); navigational lanes; lease areas; and the locations of historical and ongoing sources of contaminants to sediment.

- *Previous activities. A summary of previous investigations and dredging or interim cleanup actions conducted prior to the RI, if applicable.*

- Sampling and analysis summary (Chapters 4 and 5). This should include:

    - Data gaps identified in the RI Work Plan and a conceptual overview of the field investigations that were conducted to fill the data gaps. The preliminary CSM may be referenced since it will be updated near the end of the RI Report (Chapter 3).

    - Detailed description of all field investigations, referencing the RI SAP(s) and any deviations or additions to the SAP(s) (Chapter 3). Include investigations previously reported in interim reports to provide a comprehensive summary of all types of field sampling conducted (sediment, tissue, other media sampled, geophysical surveys, habitat surveys, etc.).

        - Field sampling methods (Chapter 4).

        - Final sampling locations, including tables of latitudes/longitudes, depths, station names, sample numbers, and maps of sampling locations (Chapter 4).

        - Tables of analytes; analytical methods; MDLs and PQLs achieved; and overview of QA/QC methods (Chapter 5).

- Physical characteristics and natural resources (Chapter 3). Include relevant information about physical characteristics and natural resources information for the site, including data obtained during field investigations and information from other sources.

- Bathymetry, *currents, tides, geologic setting, and groundwater dynamics.*
- *Climate. Vulnerabilities to climate change impacts such as sea level rise, flooding, wildfire, and landslide (Ecology 2017a).*
- Sediment grain size; presence of debris and other field observations; *stratigraphy; sediment transport; apparent redox potential discontinuity; radiometric dating; sedimentation or erosion*.
- Natural resources. Existing natural resources; habitat for shellfish, forage fish, eelgrass or kelp beds*; wetlands; abundance and diversity of organisms, organism/sediment index, succession stage; presence of ESA species.*

- Sediment chemistry results. Summarize the results of the sediment chemistry analyses for surface, subsurface, and intertidal sediments, including:
  - Data quality summary. This section may cover all categories of analytical results (Chapter 5).
  - Data preparation, including summation methods; addressing nondetects; addressing replicates and qualifiers; statistical methods used to calculate summary statistics; and methods for calculating area-wide means for bioaccumulation exposure areas (Section 6.3)
  - Tables presenting summary statistics for each subset of chemistry data, including comparisons to relevant SMS standards (e.g., benthic SCO or CSL) and/or background concentrations (see Section 6.3).
  - Maps showing chemistry results, including contours or depths corresponding to relevant standards or concentrations (see Section 6.4.2).
  - *Tables and maps of the sediment bioassay results compared to the benthic criteria (Chapter 8) should be summarized. The bioassay results should be summarized for each bioassay type (see Section 6.4.2).*

- *Tissue chemistry results.*
  - *Data quality summary (Chapter 5).*
  - *Tables summarizing tissue chemistry concentrations and summary statistics.*
  - *Comparison to background concentrations or other screening levels.*
  - *Calculation of site-specific BSAF in combination with sediment data.*

- *<u>Summary results for other types of field investigations</u>, such as porewater, surface water, biota (benthic community assessments, habitat surveys), engineering evaluations (structural surveys, shoreline surveys, and sonar), potential climate change vulnerabilities, etc. Each section should: a) discuss the quality of the data and any challenges encountered; b) summarize the results in tables and maps; and c) interpret the results.*

- *<u>In-depth human health risk assessment</u> (not typically required at sediment sites; see Section 6.4.3 and Appendix E).*

    - *CoPCs for human health.*

    - *Exposure pathways and RME scenarios. Identify populations and activities that result in risk to humans from the CoCs based on the CSM. This will most commonly include tribal subsistence or other fisher groups whose harvest areas include the site.*

    - *Data preparation, including summation methods; addressing nondetects; addressing replicates and qualifiers; statistical methods used to calculate summary statistics; and calculating area-wide means.*

    - *Equations used to calculate risks for:*

        - *Ingestion of fish and shellfish.*

        - *Dermal exposure and incidental ingestion (e.g., for beach play, shellfishing, netfishing.)*

    - *Exposure parameters:*

        - *Tables of exposure parameters and values. These should include the recommended values, any departure from the recommended values (such as a site-specific fish consumption rate), and justifications for the departure.*

    - *Risk calculations for carcinogenic and non-carcinogenic health effects. These should be combined and summarized for multiple pathways and sources and values compared to SMS acceptable risk levels.*

- *<u>Ecological risk evaluations (Appendix E)</u>.*

    - *CoPCs, CoCs, exposure pathways, and receptors. Identify CoPCs and CoCs, receptors that are potentially affected, and exposure pathways that may not be*

*adequately protected by other RI evaluations or standards (e.g., human health, background concentrations).*

- *Methods used to evaluate risks to the species and exposure pathways of concern (e.g., specialized field evaluations, literature review, modeling).*
- *Data quality and data handling procedures.*
- *Risk-based concentrations and/or other results.*
- *Summary of risks and conclusions.*

- Source control, natural recovery, and recontamination assessments.
  - Source control evaluation for current and historic sources.
  - *Natural recovery and/or recontamination modeling, or other evaluations.*
- Conceptual site model (Section 6.5). The preliminary conceptual site model (Chapter 3, Section 3.3) should be updated based on the RI results, and any remaining data gaps needed for remedy selection should be identified. This could include:
  - Physical and habitat features including vulnerabilities to climate change impacts.
  - Current and former sources and releases.
  - Transport pathways and contaminated media.
  - Ecological and human health impacts.
  - Environmental processes potentially affecting cleanup.
  - Remaining data gaps and proposals for filling data gaps.
- CoCs, SCOs, CSLs, and site-specific cleanup standards (Section 6.6, Chapters 7 through 11).
  - CoCs and justification for screening.
  - Ecological risk-based concentrations (Chapter 9).
  - Human health risk-based concentrations (Chapter 9).
  - Background concentrations (Chapter 10).

  - PQLs (Chapter 11).
  - Final SCOs, CSLs, and proposed sediment cleanup levels (Chapter 7).
  - Proposed cleanup standards, including points/areas of compliance and depths of compliance (Chapter 7).

- Site boundaries (Section 6.7).
- *Sediment management areas and/or sediment cleanup units (Section 6.7)*.
- References.
- Appendices.
  - Field investigation data (Chapter 4).
    - Sampling and field logs.
    - Chain of custody.
    - QA/QC reports.
  - *Human health exposure and risk calculations (Appendix E).*
  - *Ecological risk evaluations (Appendix E).*
  - An appendix that describes implementation of the public participation plan, including photographs, slides, and public information materials. Alternatively, this appendix can be included in the FS.

# 6.3 Data Reporting, Calculating Sums, and Summary Statistics

## 6.3.1 Data reporting

Chemistry and bioassay data should be reported in tables for the measured analytes (including conventional variables). Bioassay results should be tabulated and compared to the benthic biological criteria (Chapter 8, Table 8-1).

### 6.3.1.1 Sediment chemistry

Sediment chemistry concentrations should be reported on a dry-weight basis and include the following, depending on the data source:

- For marine sediment chemistry data, the reported concentrations for non-polar organic chemicals should be converted to TOC-normalized concentrations to allow direct comparison to the SMS marine chemical benthic criteria (Chapter 8, Table 8-1).

  Dry-weight values should also be included in cases where TOC values are either very high (> 3.5%) or very low (< 0.5%). Ecology may decide to compare the data with both the TOC normalized and dry-weight AET values under these circumstances (Chapter 8, Table 8-1). In this case, if there are SCO or CSL exceedances, the highest magnitude exceedances should be used for decision making. If more than one CoC at a station is close to exceeding the SCO, bioassays may need to be conducted for that station.

  To normalize to TOC, the dry weight concentration for each CoC is divided by the decimal fraction representing the percent TOC content (e.g., 0.01 means 1 percent) of the sediment per the equation:

  ppm OC = (ppb dry weight) / (percent TOC dry weight x 1000)

  For further discussion of TOC-normalization, see Chapter 4, Section 4.2.2(5).

- For freshwater sediment chemistry data, reported concentrations should be on a dry-weight basis since the freshwater benthic criteria are dry-weight based (Chapter 8, Section 8.2).

- For low-salinity (estuarine) sediment chemistry data, the concentrations should be compared to both the freshwater and marine benthic criteria. In general, the lower of the freshwater and marine benthic criteria will apply.

- The dry weight concentrations should also be compared to risk-based or background-based sediment concentrations for bioaccumulative chemicals.

These tables should also include additional data such as:

- Station numbers.

- Sample identification numbers (corresponding to those on laboratory data sheets).

- Date of sample collection.

- Sediment sampling interval (upper and lower depths within the sediments relative to the sediment-water interface).

- Location in latitude and longitude or in state plane coordinates such as the Washington State Plane North or South Zone with a datum of NAD 83 HARN in units of U.S. survey feet.

- Water depth from the Mean Lower Low Water to the sediment-water interface (Chapter 4, Section 4.5).

A recommended table format is one column for each individual sample and one row for each individual analyte. The results for field duplicate samples should be identified as such and reported separately (i.e., not averaged). Appropriate data qualifiers should be reported with the chemical concentrations. Laboratory data tabulated in spreadsheets should also be included as an appendix to the RI Report.

Laboratory sediment and tissue chemistry data and bioassay data should be submitted to Ecology in the electronic EIM template format, which can be downloaded from: http://www.ecy.wa.gov/eim/. For help submitting data, go to: http://www.ecy.wa.gov/eim/help.htm.

#### 6.3.1.2 EIM Data Submittal

All appropriate data must be submitted to Ecology's EIM database. Data reports will not be considered for approval until data has been submitted. The MyEIM analysis tool can be used to compare the sediment chemistry and bioassay data to the benthic chemical numeric and biological criteria for freshwater and marine sediments. These tools should always be used to ensure consistency of MyEIM results with RI Report conclusions.

If the sample result is reported with JT or U or U containing qualifiers, the PQL for that sample must be provided.

### 6.3.2 Calculating chemical sums

Some of the benthic numerical criteria (e.g., SCO, CSL) are for sums of individual compounds (e.g., total LPAHs, total HPAHs), isomers (e.g., total benzofluoranthenes), or groups of compounds (e.g., total PCB Aroclors®). Additionally, some bioaccumulative chemicals with common modes of action are summed for the purposes of human health risk assessment and determination of cleanup standards. Approaches for summing these compounds are described in the following sections.

#### 6.3.2.1 Marine benthic chemical criteria

These rules should be used to calculate sums to compare to the marine benthic criteria (WAC 173-204-562(2)):

- Total LPAH represents the sum of the concentrations of the following LPAH compounds: acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene, (WAC 173-204-562(2)(i)). 2-Methylnaphthalene is not included in the sum.

- Total HPAH represents the sum of the concentrations of the following HPAH compounds: benz[a]anthracene, benzo[a]pyrene, benzo[g,h,i]perylene, chrysene, dibenzo[a,h]anthracene, fluoranthene, indeno[1,2,3-c,d]pyrene, pyrene, and total benzofluoranthenes, (WAC 173-204-562(2)(j).

- Total benzofluoranthenes represents the sum of concentrations of the b, j, and k isomers of benzofluoranthenes (WAC 173-204-562(2)(k)). Some laboratories report the total benzofluoranthenes concentration rather than concentrations of individual compounds since they may not be able to resolve all three isomers.

- Total PCBs were derived based on the sum of the concentrations of Aroclors® 1016, 1221, 1232, 1242, 1248, 1254 and 1260. Upon Ecology approval on a case-by-case basis, Total PCB congeners may be analyzed to substitute for Total PCB Aroclors when assessing impacts to the *benthic community*. If Total PCB congeners are used instead of Total Aroclors to verify compliance with the SMS benthic criteria, bioassays should be analyzed if there are exceedances above the benthic SCO (Chapter 8). This is because Total PCB congeners are not as predictive of benthic criteria exceedances at the SCO level.

#### 6.3.2.2 Freshwater benthic chemical criteria

These rules should be used to calculate sums to compare to the freshwater benthic criteria (WAC 173-204-563)(2)):

- Total PAHs represents the sum of 1-methylnaphthalene, 2-methylnaphthalene , acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[a]pyrene, benzo[g,h,i]perylene, chrysene, dibenz[a,h]anthracene, fluoranthene, fluorene, indeno[1,2,3-c,d] pyrene, naphthalene phenanthrene, pyrene, and total benzofluoranthenes [b+j+k] (WAC 173-204-563(2)(h)).

- Total PCBs were derived based on the sum of the concentrations of Aroclors® 1016, 1221, 1242, 1248, 1254, 1260, and 1268. Upon Ecology approval on a case-by-case basis, Total PCB congeners may be analyzed to substitute for Total PCB Aroclors when assessing impacts to the *benthic community*. If Total PCB congeners are used instead of Total Aroclors to verify compliance with the SMS benthic criteria, bioassays should be analyzed if there are exceedances above the benthic SCO (Chapter 8). This is because Total PCB congeners are not as predictive of benthic criteria exceedances at the SCO level.

- DDTs and derivatives were calculated as follows: total DDDs, total DDEs, and total DDTs, (o,p' and p,p' isomers in each case), as each of the three groups was determined to have differing toxicity.

#### 6.3.2.3 Bioaccumulative chemicals

Mixtures of dioxin/furan congeners, dioxin-like PCB congeners, and cPAHs can be considered single hazardous substances when establishing cleanup levels and determining compliance with cleanup levels (WAC 173-340-708). Ecology may approve combining the dioxins/furans and dioxin-like PCB TEQs as one CoC when establishing the cleanup level for dioxin-like carcinogenic effects. The most current toxicity equivalency factor (TEF), EPA methodology, and values should be used, including:

- Using TEFs for dioxins/furans and dioxin-like PCB congeners recommended by the World Health Organization to characterize the toxicity of these mixtures.

- Using potency equivalency factors for cPAHs adopted by the California Environmental Protection Agency to characterize the toxicity of these mixtures.

For PCBs, the dioxin-like PCB congeners should be evaluated when cleanup levels are based on risks to human health and higher trophic levels, background, and PQL. Total PCB congeners (all 209) may need to be evaluated on a site-specific basis. The TEFs and minimum individual cPAHs that should be included in the TEQ calculations are listed in Table 6-1. The TEFs that should be used for TEQ calculations for dioxins/furans and dioxin-like PCB congeners are listed in Table 6-2 and Table 6-3. All TEQ sums should be reported in dry weight.

Where dioxins/furans congeners and/or dioxin-like PCB congeners are contributing to a dioxin-like TEQ, Ecology may approve establishing the SCO by combining the natural background TEQs. For example, the Puget Sound natural background value for dioxins/furans TEQ is 4 ppt (rounded up from 3.6 ppt TEQ per Chapter 6 Section 6.3.5) and the dioxin-like PCBs TEQ is 0.2 ppt. The combined TEQ would be rounded to 4 ppt. In this case, dioxins/furans or the combined TEQs that add up to less than or equal to 4 ppt TEQ could be determined to meet the SCO for dioxin-like carcinogenic effects. In addition, when these TEQs are combined to establish the SCO, the benthic SCO (Chapter 8, Table 8-1) for Total PCB Aroclors must be met on a station by station basis as they are considered a different CoC.

***Calculating TEQs in EIM using the myEIM analysis tool***

The myEIM analysis tool allows the user to:

1) Calculate TEQs for dioxins/furans, dioxin-like PCBs, cPAHs, DDE, DDTs, and DDDs from site-specific data using substitution (i.e., 0, 0.5, or 1 x the method detection limit) for non-detects (Step 1 below).

2) Create a specific cleanup criteria (e.g., natural or regional sediment background) to compare to the calculated TEQs (Step 2 below).
3) Compare the calculated TEQ to the cleanup criteria (Step 3 below).

The following steps describe how to do this in MyEIM.

***Step 1.*** *Create a User Defined Derived Variable.* This step includes creating a User Defined Derived Variable that is a sum TEQ calculated using substitution for non-detected congeners (e.g., 0, 0.5, or 1.0 x MDL) from site-specific data. It also allows the user to calculate a TEQ using different substitutions for non-detects or adding constituents (e.g., if additional cPAHs are present that are not included in the minimum seven typically used, these can be added along with their weighting factor or TEF). See subsection 6.3.3 on how to address non-detects.

MyEIM also includes some Derived Variables for some substitutions or scaling factors (e.g., the Defined Variable "cPAH-TEQ" with a scaling factor of 0.5 for non-detects) which can be used instead of creating a User Defined Derived Variable.

1. Open the *myEIM* home page (http://www.ecy.wa.gov/eim/MyEIM.htm). You may need to create an account to access this page.
2. On the MyEIM home page, select *Analysis*, which opens the Analysis homepage.
3. Select *Chemistry Criteria* under "If you need to prepare cleanup criteria…".
4. Select the *Derived Variables* tab
5. Select the Derived Variable needed by clicking the *blue* > in the first column. This highlights the row of the selected Derived Variable and displays its constituents in the table at the bottom of the page.
6. Click *Copy* in the far right column of the highlighted row. This places a copy of the selected Derived Variable in the *User Defined Derived Variables* tab with the name starting as "My…" followed by the name of the copied Derived Variable.
7. Select the *User Defined Derived Variables* tab.
8. Click *Edit* (the pencil icon) of the newly created row "My …". This opens a new row to customize the Derived Variable.
9. Fill in:
    a. *UDDerivedVariable Name*. Use a name that describes the Derived Variable but do not use special characters (e.g., !@.,#%.).
    b. *UDDerivedVariable Desc.* This allows a more detailed description of the Derived Variable.
    c. *DetectionLimitScalingFactor*. These are different substitutions (i.e., 0, 0.5 or 1 x detection limit) for non-detects that can be used to examine a range of calculated TEQs. Note the MDL should be the reported value with U qualification (this is a sample-specific detection limit).

   d. *Subsidiary*. This identifies the original Derived Variable that was copied and the constituents in the calculated TEQ. Confirm these constituents and their TEFs are listed in the table.
   e. *Comments*. This is additional information that may be useful.
10. Click *Save* (diskette icon) and the created User Defined Derived Variable will be available for future data searches.
11. At this stage, additional constituents can be added for the TEQ calculation. For example, if an additional cPAH is present at the site but not included in the minimum seven constituents for cPAHs, it can be added with its corresponding TEF to the TEQ calculation.
    a. Click *Add Constituent* (green button). This opens a new line at the bottom of the table.
    b. Fill in:
       i. *Constituent*. Select from dropdown list.
       ii. *Weight*. Use the TEF for the specific constituent.
    c. Click *Save* (diskette icon) and the new constituent will be added to the User Defined Derived Variable.
12. To share this, click *Share* (green button) on the last column of the User Defined Derived Variable row.

***Step 2.*** *Create a User Defined Cleanup Criteria.* This step has two functions: 1) creation of User Defined Cleanup Criteria such as natural or regional background or PQL and 2) selection of a Derived Variable, User Defined Derived Variable, or both to compare to the User Defined Cleanup Criteria (Step 3).

1. Open myEIM home page (http://www.ecy.wa.gov/eim/MyEIM.htm). You may need to create an account to access this page.
2. Select *Analysis* on the myEIM home page. This opens the *Analysis* homepage.
3. Select *Chemistry Criteria* under "If you need to prepare cleanup criteria…"
4. Select *User Defined Cleanup Criteria*
5. Select *New Criteria* (green button) along the left margin. This opens a new row to enter criteria.
6. Fill in *Enter your User Defined Criteria Name.* Use a name that defines the User Defined Cleanup Criteria but do not use special characters (e.g., !@.,#%.).
7. Select *Save* (diskette icon). This opens a *Constituent List* on the bottom of the page.
8. Select *Add Constituent* (green button) at the bottom of the page. The term 'constituent' refers to the Derived Variable that will be compared to the User Defined Cleanup Criteria.
9. Fill in:
   a. *ConstituentType*. This can be:
      i. The Derived Variable. This opens a column to select the TEQ constituent

types (e.g., cPAHs, dioxins/furans, dioxin-like PCBs) which typically uses 0.5 x detection limit substitution method.

ii. The User Defined Derived Variable. For example, a TEQ calculated in Step 1, using either 0 or 1.0 x detection limit substitution method.

b. *Constituent* = __. A drop down list includes a range of Derived Variable constituents.

c. *Concentration* = __. This is the User Defined Cleanup Criteria (e.g., natural or regional background or PQL)to compare against. This must be filled in.

d. *UnitOfMeasure*. This is typically ng/kg for dioxins and dioxin-like PCBs or ug/kg for cPAHs.

e. *Measurement Basis*. Use *Dry* for sediment and *Wet* for tissue.

f. *Comments*. Add any additional information as appropriate.

10. Click *Save* (diskette icon). The User Defined Cleanup Criteria will be available for future data searches.
11. To add more Derived Variables or User Defined Derived Variables, highlight the User Defined Cleanup Criteria and Click *Add Constituents* (green button), then repeat steps 7 to 8 for each Derived Variable or User Defined Derived Variable you wish to compare to the User Defined Cleanup Criteria. Be sure to enter the same chemical *Concentration* for each of the added constituents.

***Step 3.*** *Perform an EIM data query* for the area of interest and carry out the comparison to the User Defined Cleanup Criteria from Step 2. Then export the results as Excel spreadsheets.

1. Open myEIM home page
2. Perform a chemistry data search for the study or area of interest.
3. Select *Analyze Data*
4. Select *User Defined Cleanup Criteria*
5. Click on the box in first column of the User Defined Cleanup Criteria, then click *Compare* (red button on upper right side of page) and wait for results.
6. Export Results. This will be in two Excel files 1) the calculated TEQ results for each Derived Variable that was compared to the User Defined Cleanup Criteria and 2) each constituent and its weighted concentration used to derive the TEQs for each sample.

### 6.3.3 Addressing non-detects in chemical sums

In this section, non-detects represent any “U” qualified data, which may be data reported at the PQL, the MDL, or the RL, or blank contaminated sample results reporting above the RL but not exceeding 3x above the RL. For the calculations described herein, no distinction is made between these different types of detection limits, and any “U” qualified data are treated as “non-detects” at whatever limit or result was used for reporting.

#### 6.3.3.1 Marine and freshwater benthic criteria

These rules should be used for reporting and summing non-detects for comparison to the marine and freshwater benthic criteria:

- When all chemicals in a group are undetected, only the single highest individual chemical quantitation limit in a group should be reported and appropriately qualified.

- If some concentrations were detected and others were not, only the detected concentrations are included in the sum.

#### 6.3.3.2 Bioaccumulative chemicals

When non-detects for bioaccumulative chemicals are present in a dataset, there are specific methods available for calculating TEQ sums of bioaccumulative chemicals that are recommended in place of substitution methods (e.g., substituting one-half of the detection limit). In particular, Ecology recommends the Kaplan-Meier (KM) method for estimating the TEQ sums when < 50% of non-detected congeners are present within a sample for each CoC (Table 6-4). The general approach is as follow (see Appendix F, Section F.1.2 for more detail):

- If the highest non-detected value exceeds all the detected values, substitute the detection limit for the non-detected value and treat it as a detected value to estimate the KM sum. An "L" qualifier should be assigned to the TEQ to indicate this is an upper bound estimate of the total. This qualifier may be over-ridden by the qualifier described in the next bullet.

- For all levels of detection frequency, calculate a KM sum with the knowledge that there is a positive bias that increases with the percentage of non-detects. Using Efron's bias correction will reduce the positive bias somewhat, although not remove it entirely. When more than 50% of the congeners within a sample are not detected, the KM sum should be "L" qualified to indicate there is a positive bias, and should include the number of censored congeners in the sample: "L*." For example, for dioxin/furan TEQ, if 12 of the 17 congeners were non-detected, the detection frequency is 29% (less than 50%), so the KM TEQ would be calculated and qualified with "L12."

- If any of the upper bound TEQ sums (with qualifiers described in the previous bullets) are in a range that is of concern, then reanalysis of those samples using lower detection limits is recommended when possible.

- If the KM method for estimating the sum is too burdensome, substitution at one-half the method detection limit may be used as a simple alternative. EIM—using the *MyEIM* analysis tool—includes Derived Variables (summed TEQs) calculated using one-half the method detection limit substitution method. However, using this alternative will result in

generated sums that are estimates with unknown bias and precision. Such values should be qualified appropriately as "Estimates" to indicate the variable accuracy of the estimated sums. These estimates may be bounded by also reporting sums using substitution at zero and at the full detection limit. Examining the range of calculated TEQs with different substitution methods may reveal the sensitivity of the TEQ to the scaling factor of the substitution.

## 6.3.4 Calculating summary statistics for a dataset

Basic summary statistics, such as the arithmetic mean, median, upper and lower percentiles, ranges, and variance are frequently used to describe the general characteristics of a dataset. These summary statistics are useful for reporting general conditions, identifying potential problem areas, and screening CoCs (i.e., if the mean is below natural background, then it will be below any cleanup standard and therefore in compliance).

When datasets are fully detected, basic methods can be used to calculate summary statistics. However, when non-detects are present in a dataset, there are more robust methods other than substitution that should be used to interpret the important information provided by the data, without introducing patterns that may not actually be present. Generally speaking, substitution methods are not a recommended option for dealing with censored data, although substitution of 0 and the full detection limit can be used to place upper and lower bounds on the estimated mean value at the site. Since these upper and lower bounds can span fairly large ranges relative to potential cleanup levels, the methods described below are preferred.

### 6.3.4.1 Mean, variance, and percentiles when non-detects are present

The most appropriate method for calculating summary statistics (e.g., means, medians, upper or lower percentiles, and standard deviations) will vary depending on the sample size and the proportion of censored data. Table 6-4 (Table 6.11 in Helsel 2005) provides recommended methods for estimating summary statistics when non-detects are present. A brief description of each approach is provided below. See Appendix F for more detail.

- Kaplan-Meier (KM). Kaplan-Meier estimation is a non-parametric method borrowed from survival analysis. Percentiles for detected concentrations are calculated by including the number of censored data below each detected concentration. This information can be plotted on a survival function plot. Percentiles, including the median, can be estimated from the plot (the concentration associated with a value of 0.5 of the y-axis). Percentiles at or below the proportion censored cannot be estimated. For example, if more than 50% of the dataset is below detection, then the median value cannot be estimated. KM methods can also be used to estimate the mean and standard deviation when non-detects are present. However, the higher the proportion of non-detects, the greater the uncertainty in these estimated values.

- Maximum Likelihood Estimation (MLE). This procedure requires an assumption that the observed data were derived from a particular parametric distribution (e.g., normal, lognormal, gamma). The successful outcome of this method relies on an accurate assumption about the underlying distribution. The underlying distribution should be checked using probability plots for censored data and is best applied with large samples size ($n > 50$). The likelihood function is unique to each distribution and is defined as the probability of having observed the set of data, given values for the population parameters (e.g., the mean and variance for a normal or lognormal distribution). Estimates for the population parameters that produce values that most closely resemble the observed dataset are the maximum likelihood estimates (MLEs).

- Robust Regression on Order Statistics. Regression on order statistics (ROS) refers to the regression lines shown in probability plots for data with NDs. The probability plots show the theoretical quantiles against the observed quantiles for the detected data only, where the probabilities associated with the observed detected data take into consideration the number of censored data points below each detected concentration (similar to KM methods). Robust ROS uses this regression line to extrapolate values for NDs based on their estimated probabilities. The estimated probabilities (or plotting positions) for NDs are calculated using the proportion of samples detected above each detection limit. The regression line fit to the quantiles for the detected data is then used to predict values for the NDs based on their estimated plotting positions. The combined set of observed detected values and the predicted values for the NDs is treated as a complete sample. Summary statistics can be estimated using standard equations for the mean and variance or using methods such as bootstrapping. ProUCL 5.0.00 computes and saves imputed ROS values, but these predicted observations should not be used as if they were valid substitution values associated with any particular sample.

#### 6.3.4.2 Averaging over exposure areas

The following procedures may be used: a) to characterize concentrations or risks over a large exposure area in the RI Report; b) to identify sediment management areas for the FS (Section 6.7 and Chapter 12); or c) during compliance monitoring (Chapter 13) to evaluate compliance with bioaccumulative cleanup standards.

For any of these purposes, if the samples have been collected using a fully random or grid design, the concentrations may be averaged using a straight average of all sample concentrations in the area. If the samples have been collected using a stratified random sampling design, the concentrations may be averaged using a straight average within each stratum. Area-weighted procedures are then used to average across strata, as described below.

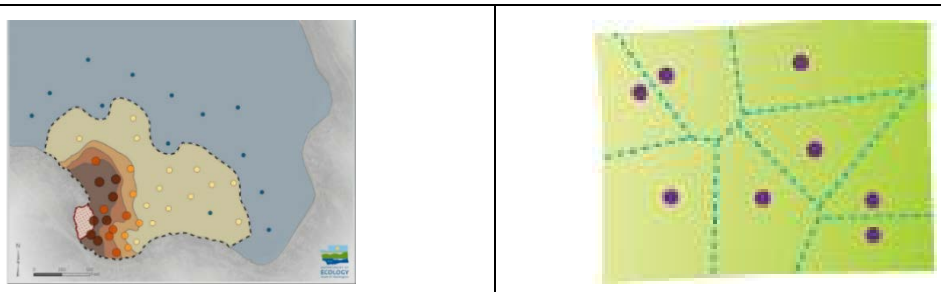
Area-weighted averages should be used:

- When a non-random or biased sampling design was used to collect the data, such as when sampling to target particular areas of concern.
- When different sampling strata or sediment management areas need to be combined to estimate a site-wide mean.

***Inverse distance weighting (IDW)***

When a non-random or biased sampling design is used to collect the data, Ecology recommends the use of inverse distance weighting (IDW) for spatial characterization. IDW includes use of a GIS application and interpolation methods with algorithms to interpret the influence of multiple neighboring points, their concentrations, and distances from one another when estimating a value at unsampled locations. IDW can more accurately determine the site boundary and more precisely interpolate concentrations at unsampled locations than Thiessen polygons.

In Figure 6-1, the points represent sampling locations and the curvilinear contour lines represent equal concentrations (isoconcentrations) identified by IDW. The contours of similar color represent ranges between the adjacent isoconcentrations of importance, such as the SCO, CSL or cleanup level value. The outer isoconcentration represents the site boundary when it is established at those concentrations.



| Inverse Distance Weighting | Thiessen polygon |
|---|---|

**Figure 6- 1:** Sample depiction of inverse distance weighted interpolated concentrations and Thiessen polygons calculated for a set of sampling locations.

***Thiessen polygons***

This method assumes the area defined is represented by the data point within that area. The polygon has boundaries midway between adjacent sampling locations, so that any point inside a sampling location's Thiessen polygon is closer to that sampling location than other sampling locations. In Figure 6-1, the points represent sampling locations and the dashed lines represent boundaries of the Thiessen polygons.

***Calculating the area-weighted average***

To calculate the area-weighted average (AWA) using Inverse Distance Weighting, algorithms integrated into GIS are used to select the area of interest to calculate the area-weighted average. This can be done for the entire site (i.e., identify site-boundary) or to determine the area-weighted average within individual sediment cleanup units or sediment management areas. This process can simplify the hill-topping method to determine the remediation area necessary to meet cleanup levels.

To calculate the area-weighted average using Thiessen polygons, the sample concentrations are weighted (multiplied) by the proportional areas of their respective Thiessen polygons (i.e., the proportional area is the area of each polygon divided by the total area of the site, so that the sum of the proportional areas equals one; see Appendix F, Section F.2.3).

Similarly, if different sediment management areas need to be combined to determine a site-wide mean concentration, the means for individual sediment management areas can be area-weighted and the same calculation performed to determine the site-wide mean. In this case, the area-weighted average is the sum of the sediment management area means, weighted (multiplied) by the proportional areas of their respective sediment management areas, and divided by the total area of the site.

When non-detects are present in a dataset for which an area-weighted average needs to be calculated, the KM method can be used, where the proportional area weights described in the above paragraph are analogous to the TEFs that weight the congener concentrations in the summing of TEQs (Appendix F, Section F.1.2).

## 6.3.5 Significant figures and rounding

Data in report tables and for EIM submittals should be rounded to the appropriate number of significant figures. However, laboratory reports in appendices should be exact copies. The appropriate number of significant figures will vary depending on the concentration and the analyte, and may not match the output provided in laboratory reports.

Within a dataset, the same number of significant digits should be reported, regardless of the number of decimal places or the number of non-zero values to the left of the decimal. For example, when reporting using two significant figures, 11 and 9.9 should be reported rather than 11.2 and 9.9. Values close to the MDL or PQL should have no more than 1 - 2 significant figures, while values well above the PQL may have 2 - 3 significant figures.

All calculations such as sums, TEQs, means, etc., should be performed before rounding and the final value should be rounded according to the following rules:

- Calculated values should be rounded to the number of significant figures equal to the lowest number of significant figures in any of the measured values used in the calculation. For the purposes of TEQ calculations, TEFs should be considered to have one significant figure. However, non-measured or theoretical values are considered to have an infinite number of significant figures (such as unit conversion factors or acceptable risk levels) and do not affect the final number of significant figures.

- When rounding, fractional values of ≥ 0.5 should be rounded up to the next highest whole number. Fractional values < 0.5 should be rounded down to the next lowest whole number. For example, 1.251 is rounded up to 1.3, while 1.249 is rounded down to 1.2.

- Use zeros appropriately to indicate significant figures to the right of the decimal place. For example, 1.30 has three significant figures, while 1.3 has two.

- A zero should be placed to the left of the decimal point for values < 1. This zero is not considered significant. For example, 0.32 has two significant figures.

## 6.4 Data Analysis and Presentation

Data analysis is the numerical and/or statistical analysis of chemistry and biological test data in order to:

- Map chemical concentrations and bioassay results relative to natural and anthropogenic features of the site.

- Determine whether the data exceed risk-based values, background concentrations, and/or PQLs, on a point-by-point and/or an area-wide basis.

- Support other decisions relating to the investigation, cleanup, and source control of contaminated sediments, which includes assessing the potential for natural recovery and/or recontamination.

Typically, it is the PLP's responsibility to analyze data that is collected in a sediment investigation. PLPs should evaluate laboratory results by providing general descriptions of the sediment chemistry data and any biological data. Stations should be clearly identified on a map if: a) they exhibit exceedances of SMS criteria, or b) the PQLs are above chemical criteria for the undetected chemicals.

### 6.4.1 Graphing datasets

Graphing the data should be one of the first steps when evaluating a dataset. It is an essential part of data analysis that aids in data characterization and identifying CoCs and elevated values. Some useful plot types are described below, but other types may be included as appropriate (e.g., scatterplots for evaluating correlations between data). These plots have options for properly representing non-detected data in both R and ProUCL (see Appendix F for more detail):

- Boxplots. Boxplots or box-and-whisker plots are used to illustrate the distribution of the data and provide information about the location, spread of the data, and skewness.

    - When several boxplots are placed side by side, it allows comparisons between: a) regions within a site, and b) between site and background populations. A horizontal line may be added to indicate SCO, CSL, or cleanup level.

    - Boxplots can show skewness (non-normality); the overlap or complete separation of ranges between site and background; and unusual/elevated values that warrant further investigation.
    - Each boxplot has a shaded/colored rectangle (the "box") that shows the spread of values between the 1$^{st}$ and 3$^{rd}$ quartiles (i.e., the 25$^{th}$ and 75$^{th}$ percentiles). The height of this box is the interquartile range (IQR), which is the value of the 3$^{rd}$ quartile minus the value of the 1$^{st}$ quartile.

    - The horizontal line inside the box indicates the median. The outer brackets (the "whiskers") represent the minimum and maximum values (or 1.5 times the IQR from the median, whichever is less). The median (+) and (-) 1.5x the IQR is expected to contain about 98% of a normal (Gaussian) distribution.

    - Values outside the whiskers are possible elevated values.

    - When non-detects are present, different methods may be used to represent the calculable percentiles, the uncensored data, and censoring limits. At a minimum, the maximum detection limit should be shown as a horizontal line on the plot, and any features of the distribution that fall below this line should not be interpreted.

    - Examples of boxplots generated in R are shown in Figure 6-2. (R is a language and environment for statistical computing and graphics available for free on the web; see www.r-project.org for more information.) Boxplots can also be generated in ProUCL.

- Probability Plots. Probability plots or Quantile-Quantile (Q-Q) plots are used to compare a dataset to a specific theoretical distribution (e.g., normal, lognormal, or gamma distribution). The measured data quantiles are plotted against the theoretical quantiles for that distribution. If the data fit the theorized distribution, then the data points will fall along a straight line. When non-detects are present, quantiles are calculated for the detected concentrations only, but these quantiles still take into account the number of non-detects below each detected concentration to determine the appropriate quantile. Figures 6-3 and Figure 6-4 show probability plots generated in R and ProUCL, respectively.

- Empirical Cumulative Distribution Function (ECDF) Plots. These plots display the percentiles or cumulative probabilities for each observation in the dataset. They are shown as a step function with a step up at each unique concentration. The stair-step display illustrates the discrete (i.e., discontinuous) nature of the dataset and emphasizes sample size (i.e., smaller sample sizes have fewer steps). As above, percentiles are shown only for detected concentrations, but the number of non-detects below each detected concentration is used in determining the percentile. These plots can facilitate comparisons between two or more distributions by overlaying the ECDFs for multiple datasets (e.g., site vs. background) on the same plot. ECDF plots allow interpretation of distributional characteristics: a) steeper curves have less variance; b) curves shifted to the right have higher values; and c) specific percentiles can be compared (e.g., median, or the $90^{th}$ or $95^{th}$ percentiles). Figure 6-5 shows two ECDF plots generated in R.

### 6.4.2 Mapping datasets

Mapping data allows for a clear presentation of complex datasets. GIS mapping portrays contaminant distributions, as well as the magnitude, areal, and vertical extent of exceedances. Physical features of a site and their influences on contaminant distributions or remediation options are readily shown using maps. Examples of such features include shoreline features, beach slopes, site bathymetry, engineered structures, sediment transport, substrate type, grain size, point sources, wave and wind exposure, water currents, potential vulnerabilities to climate change impacts (e.g., sea level rise, flooding, wildfire, landslide; Ecology 2017a), and more.

Maps generated for the RI Report are important tools that will be referenced for the duration of the project. They are most useful when kept simple, clear, and concise. The following scenarios demonstrate different methods for portraying RI data using commonly available data-rendering tools. Other approaches may also be appropriate for specific sites and data types. When using colored maps, take care to select accessible color schemes (i.e., those that consider forms of color-blindness), and consider how well the maps will reproduce and/or project. Below are examples of how to present data:

- Simple site with sample stations shown as colored and scaled dots. If the concentrations of the CoCs are poorly distributed spatially or the sample size is small, interpolation can introduce method-specific errors and complicate interpretation. In this case, presenting the data as individual points using a meaningful color and proportional symbol size is more useful. The CoC and relevant potential cleanup levels should drive the class breaks of colors and symbol sizes (Figure 6-6).

- Simple site with interpolation of data. Interpolation of discrete data samples to create a continuous surface can be used to understand distribution patterns of contaminants. Given that the abstraction of data inherently introduces error, it is critical that the interpolation method of its application will allow adequate scrutiny of the data. Many current geostatistical tools (e.g., Geostatistical Analyst in ArcMap™) provide the ability to analyze the error associated with an interpolative surface. When accompanied by analysis, this information can provide context and help guide interpretation of the data (Figure 6-7).

- Simple site with bioassay pie chart. Presenting categorical data with pie charts or bar graphs is a visually efficient way to display the results of multiple bioassays at one location (Figure 6-8).

- Complex site with overlapping footprints. Overlaying the footprints of multiple CoCs is one technique to illustrate the areas where a cumulative risk exists due to the co-occurrence of multiple CoCs. Maintaining the colors and graphic elements of the original contaminant maps can help preserve continuity when interpreting overlapping data (Figure 6-9).

- Complex site with overlapping CoCs normalized to cleanup levels. Converting the concentration of multiple contaminants to normalized "exceedance factors" is another way to identify the areas of highest concern. Each contamination footprint can be normalized relative to its respective cleanup level, background concentration, etc. These normalized footprints can then be overlain and summed. The areas of highest cumulative value are those where the greatest reduction of risk will be achieved through remediation. Therefore, a map of exceedance factors can provide one consideration when dividing a site into sediment management areas (Figure 6-10).

- Plan view and cross sections of contaminant distributions. This type of map is used to portray the data at depth (e.g., geologic strata or contaminant concentrations). A plan view showing transects that correspond to the cross sections should be included, along with side views of the cross sections showing depths, sampling locations (such as core samples), and interpolations of data between them (if any) (Figure 6-11).

### 6.4.3 Risk assessment results (optional)

In general, human health and ecological risks are addressed through the development of protective risk-based cleanup concentrations (Section 6.6), using the methods described in Chapters 7 through 9. In some cases, however, a more in-depth risk assessment may be needed for human health or ecological receptors, particularly when resources or receptors of special sensitivity are present. Appendix E describes these optional evaluations and when they may be appropriate. If additional risk assessments are conducted, their results should be described in the RI Report or in an appendix.

Risk assessment methods and results should be presented in detail, including all equations and input parameters used. Deviations from the default parameters should be described and justified, and literature sources identified. Results should be presented for individual chemicals and exposure pathways, as well as be summed (as appropriate) across pathways and chemicals using the rules described in Chapter 9 and Appendix E. Risk communication can be enhanced by presenting risks in both tabular and graphic form. For example, pie charts or graphs can show the relative contributions of various chemicals or exposure pathways. Risks can also be mapped spatially, if appropriate. It may also be helpful to compare site risks to background risks to gain perspective on incremental site risks and the potential benefits associated with cleanup. Discussion of risk assessment should focus on meeting RI/FS objectives and filling data gaps, such as:

- Screening CoPCs to identify a final CoC list.
- Identifying exposure pathways that are incomplete or complete.
- Identifying receptors or exposure pathways associated with unacceptable risk (e.g., where CoCs are above background).
- Identifying areas of the site that require risk-based cleanup standards and/or special management (e.g., institutional controls during recovery, special susceptibility to impacts during cleanup, habitat improvements, etc.).

### 6.4.4 Source control, recontamination, and natural recovery evaluations

The RI Report should describe any assessments that were conducted to evaluate source control at the site. These could include file reviews; site inspections; sampling or monitoring results (in-pipe or receiving water or sediments); and/or modeling. Each historical and ongoing source under the PLP's legal authority or responsibility should be described, accompanied by its current status. A clear conclusion should be drawn regarding whether the sources have been eliminated

and/or are under control such that they will not recontaminate the site above the proposed cleanup standards. If remaining sources may result in recontamination, the CoCs and expected degree of recontamination should be described. In addition to this description, sources may also need to be addressed as part of the cleanup actions evaluated in the FS. If there is concern about offsite sources recontaminating the site, and the PLPs have information or modeling that suggests this potential, such information should also be presented. See Chapter 13, Section 13.2 for further information on source control monitoring. See Chapter 3 and Chapter 14, Section 14.2.4 for more information on recontamination.

If monitored natural recovery (MNR) or enhanced monitored natural recovery (EMNR) is expected to be one of the cleanup action alternatives evaluated for the site, the results of natural recovery evaluations should be presented in the RI Report. These evaluations should identify the expected timeframe to achieve the proposed cleanup standards through MNR, and provide information needed to design EMNR alternatives that might achieve the cleanup standards more rapidly. All equations, models, and assumptions used for natural recovery evaluations should be explicitly described. Results should be graphed and areas that might require an SRZ should be identified on a map.

## 6.5 Revised Conceptual Site Model

Guidance on preparing the preliminary CSM is provided in Chapter 3. The updated CSM should integrate all of the data that was collected during the RI. If there are data reports following intermediate phases of sampling, each report should include an updated CSM based on the new information to inform the next phase of sampling.

The updated CSM in the RI Report should comprehensively address all aspects of the site that are important to meeting key RI/FS goals. It is not necessary to repeat all information that was presented in the preliminary CSM (e.g., hydrology, climate, etc.) if that information has not changed and is not a key factor in selecting cleanup standards or evaluating cleanup action alternatives. However, new information should be noted and referenced. The CSM in the RI Report should include:

- All aspects discussed in Chapter 3, Section 3.3 that affect identification of CoCs; cleanup standards; site boundaries; key environmental processes at the site including potential vulnerabilities to climate change impacts (Ecology 2017a); source control; recontamination or natural recovery; and design and selection of cleanup action alternatives. New information gained during the RI should be included. When possible, place an emphasis on reaching clear conclusions with respect to RI/FS goals and tasks.

- An updated graphic or chart showing the sources, releases, contaminated media, complete exposure pathways, and receptors. Primary and secondary sources, releases, pathways,

and receptors can be shown. Chemical classes or indicator CoCs should be differentiated if their CSM differs.

- Final identification of CoCs and proposed indicator chemicals (if any), based on the new information gained. The basis for screening CoPCs to determine CoCs and a rationale for each decision should be clearly described. If final identification of CoCs depends on developing proposed cleanup levels, this step may be conducted in conjunction with the next section.
- A discussion of whether and how: a) all data gaps identified in the RI/FS Work Plan have been filled; b) whether any data gaps remain; and c) whether such data gaps need to be filled prior to the FS or could be addressed during remedial design.

## 6.6 Proposed Cleanup Levels and Cleanup Standards

Chapter 7 provides an overview of how the final sediment cleanup objective (SCO), final cleanup screening level (CSL), and site-specific sediment cleanup levels are determined. The required information includes:

- The benthic criteria (SCO and CSL) provided in Chapter 8.

- Site-specific risk-based cleanup standards for bioaccumulative chemicals, described in Chapter 9. Chapter 9 includes two options. Option 1 is a simpler and more protective approach based on natural or regional background concentrations, while Option 2 requires back-calculation of risk-based sediment concentrations from risk-based tissue concentrations.

- Natural and regional background concentrations (if defined), described in Chapter 10.

- Practical quantitation limits (PQLs), described in Chapter 11.

Each of these chapters should be reviewed in order to assemble information needed to derive the SCO and the CSL for each CoC at the site. Alternatively, cleanup levels may be developed for each CoPC and then each CoPC screened against these values to identify final CoCs for the site.

For the benthic criteria CoCs (that are not also bioaccumulative CoCs) the values will often be above both a) PQLs, and b) natural and regional background (except in rare cases where, for example, metals concentrations may be naturally high). Therefore, the criteria listed in Chapter 8 can normally be used directly as the SCO and CSL without modification. Either the chemical or biological criteria in that chapter can be used.

For bioaccumulative CoCs (for protection of human health and higher trophic levels), all of the information in Chapters 9, 10, and 11 may be needed. The SCO and CSL are defined as follows:

**The SCO is the highest of these three values**:

- *The risk-based value* calculated using Option 2 in Chapter 9, using SCO acceptable risk levels (optional). This assumes that, for CoCs having both benthic and bioaccumulative criteria (such as mercury), the human health or higher trophic level risk-based concentrations are lower than the benthic criteria.
- *Natural background.*
- *The PQL.*

**The CSL is the highest of these three values:**

- *The risk-based value* calculated using Option 2 in Chapter 9, using CSL acceptable risk levels (optional). This assumes that, for CoCs with both benthic and bioaccumulative criteria (such as mercury), the human health or higher trophic level risk-based concentrations are lower than the benthic criteria.
- *Regional background.*
- *The PQL.*

For both benthic and bioaccumulative criteria, the sediment cleanup level can be established within a range of levels at the SCO, the CSL, or at a level in between (Chapter 7, Figure 7-1). The sediment cleanup level can be adjusted upwards from the SCO without exceeding the CSL (WAC 173-204-560(2)(a)(iii)) based on technical possibility and net adverse environmental impacts (see Chapter 7, Section 7.2.3.) If a sediment cleanup level other than the SCO is proposed in the RI Report, a discussion and rationale should be presented for increasing the cleanup level based on these adjustment factors.

A cleanup standard consists of three parts:

1. The cleanup level, which is a numeric value.
2. The depth of compliance, which is the depth within the sediments where the cleanup level must be met.
3. The area of compliance, which is the area over the site where the cleanup level must be met.

All of these factors may vary depending on the type of exposure—benthic organisms, human health, or higher trophic levels. Different areas of the site may have different combinations of cleanup standards and remediation levels, depending on the types of exposures present in those areas. The RI Report should clearly identify the proposed cleanup standards that are considered

applicable to each area of the site, as well as the three parts of each cleanup standard identified above.

In addition, the benthic community standards must be met at each individual station (Chapter 13, Option A). Human health and higher trophic levels are considered to have area-wide exposures, and are evaluated based on an area-wide mean concentration (Chapter 13, Option B).

## 6.7 Identifying Site Boundaries, Sediment Cleanup Units, and Proposed Sediment Management Areas

Once the proposed cleanup standards for each CoC have been developed, maps should be prepared that clearly identify areas of the site that exceed the standards for each CoC. If the site will include both sediment cleanup levels and remediation levels applicable to different areas (e.g., benthic vs. human health, or intertidal exposures vs. subtidal), the areas where those levels are exceeded should be clearly distinguished. Areas where the CoCs might overlap based on their different cleanup levels. For example, the footprint for a CoC with a regional background-based cleanup level that overlaps with the footprint for a different CoC with a risk-based cleanup level.

The maps should show boundaries where concentrations exceed the SCO, CSL, and site-specific sediment cleanup levels for each CoC. A site may be divided into sediment management areas (SMAs) or sediment cleanup units (SCUs). This step may be done at the end of the RI Report or the beginning of the FS Report. Use of SMAs or SCUs is optional and, for simpler sites, multiple SMAs may not be needed. SMAs may be helpful if there are both cleanup levels and remediation levels for the same CoC that apply to different receptor types and different areas of the site. Dividing these areas into SMAs may simplify and clarify both compliance monitoring and selection of cleanup action alternatives. SMAs may also be appropriate when various natural and built features of the site might affect the appropriate cleanup action alternatives for different areas of the site. These factors are described in more detail in Chapter 12 Section 12.3.

**Table 6-1.** Toxicity Equivalency Factors (TEFs) for the minimum[a] required cPAHs.

| CAS Number | cPAH | TEF (Unitless)[b] |
|---|---|---|
| 50-32-8 | Benzo[a]pyrene[c] | 1 |
| 56-55-3 | Benzo[a]anthracene | 0.1 |
| 205-99-2 | Benzo[b]fluoranthene | 0.1 |
| 207-08-9 | Benzo[k]fluoranthene | 0.1 |
| 218-01-9 | Chrysene | 0.01 |
| 53-70-3 | Dibenz[a,h]anthracene | 0.1 |
| 193-39-5 | Indeno[1,2,3-cd]pyrene | 0.1 |

a, Ecology may require additional compounds from the CalEPA list to be included in the methodology, should site testing data, or information from other comparable sites or waste types, indicate that the additional compounds are potentially present at the site.

b, Source: Cal-EPA, 2005.

c, For mixtures of cPAHs, the reference chemical is benzo[a]pyrene. Benzo[a]pyrene was chosen as the reference chemical because the toxicity of the chemical is well characterized. The toxicity equivalency factor for each cPAH is an estimate of the relative toxicity of the cPAH compound compared to benzo[a]pyrene.

**Table 6-2.** Toxicity Equivalency Factors (TEFs) for dioxin/furan congeners.

| CAS Number | Dioxin Congeners | TEF (Unitless)[a] |
|---|---|---|
| 1746-01-6 | 2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) | 1 |
| 40321-76-4 | 1,2,3,7,8-Pentachlorodibenzo-p-dioxin (1,2,3,7,8-PeCDD) | 1 |
| 39227-28-6 | 1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin (1,2,3,4,7,8-HxCDD) | 0.1 |
| 57653-85-7 | 1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin (1,2,3,6,7,8-HxCDD) | 0.1 |
| 19408-74-3 | 1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin (1,2,3,7,8,9-HxCDD) | 0.1 |
| 35822-46-9 | 1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin (1,2,3,4,6,7,8-HpCDD) | 0.01 |
| 3268-87-9 | 1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (1,2,3,4,6,7,8,9-OCDD) | 0.0003 |
| **CAS Number** | **Furan Congeners** | **TEF (Unitless)** |
| 51207-31-9 | 2,3,7,8-Tetrachlorodibenzofuran (2,3,7,8-TCDF) | 0.1 |
| 57117-41-6 | 1,2,3,7,8-Pentachlorodibenzofuran (1,2,3,7,8-PeCDF) | 0.03 |
| 57117-31-4 | 2,3,4,7,8-Pentachlorodibenzofuran (2,3,4,7,8- PeCDF) | 0.3 |
| 70648-26-9 | 1,2,3,4,7,8-Hexachlorodibenzofuran (1,2,3,4,7,8-HxCDF) | 0.1 |
| 57117-44-9 | 1,2,3,6,7,8-Hexachlorodibenzofuran (1,2,3,6,7,8- HxCDF ) | 0.1 |
| 72918-21-9 | 1,2,3,7,8,9-Hexachlorodibenzofuran (1,2,3,7,8,9- HxCDF ) | 0.1 |
| 60851-34-5 | 2,3,4,6,7,8-Hexachlorodibenzofuran (2,3,4,6,7,8-HxCDF) | 0.1 |
| 67562-39-4 | 1,2,3,4,6,7,8-Heptachlorodibenzofuran (1,2,3,4,6,7,8-HpCDF) | 0.01 |
| 55673-89-7 | 1,2,3,4,7,8,9-Heptachlorodibenzofuran (1,2,3,4,7,8,9-HpCDF) | 0.01 |
| 39001-02-0 | 1,2,3,4,6,7,8,9-Octachlorodibenzofuran (1,2,3,4,6,7,8,9-OCDF) | 0.0003 |

a, Source: Van den Berg et al. 2006.

**Table 6-3.** Toxicity Equivalency Factors (TEFs) for dioxin-like PCB congeners.

| CAS Number | Dioxin-like PCBs | TEF (Unitless)[a] |
|---|---|---|
| 32598-13-3 | 3,3',4,4'-Tetrachlorobiphenyl (PCB 77) | 0.0001 |
| 70362-50-4 | 3,4,4',5- Tetrachlorobiphenyl (PCB 81) | 0.0003 |
| 32598-14-4 | 2,3,3',4,4'-Pentachlorobiphenyl (PCB 105) | 0.00003 |
| 74472-37-0 | 2,3,4,4',5-Pentachlorobiphenyl (PCB 114) | 0.00003 |
| 31508-00-6 | 2,3',4,4',5-Pentachlorobiphenyl (PCB 118) | 0.00003 |
| 65510-44-3 | 2',3,4,4',5-Pentachlorobiphenyl (PCB 123) | 0.0003 |
| 57465-28-8 | 3,3',4,4',5-Pentachlorobiphenyl (PCB 126) | 0.1 |
| 38380-08-4 | 2,3,3',4,4',5-Hexachlorobiphenyl (PCB 156) | 0.00003 |
| 69782-90-7 | 2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157) | 0.00003 |
| 52663-72-6 | 2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167) | 0.00003 |
| 32774-16-6 | 3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169) | 0.03 |
| 39635-31-9 | 2,3,3',4,4',5,5'-Heptachlorobiphenyl (PCB 189) | 0.00003 |

a, Source: Van den Berg et al. 2006.

**Table 6-4.** Recommended methods for estimating summary statistics (after Table 6-11 in Helsel, 2012).

| | **Amount of Available Data** | |
|---|---|---|
| **Percent Censored** | **< 50 samples** | **≥ 50 samples** |
| < 50% non-detects (of samples for each CoC) | Kaplan-Meier | Kaplan-Meier |
| 50 – 80% non-detects (of samples for each CoC) | Robust MLE or ROS | MLE |
| > 80% non-detects (of samples for each CoC) | Report only % above a meaningful threshold | May report high sample percentiles (90$^{th}$, 95$^{th}$) |

MLE, maximum likelihood estimate

ROS, regression on order statistics

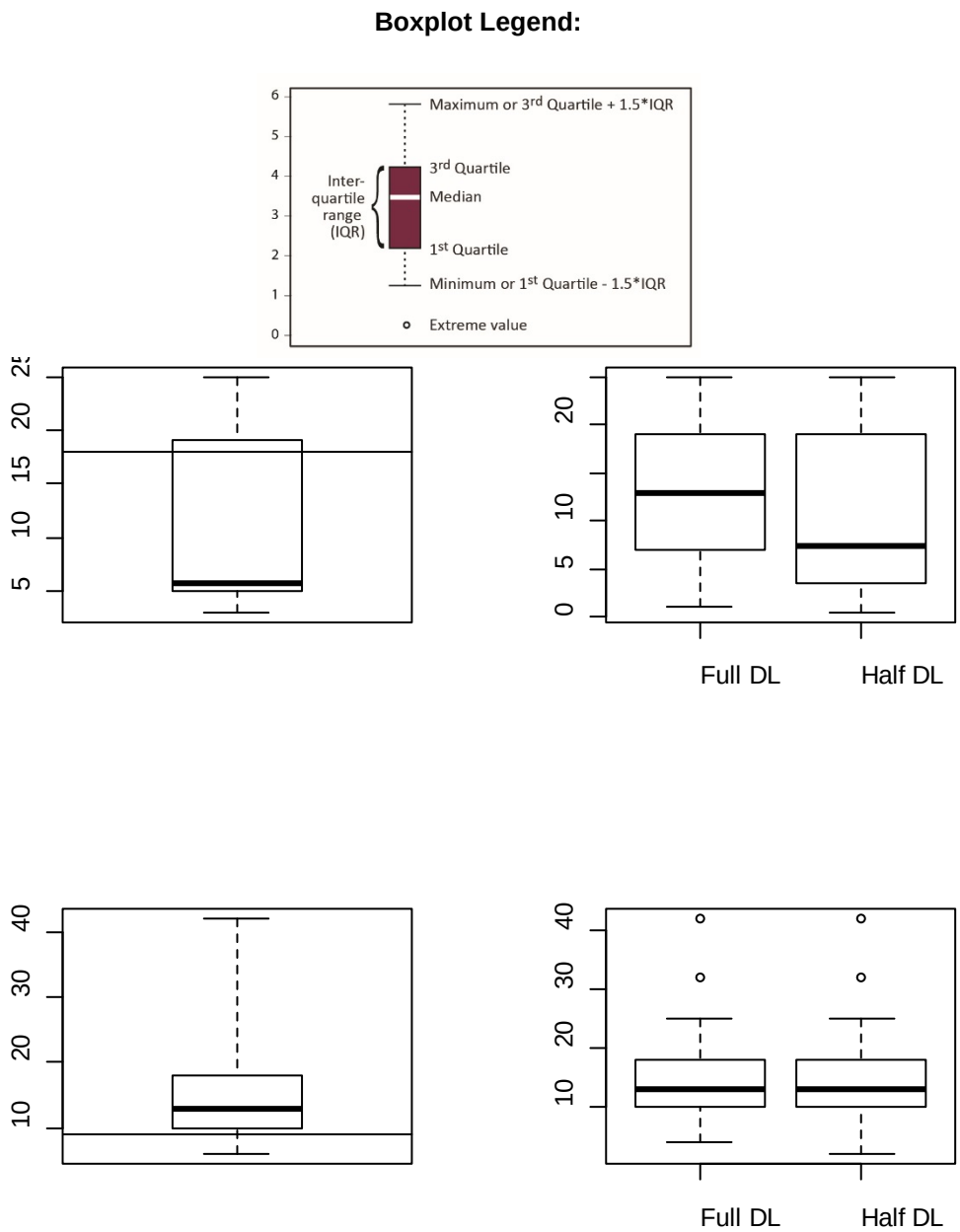



**Figure 6-2.** Boxplots for two censored datasets.

The dataset in the top row has 25 observations, of which 13 are censored data points with DLs ranging from 1 to 18, and 12 are detected data points with concentrations ranging from 3 to 25. The dataset in the bottom row has 27 observations, of which 6 are censored data points with DLs ranging from 4 to 9, and 21 are detected data points with concentrations ranging from 10 to 42. The left-hand plots show the distribution of the data with 1st, 2nd, and 3rd quartiles estimated using Kaplan-Meier for censored data; the horizontal lines indicate the highest detection limit. The right-hand plots show the distribution of the data ignoring censoring, using two levels of substitution for DLs. The plots were generated in R using the *cenboxplot()* function (left-hand plots) and *boxplot()* function (right-hand plots). Substitution can strongly influence the median estimate with censoring at approximately 50% (figure on the top row).

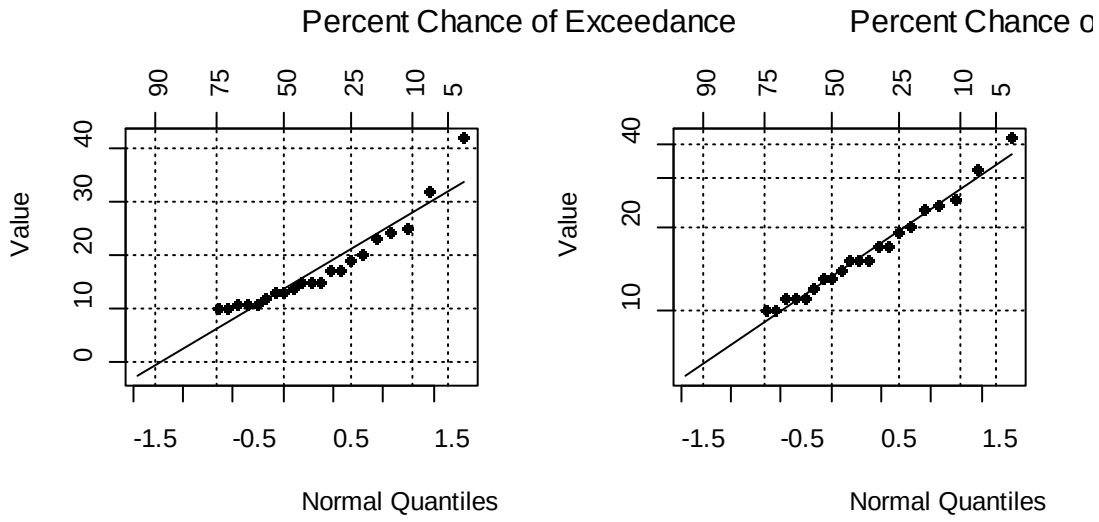



**Figure 6-3.** Probability or quantile-quantile (Q-Q) plots for a censored dataset (the same data shown in the bottom row of boxplots in Figure 6-2).

On the left, these data are plotted against normal quantiles; on the right, the log of these data are plotted against normal quantiles (notice the logarithmic points are closer to the straight line). Censored data are <u>not</u> shown on the plot, but they <u>are</u> used to calculate the quantiles for the detected observations. The lowest detected observation has a quantile of 25%, corresponding to a percent chance of exceedance of 75% (top axis). These plots were generated in R on ROS (regression-on-order statistics) objects.

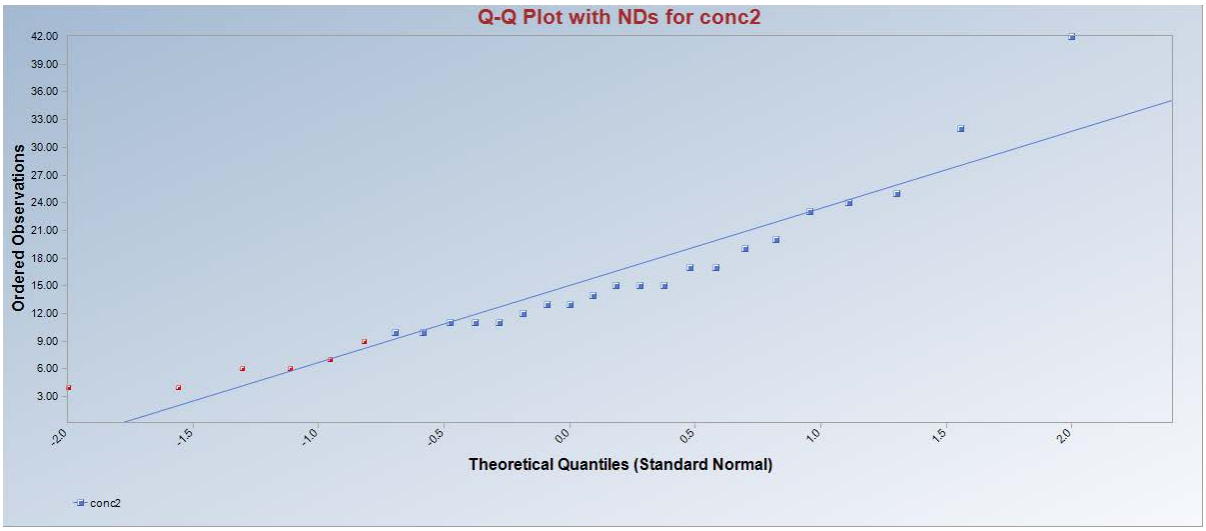



**Figure 6-4.** A normal distribution Q-Q plot generated in ProUCL under Graphs > Multi-QQ > With NDs.

The same data shown in Figure 6-3 are shown here on the original scale (no log transform). Detected values are shown in blue; censored data points are shown in red at their reported values. Note that this is somewhat misleading, since the quantiles for the censored data are actually unknown. The optional line, when added, is fit to the entire dataset using substitution of the DL or one-half the DL for the censored data points, rather than just the detected blue data points.

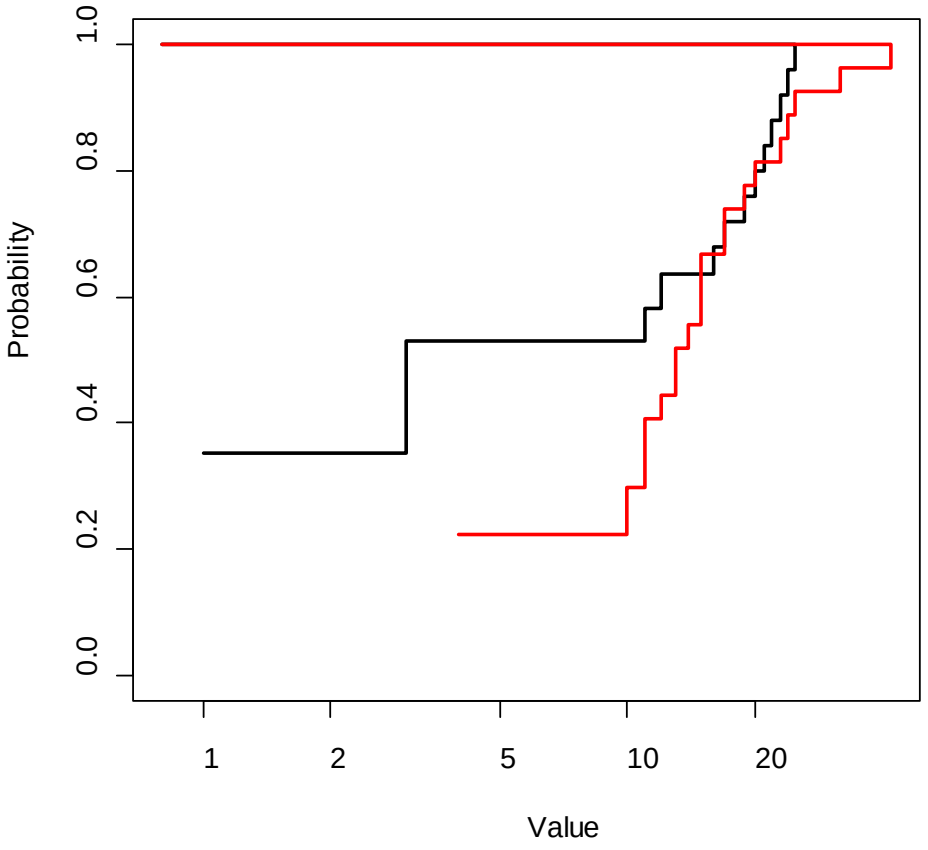



**Figure 6-5.** Empirical cumulative distribution function (ECDF) plots for the two datasets shown in the boxplots in Figure 6-2**.**

The ECDF for the data shown in the top row of Figure 6-2 is shown in black; the ECDF for the data shown in the bottom row is shown in red. Each step up in these ECDF plots indicates a detected concentration (concentration value on the x-axis) and the proportion of observations both censored and uncensored below this concentration (y-axis). Longer horizontal pieces for a line segment indicate larger gaps in concentrations between detected data values; taller vertical steps indicate multiple observations (censored values with the same DL or uncensored values with the same concentrations). These plots were generated in R on Kaplan-Meier estimates of percentiles estimated using the *cenfit()* function.

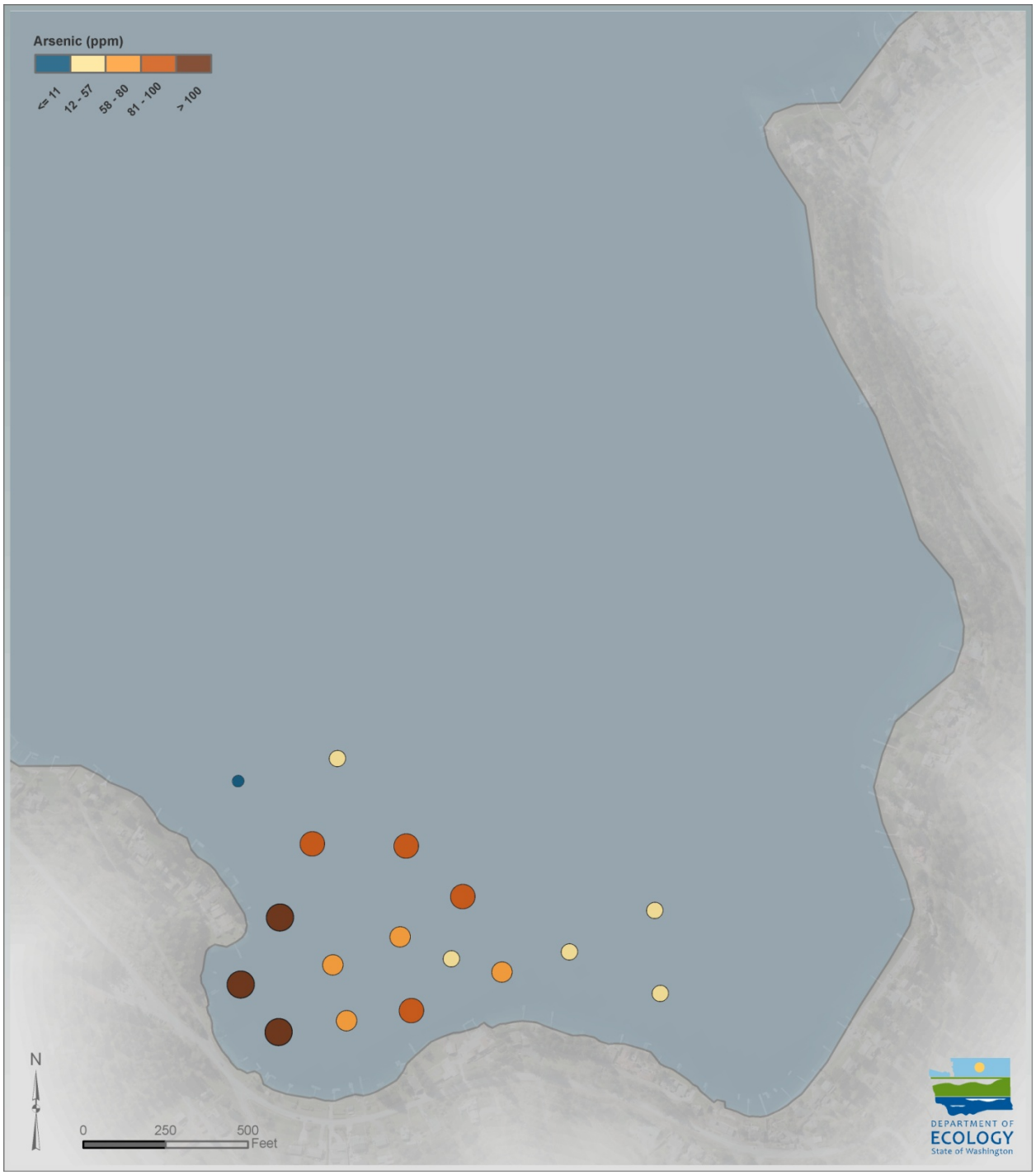



**Figure 6-6.** Simple site with sample stations shown as colored and scaled dots.

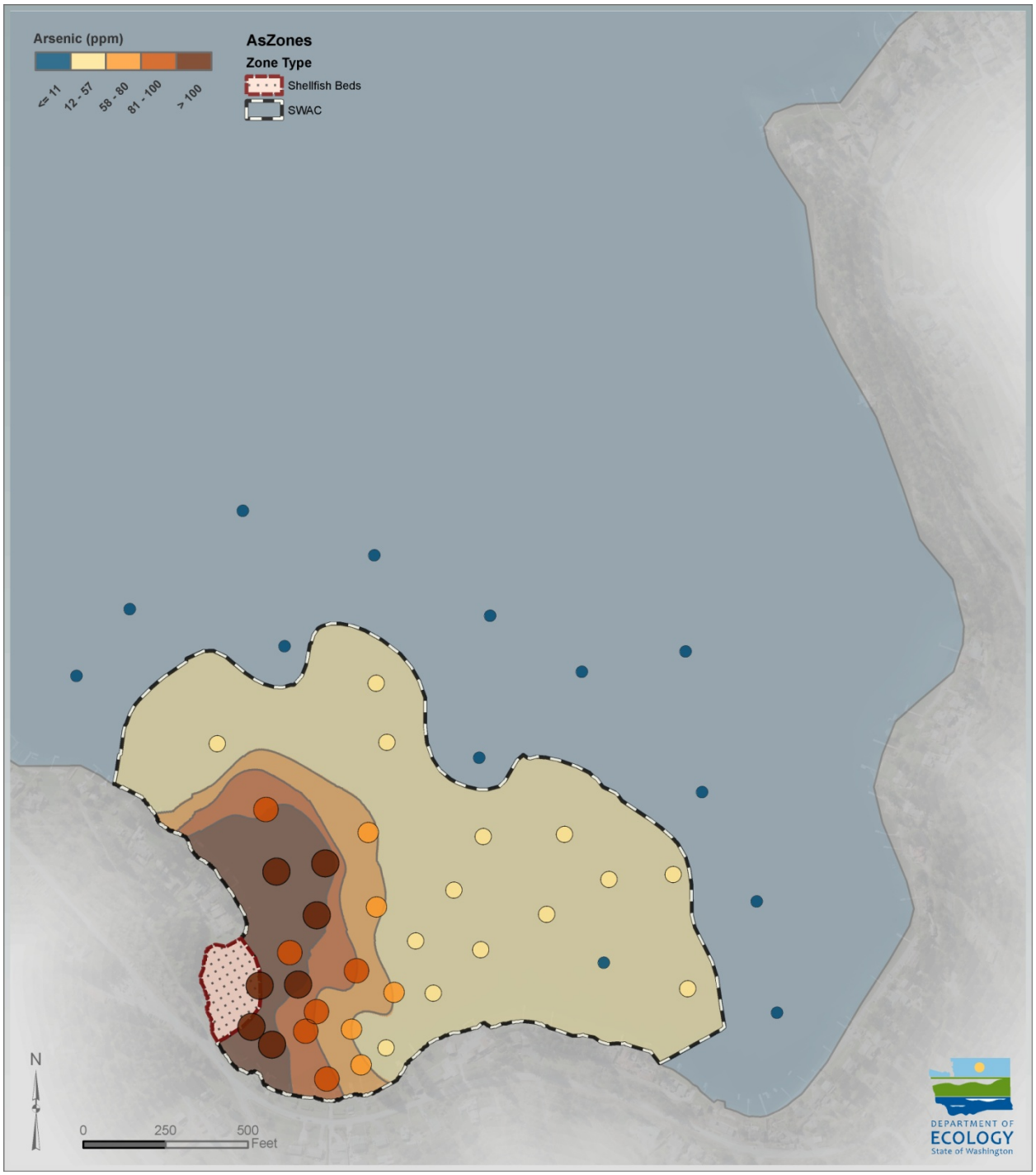



**Figure 6-7.** Simple site with interpolation of data.

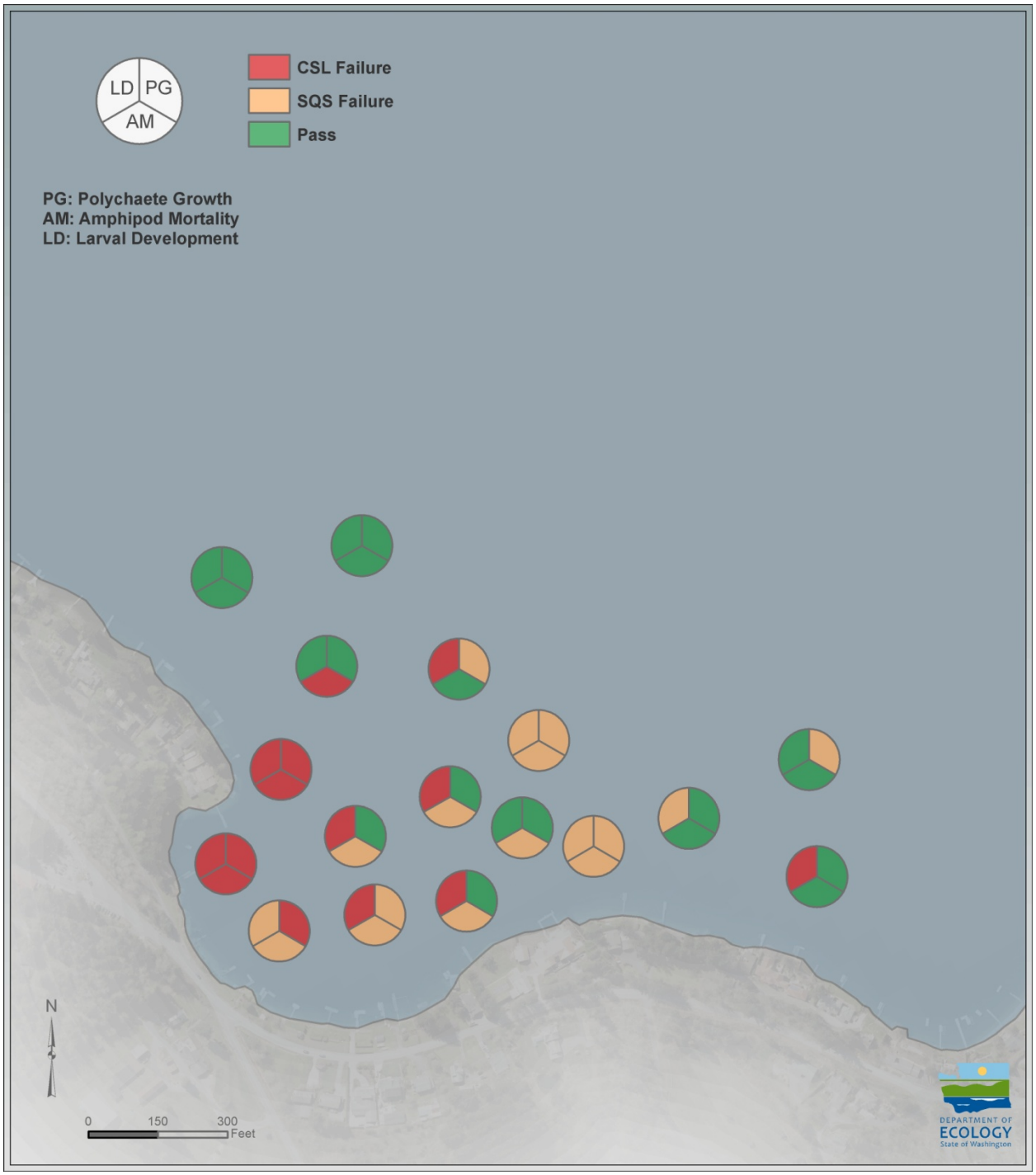



**Figure 6-8.** Simple site with bioassay pie chart and color showing exceedances (no-exceedance / SCO / CSL).

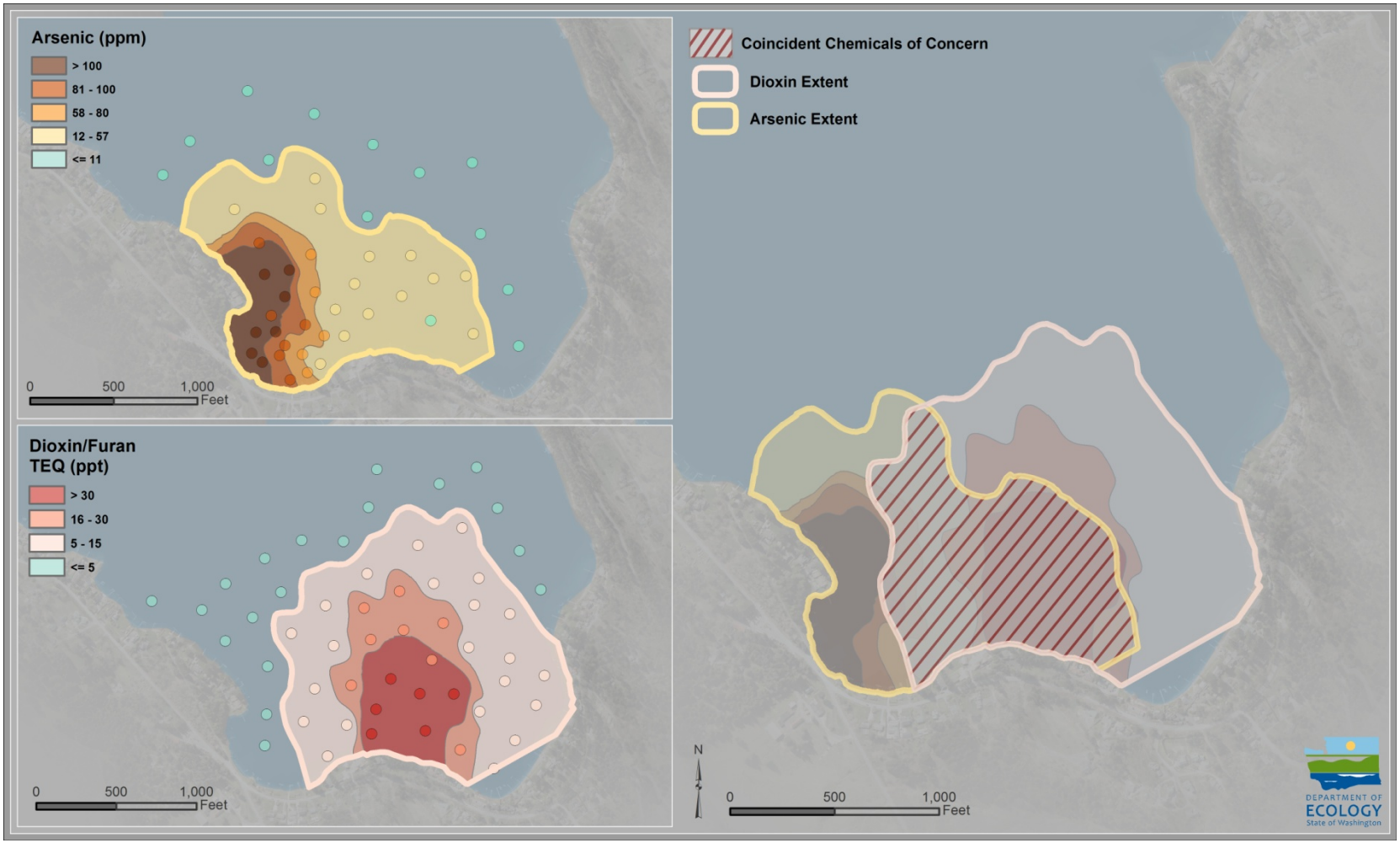



**Figure 6-9.** Complex site with overlapping footprints.

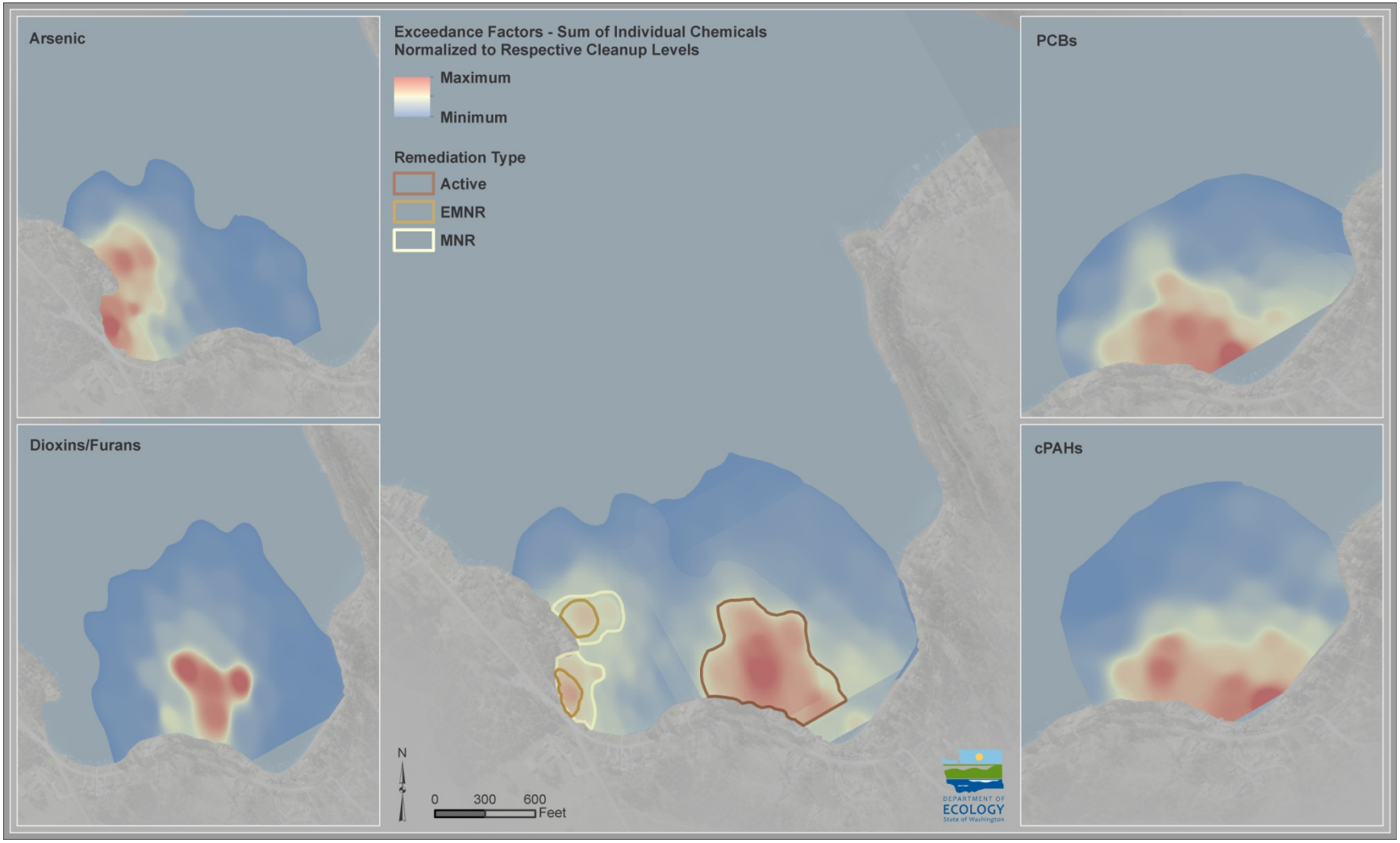



**Figure 6-10.** Complex site with overlapping CoCs normalized to cleanup levels ("exceedance factors"), summed to portray areas of highest concern.

.

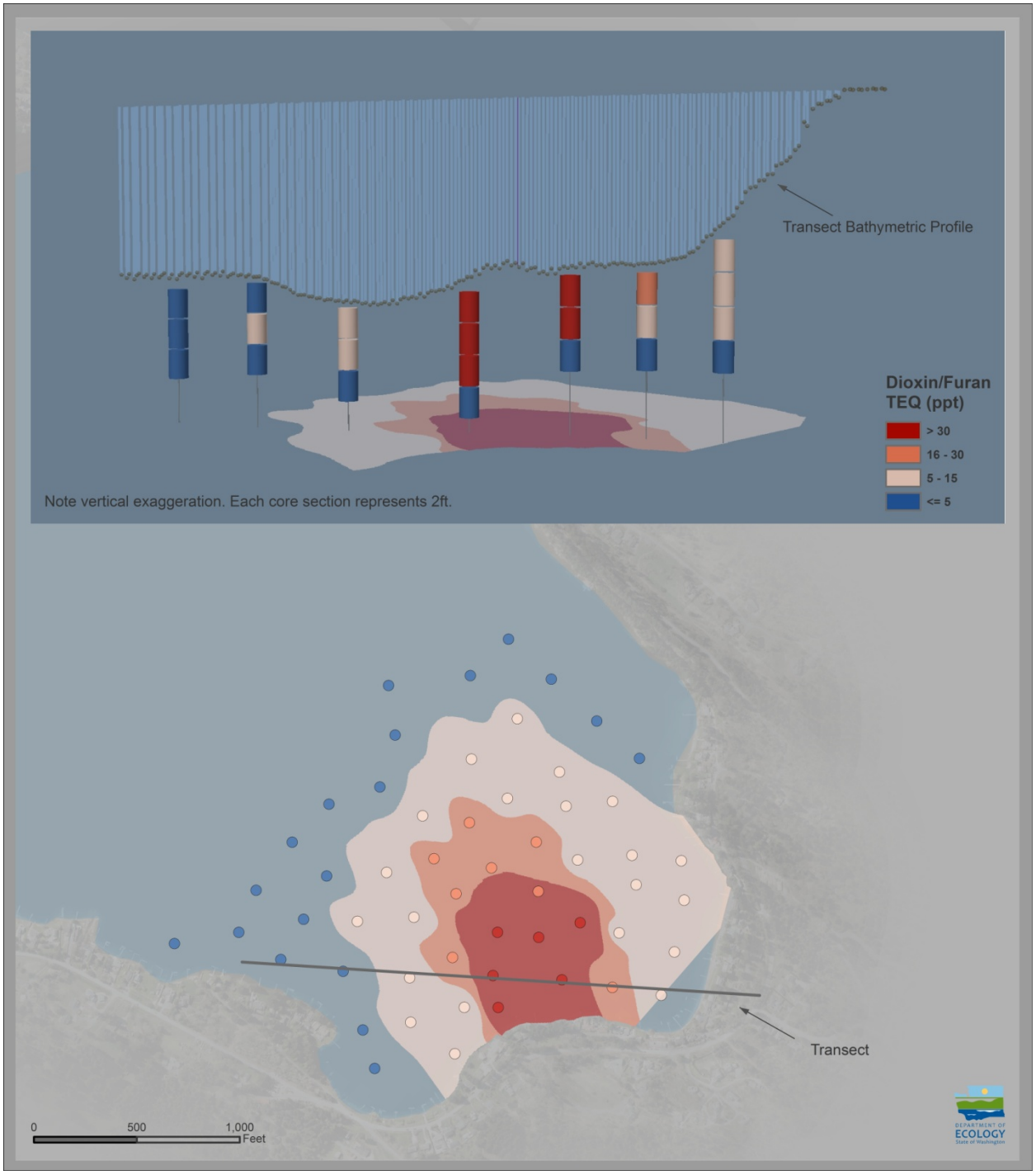



**Figure 6-11.** Plan view and cross sections of contaminant distributions.

*This page intentionally left blank*

# Chapter 7
# Establishing Sediment Cleanup Standards
# WAC 173-204-560

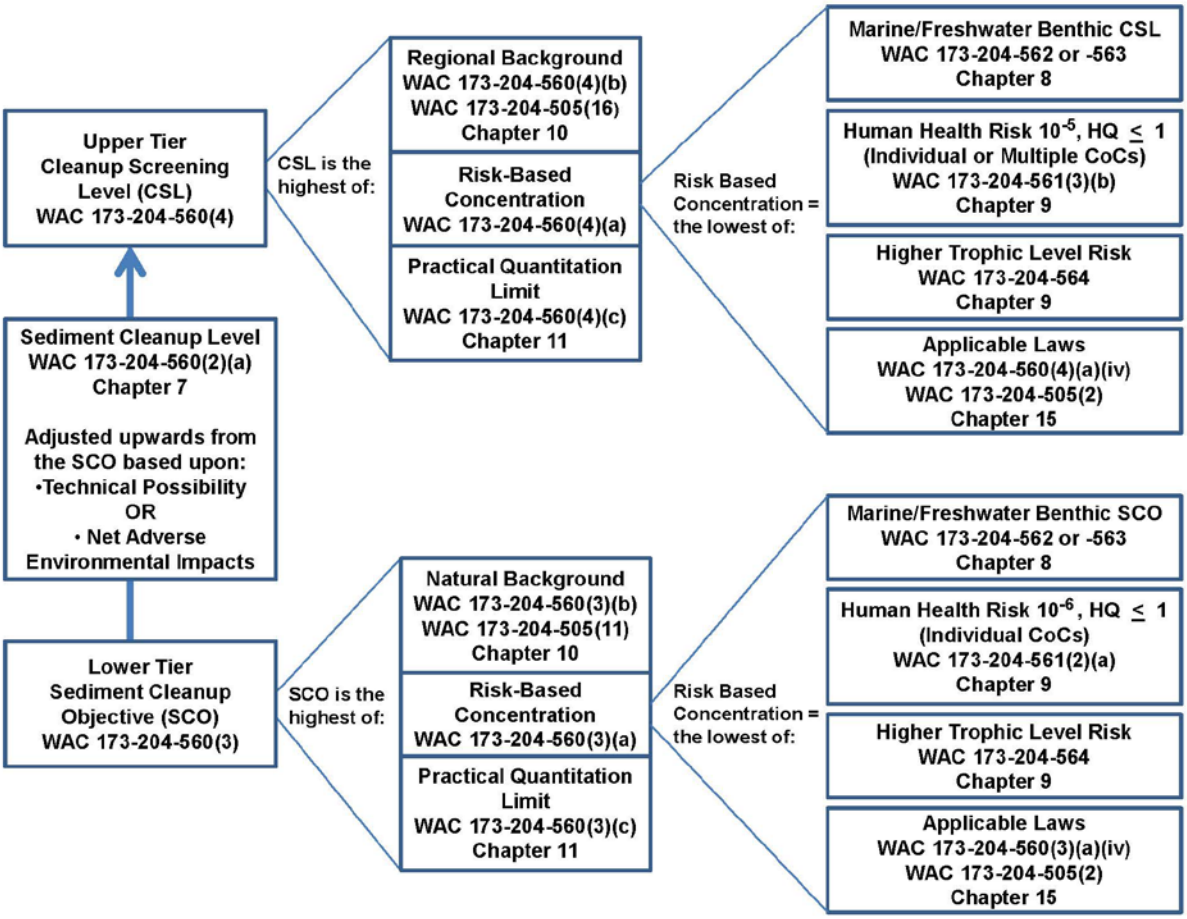



**Figure 7-1.** SMS framework for establishing sediment cleanup levels.

## 7.1 Introduction

At this stage in the cleanup process, a conceptual site model (CSM)—which includes the RME—has been developed, CoCs have been identified, and the RI field work has been completed. This chapter describes the general process for establishing sediment cleanup standards and the relationship between different terms used in the SMS rule: *sediment cleanup objective*, *cleanup screening level*, *sediment cleanup level*, *sediment cleanup standard*, and *point of compliance*. The RI report (Chapter 6) should include the proposed sediment cleanup levels and standards for

the site or sediment cleanup unit, which are established based on the below framework. It is recommended that the RI report include a table with the SCO and CSL for each CoC including:

- Natural and regional background for CoCs that have an established background value.
- Practical quantitation limit (PQL), and
- The risk-based concentration for each applicable CoC.

The final sediment cleanup levels and standards for the site or sediment cleanup unit will be established in the final Cleanup Action Plan. Although the SMS requires cleanup standards to be based on bulk sediment, tissue and/or porewater concentrations can inform decisions on bioavailability, appropriate remedies, and risk reduction over time for specific receptors.

## 7.2 Sediment Cleanup Levels

### 7.2.1 The two-tier framework

Figure 7-1 represents the SMS two-tier framework for establishing the sediment cleanup objective (SCO) and the cleanup screening level (CSL). Establishing the SCO and CSL is the first step necessary to establish the sediment cleanup level. The SCO and CSL are sediment values that include:

- Chemical concentrations or biological effects levels based on:
    - Benthic risk: Acute or chronic toxicity to the benthic community (WAC 173-204-562 through 173-204-563, Chapter 8, Table 8-1).
    - Bioaccumulative risk: Toxicity to human health and higher trophic level species (WAC 173-204-561 and -564, Chapter 9).
- Chemical concentrations based on regional or natural background (Chapter 10, Table 10-1 for natural background).
- Chemical concentrations based on the PQL (Chapter 11, Table 11-1).

The SCO is the long term sediment quality goal. It is the lower end of the range of chemical concentrations or biological effects level used to establish a sediment cleanup level (WAC 173-204-560(3)).

The CSL is used to identify sediment cleanup sites and is the maximum chemical concentration or biological effects level allowed as a sediment cleanup level (WAC 173-204-560(4)).

The sediment cleanup level is initially established at the SCO, but may be adjusted upwards to the CSL. This determination is based on the technical possibility and net adverse environmental

impacts associated with meeting and maintaining the sediment cleanup level. See Section 7.2.3 for further detail.

## 7.2.2 Establishing the SCO and CSL

### 7.2.2.1 Establishing the Sediment Cleanup Objective

To establish the final SCO, individual values (risk-based, natural background, and PQL) need to be determined then compared (Figure 7-1). The final SCO is established as the highest value of one of the following:

1. Natural background (Chapter 10)

2. PQL (Chapter 11)

3. A risk-based value (Chapters 8 and 9). The risk-based value for comparison to natural background and PQL is the lowest of one of the following:

    a. The SCO benthic criteria (Chapter 8).

    b. The SCO human health criteria (Chapter 9) which includes:

        i. $10^{-6}$ risk level for individual carcinogens.
        ii. $10^{-5}$ risk level for multiple carcinogens or exposure pathways.
        iii. Hazard quotient of 1 for individual non-carcinogens.
        iv. Hazard index of 1 for multiple non-carcinogens.

    c. The higher ecological trophic level species criteria (Chapter 9).

    d. Other applicable laws (Chapter 15).

### 7.2.2.2 Establishing the Cleanup Screening Level

To establish the final CSL, individual values (risk-based, regional background, and PQL) need to be determined then compared (Figure 7-1). The CSL is established at the highest of one of the following:

1. Regional background (Chapter 10), if it has been established.

2. PQL (Chapter 11).

3. A risk-based value (Chapters 8 and 9). The risk-based value for comparison to regional background and PQL is the lowest of one of the following:

a. The CSL benthic criteria (Chapter 8).

b. The CSL human health criteria (Chapter 9):

   i. $10^{-5}$ total site risk level for individual or multiple carcinogens and exposure pathways.
   ii. Hazard quotient of 1 for individual non-carcinogens.
   iii. Hazard index of 1 for multiple non-carcinogens.

c. The higher ecological trophic level species criteria (Chapter 9).

d. Other applicable laws (Chapter 15).

## 7.2.3 Establishing sediment cleanup levels

Once the final SCO and CSL have been established (Section 7.2.2), the sediment cleanup level can be established within a range of levels at the SCO, the CSL, or at a level in between (Figure 7-1).

### 7.2.3.1 Criteria for adjusting the sediment cleanup level

As shown in Section 7.2, the cleanup level is initially established at the SCO, which is the goal for all sediments in the state. However, the sediment cleanup level can be adjusted upwards from the SCO without exceeding the CSL (WAC 173-204-560(2)(a)(iii). Ecology will allow this if one of the following conditions are met:

- Technical possibility. Whether is it technically possible to achieve and maintain the cleanup level at the applicable point of compliance, WAC 173-204-560(2)(a)(ii)(A), or

- Net adverse environmental impacts. Whether achieving and maintaining the cleanup level will have a net adverse environmental impact on the aquatic environment, WAC 173-204-560(2)(a)(ii)(B).

Only one of these factors need to be met to conduct the upwards adjustment.

### 7.2.3.2 Technical possibility

In WAC 173-204-505(23), *technically possible* is defined as "capable of being designed, constructed and implemented in a reliable and effective manner, regardless of cost." The determination of whether it is technically possible to attain the SCO, or a level above the SCO up to the CSL, will depend on a variety of site-specific factors. Some of these factors include, but are not limited to:

- The ability to achieve the cleanup level using available cleanup technologies in WAC 173-204-570(4)(b). These technologies include, but are not limited to:
    - Dredging
    - Capping
    - Enhanced monitored natural recovery
    - Monitored natural recovery
    - Treatment
    - Source control. This includes controlling sources that are under the legal authority or responsibility of the PLP, so that the source will not contaminate receiving sediment at the site or sediment cleanup unit above the sediment cleanup level.
- The ability to maintain the sediment cleanup level after cleanup construction. This would meet the "implemented in a reliable and effective manner" requirements of WAC 173-204-505(23). To determine if the sediment cleanup level can be maintained, the following should be considered:
    - The potential for diffuse sources, not under the authority or responsibility of the PLP, to recontaminate the site or sediment cleanup unit.
    - It is expected that the PLP will conduct source identification and reasonable measures to address incoming contamination from sources that are under the PLP's authority or responsibility. Ecology will accept that PLP sources are controlled when the PLP can reasonably demonstrate that their source(s), in the absence of any other sources, will not result in contaminating sediment above the sediment cleanup level. After these measures are established, if there is still contamination from diffuse sources causing the site to exceed the sediment cleanup level, Ecology may determine it cannot be maintained. Therefore, an adjustment upwards from the SCO to establish the sediment cleanup level may be appropriate.
    - However, it is inappropriate to consider a cleanup action "not technically possible" solely because there is a risk of recontamination at the site. If there is a high risk of recontamination of the sediment from sources under the authority or responsibility of the PLP, then additional source control, study, or cleanup should take place in the upland portion of the site. See Chapter 14 Section 14.2.4 for further information on Ecology's expectations regarding recontamination.

- Additionally, when a site has multiple PLPs, it would be inappropriate to consider a cleanup action "not technically possible" because of a risk of recontamination from a source that is under the authority or responsibility of one of the PLPs.

- If regional background has been established, approved, and determined by Ecology to be applicable to a particular site, it could represent the concentration in sediment that is technically possible to maintain. Therefore, Ecology could (but is not obligated to) allow upwards adjustment of the sediment cleanup level to the CSL if regional background has been established as the final CSL. However, if the site is located in an area where the surrounding sediment is at natural background, this may not be appropriate. If regional and natural background values are determined to be the same for a geographic area, this would result in just a background-based SCO with no background-based CSL.

#### 7.2.3.3 Net adverse environmental impacts

The factors listed below should be considered and balanced to determine the net adverse environmental impact that may result from attaining the SCO, or a level above the SCO up to the CSL. Determining net adverse environmental impacts is based on the following considerations (WAC 173-204-560(2)(a)(ii)(B)):

- <u>The short- and long-term positive effects on the aquatic environment on</u>:
  - Natural resources, including shellfish, forage fish, eelgrass beds, and threatened or endangered species (if they inhabit the site).
  - Aquatic habitat, including existing habitat for shellfish, forage fish, threatened or endangered species.
  - Habitat restoration and enhancement, including current or future planned habitat restoration.
- <u>The short- and long-term adverse impacts on the aquatic environment that may be caused by implementing the cleanup action necessary to attain the SCO or a level above the SCO up to the CSL</u>. This should include considering a) whether there will be significant disturbance or destruction on the following; and b) their length of recovery time after the cleanup action is implemented:
  - Natural resources, including shellfish, forage fish, eelgrass beds, threatened or endangered species (if they inhabit the site).
  - Aquatic habitat, including existing habitat for shellfish, forage fish, threatened or endangered species.

The resulting net adverse environmental impacts must be determined by balancing the above considerations. Some adverse environmental impacts are expected during a cleanup action. But if attaining and maintaining the SCO will result in a net adverse environmental impact, the sediment cleanup level can be adjusted upwards to a level that minimizes the impact to the greatest extent possible. In such a case, the adjustment must not exceed the CSL.

## 7.3 Sediment Cleanup Standards

A sediment cleanup standard includes a *sediment cleanup level* (Section 7.2) and a *point of compliance.*

1. Sediment cleanup level. This includes the chemical concentration or biological effects level for each CoC as described in Section 7.2. The term is often used interchangeably with "sediment cleanup standard." A sediment cleanup level and point of compliance should be established for each CoC.

2. Point of compliance. When establishing the point of compliance for each CoC, the appropriate spatial scale that represents the exposure scenario should be considered. The point of compliance may be different for risks to the benthic community and risks to human health and upper trophic levels as follows:

    a. For benthic risk, the point of compliance is based on the depth of the biologically active zone (BAZ) and is measured point by point (or station by station). For a typical subtidal, soft-bottom marine sediment, the BAZ is typically 10 cm. However, this can be adjusted based on site-specific circumstances (e.g., shellfish or burrowing shrimp may be present at depths greater than 10 cm). For freshwater sediment, the BAZ is established site-specifically due to the highly variable nature of freshwater sediment environments. See Chapter 3 Section 3.4.1 for further information on the biologically active zone.

    b. For human health and upper trophic level risk, the point of compliance can be based on both depth and area (e.g., area-wide average). The depth should be established depending on the:

        i. Exposure scenario established for the cleanup level based on the CSM (Chapter 3) and should be established based on what consumed species are likely to be present—currently and in the future—and at what depth. For example, the point of compliance based on the fish consumption exposure pathway may be limited to surface sediment (unless consumed species are present at greater depths, while the point of compliance for the direct contact exposure pathway may be different (Chapter 3 Sections 3.4.1 and 3.4.2).

ii. Site-specific circumstances established in the CSM (Chapter 3 Sections 3.4.1 and 3.4.2). For example, if the remediated site has the potential to be disturbed by anchoring or propeller wash, the point of compliance may be deeper than the typical depth for the exposure pathway and receptors of concern. This should be established based on the CSM.

c. A site may include different exposure pathways, receptors of concern, and methods for determining compliance for the same CoC. The SMS requires that only one cleanup standard (hence, one point of compliance) be established for each CoC. However, remediation levels may be established with additional points of compliance for the same CoC to protect different receptors with different exposure pathways. For example, a cleanup standard for the site can be established based on regional background at a point of compliance that addresses the exposure pathway for consumption of fish and shellfish for a CoC. In addition, a remediation level for the same CoC (with a different point of compliance) may be established for the direct contact exposure pathway if it is determined to be particularly high risk for a particular part of the site. These decisions are very site-specific and should be made based on the CSM.

# Chapter 8
# Risk-Based Benthic Sediment Cleanup Standards
# WAC 173-204-562 and 173-204-563

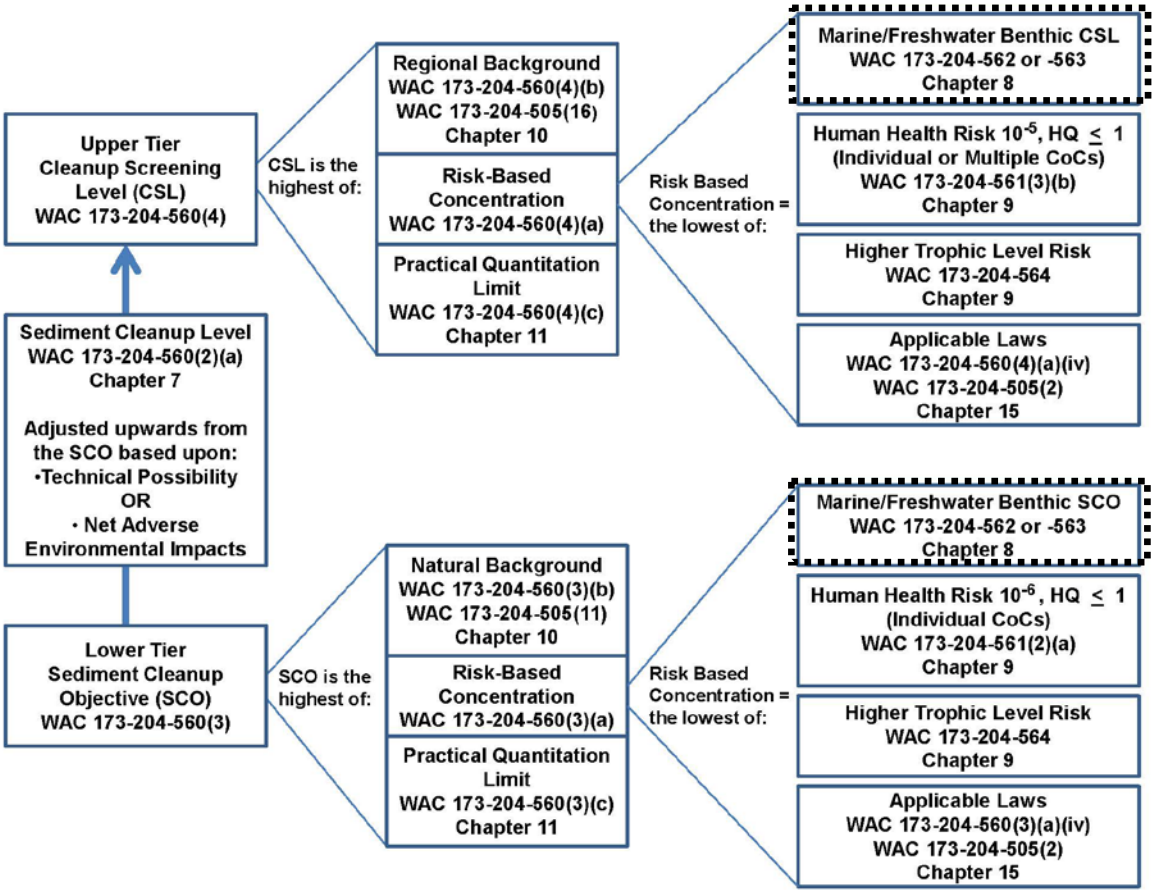



**Figure 8-1.** Framework for establishing sediment cleanup levels, WAC 173-204-560. Benthic criteria are highlighted.

## 8.1 Introduction

The purpose of this chapter is to present the numeric chemical and biological benthic criteria for marine and freshwater sediment for protection of the benthic (macroinvertebrate) community. For cleanup, once benthic risk-based concentrations at the SCO and CSL are established, they should be compared to other risk-based concentrations, background, and PQL to establish the final SCO and CSL for each CoC (Figure 8-1 or Chapter 7).

As discussed in Chapter 7, the SMS rule has a two-tiered decision-making framework to protect the function and integrity of the benthic community and human health. For benthic criteria, the lower tier includes the Sediment Quality Standards (SQS, in Part III of the SMS) and the SCO (in Part V of the SMS) chemical and biological criteria that represent levels predicted to have no adverse effects on the benthic community. The upper tier includes the SIZmax (in Part IV of the SMS) and CSL (in Part V of the SMS) chemical and biological criteria that predict minor adverse effects on the benthic community.

There are three parts to the SMS rule where the benthic criteria noted above apply to source control and cleanup. Part V of the SMS rule was amended in 2013 but Parts III and IV were not. Therefore, the way these parts refer to and include freshwater standards are somewhat different:

- Part III, SQS (WAC 173-204-300 through 350): For marine sediment, the SQS includes chemical and biological benthic criteria (Table 8-1). They are the same values as the marine SCO criteria in Part V. For freshwater sediment, the SQS is a narrative standard.

- Part IV, SIZmax (WAC 173-204-400 through 420): Part IV is similar to Part III, including marine chemical and biological benthic criteria and a freshwater narrative standard. The marine SIZmax criteria are the maximum allowable levels authorized in a sediment impact zone. They are the same values as the marine CSL criteria in Part V (Table 8-1).

- Part V, SCO and CSL (WAC 173-204-500 through 590): Part V includes numeric chemical and biological benthic criteria for both marine and freshwater sediment (Table 8-1).

The benthic criteria were developed using a suite of toxicity tests for organisms that live in close contact with sediment and sediment-borne contaminants. Benthic criteria represent relevant endpoints of sensitive life forms at a sensitive life stage. The criteria are intended to protect the function and integrity of the benthic community, even though some level of effects to individual organisms or species may occur. The criteria not only protect the functions performed by different benthic species and life history stages that are critical for maintaining overall benthic community health, they protect the services those species provide to the surrounding environment, such as:

- Shredders, which tear or physically chew up organic matter such as leaf litter.
- Grazers, which feed on new bacterial, detrital, or plant growth.
- Deposit feeders, which scavenge newly-deposited or buried organic material.
- Bioturbators, which vertically mix depositing material into the surface sediment.
- Prey species, which provide food for higher trophic level animals such as insects, fish or waterfowl.
- Predators, which feed on other benthic or aquatic organisms.

## 8.2 Marine and Freshwater Chemical Criteria

Under the SMS, the chemical benthic criteria can be used as screening criteria or as cleanup levels where appropriate. Generally, samples are first analyzed for exceedances of the chemical criteria (screening). If exceedances occur, bioassays are conducted to confirm these exceedances. However, Ecology can require bioassays at any time if the SMS chemical criteria are not considered representative of site conditions. For example, if the site includes chemicals without SMS criteria or other adverse conditions exist that can impact the benthic community (e.g., woodwaste).

The chemical benthic criteria were developed using paired chemistry and bioassay data for sediments and are based on the ability of chemical criteria to reliably predict toxicity to the benthic community (Table 8-1). The criteria were developed from regional databases that included a broad suite of metals and organics concentrations, as well as toxicity data for a variety of different tests and endpoints.

The marine criteria are applicable to coastal and Puget Sound marine sediment. The criteria were developed using the Apparent Effects Threshold (AET) approach (Barrick, 1988). The sampling stations for each chemical were divided into those with no toxicity and those with toxicity. Because many contaminants could be contributing to toxicity at any one station, the highest no-hit concentration for each chemical was selected as the AET for that chemical, after removing outliers. AETs were calculated separately for each biological test and endpoint, with the lowest AET set at the SCO and the second-lowest at the CSL.

The freshwater criteria are applicable to freshwater bodies (e.g., rivers, lakes, and streams). Where marine and freshwater intersect, in general the most conservative standards apply. The criteria were developed using the Floating Percentile Method (FPM) (Ecology, 2011a). The FPM is a multivariate statistical approach that iteratively reduces predictive errors among all chemicals at once. This method results in chemical concentrations that maximize the overall reliability of the criteria to predict toxicity, and reduces the number of incorrect predictions of toxicity (false positives) or absence of toxicity (false negative). Like the AETs, these values were developed for each individual biological test endpoint with the lowest FPM value set at the SCO and the second-lowest at the CSL.

## 8.3 Marine and Freshwater Biological Criteria

Under the SMS, the biological benthic criteria are the confirmatory criteria. This means bioassay results can override chemistry results and Ecology can require bioassay testing at any time. Biological benthic criteria have been developed for a suite of biological tests that include bioassays and/or benthic community tests (Table 8-2 through Table 8-5). The suite of tests was chosen to best represent the range of species that comprise a benthic community, including

sensitive species, life stages, and biological endpoints. The biological criteria were designed to be as consistent as possible for marine and freshwater environments given the tests available.

The SCO was set at a level considered to be biologically meaningful for population-level effects, or set at the minimum detectable difference (MDD) between the test and control or reference sample, whichever level was higher. The CSL was set at an effects level approximately 10–15 percent greater than the SCO.

## 8.3.1 Selection of biological tests

Biological tests can include sediment toxicity tests (bioassays) or benthic community analysis tests. It may be necessary to conduct biological testing when:

- There is an exceedance(s) of the chemical benthic criteria for any one station (Table 8-1).
- There is reason to believe the site contains chemicals that are not listed in Table 8-1 that may be contributing to toxicity (e.g., pesticides).
- There are physical factors contributing to toxicity (e.g., wood waste, slag).
- There is a need to confirm or override chemistry results or to preclude the need for a second round of sampling or testing.

### 8.3.1.1 Marine and estuarine biological criteria

Table 8-2 includes the marine biological criteria at the SQS (applicable to Parts III and IV of the SMS) and the SCO and CSL (applicable to Part V of the SMS) which can be used for source control and cleanup purposes. A failure of any one bioassay at the SQS/SCO or CSL level equates to an SQS/SCO or CSL exceedance, respectively. A failure of any two bioassays at the SQS/SCO level also equates to a CSL exceedance.

Each sampling station must be evaluated using at least three bioassays that include:

- At least two acute effects tests; and
- At least one chronic effects test.

Table 8-3 includes the list of marine biological tests in the SMS rule. For further information on these biological tests and how to choose among them, refer to Chapter 4, Section 4.2.3.

### 8.3.1.2 Freshwater biological criteria

Table 8-4 includes the freshwater biological criteria at the SCO and CSL which are applicable to Part V of the SMS for cleanup purposes. A failure of any one bioassay at the SCO or CSL level equates to an SCO or CSL exceedance, respectively. A failure of any two bioassays at an one station at the SCO level equates to a CSL exceedance.

When freshwater biological tests are conducted, the SMS requires using at least:

- Three toxicity test endpoints using at least two species,
- Both acute and chronic tests, and
- At least one sublethal endpoint (e.g., growth).

Table 8-5 includes the list of freshwater bioassays in the SMS rule. For further information on these bioassays and how to choose among them, refer to Chapter 4, Section 4.2.3. In addition, although the Microtox bioassay test is not included in the SMS rule and therefore cannot be sued to establish cleanup levels, it may be used for remedial investigation purposes. For example, as a first phase of bioassay testing to help define impacted areas that may require additional investigation or cleanup. Appendix C includes testing protocols and information on how to define the SCO and CSL. The narrative standard for Parts III and IV of the SMS rule remains and criteria are determined on a case-by-case basis. However, Table 8-4 and Table 8-5 may be used as guides for developing source control limits on a site-specific basis.

## 8.4 Establishing Site-Specific Standards

### 8.4.1 Introduction

The SMS rule allows for using latest scientific knowledge when evaluating sediment quality for cleanup and source control (WAC 173-204-130(3) and (4)). While the benthic criteria are applicable for most types of environments, there may be site-specific exceptions. For example physical and chemical characteristics of freshwater systems can vary considerably, while marine environments can have some site-specific variability. Factors such as atypical water bodies, unusual water quality characteristics (e.g., pH, alkalinity, or hardness) or high organic content can also affect bioavailability and biological test performance. In addition, cleanup actions must be protective of threatened or endangered species (although no benthic invertebrate species are currently listed in Washington State). See Chapter 4, Section 4.2.2 for a complete discussion of site- and chemical-specific factors that may require site-specific approaches, and the sampling and testing requirements for same.

When site-specific approaches are needed, the SMS identifies alternative methods for evaluating sediment in the following order of preference (WAC 173-204-562(3)(f) and 173-204-563(2)(n)):

- Conduct biological testing using the biological criteria of Table 8-3 through Table 8-5;
- Establish site-specific chemical standards using site chemistry and the biological criteria in Table 8-3 through Table 8-5;
- Conduct biological testing using other methods approved by Ecology (Chapter 4, subsection 4.1.3);

- Other approaches in accordance with WAC 173-204-130.

Chemical criteria developed by other jurisdictions in the United States and Canada have low reliability for predicting the presence and absence of toxicity in Washington State sediments. They do not address site- or chemical-specific conditions that affect bioavailability. Therefore, the above site-specific methods are recommended. Alternative chemical criteria should only be used when they have been developed site-specifically or are ARARs (e.g., sediment criteria adopted by Tribes).

In many cases, unusual conditions (Chapter 4, Section 4.2.2) can affect the availability of CoPCs, resulting in either increasing or decreasing toxicity. For such cases, the recommended alternative is to conduct biological tests (bioassays or benthic community analyses in Table 8-3 through Table 8-5) concurrent with sediment chemistry. In addition, the chemistry list in Table 8-1 may be expanded to cover those contaminants or characteristics that may be contributing to toxicity. The recommended biological tests and performance criteria are listed in Tables 8-3 and 8-5.

## 8.4.2 Use of alternate biological tests

The benthic criteria were based on toxicity tests considered to be protective of the benthic community. However, there may be some sites that have species of concern that require an alternative test species, such as mollusks (e.g., the freshwater mussel, *Anodonta californiensis* or the gastropod snail, *Fluminicola columbiana*) or amphibians (e.g., the frog, *Rana pipiens*). In such cases, the SMS rule allows for the use of latest science to adequately assess sediment quality and evaluate sites. For more detailed information on alternative biological tests and methods refer to Chapter 4, Section 4.2.3.

## 8.4.3 Development of site-specific chemical criteria

For sites that have unusual conditions where bioavailability may be altered, or if a CoC exists that is not included in the SMS benthic chemical criteria, Ecology may allow the development of site-specific chemical criteria that better predict toxicity to the benthic community. Those criteria can then be used to further define the site boundaries or determine the potential actions necessary at a site. In such cases, the recommended alternative is to conduct biological toxicity tests (Chapter 4, Table 4-3 andTable 4-4) concurrent with analysis of site sediment chemistry. The biological toxicity tests in the SMS rule should be used to develop site-specific chemical cleanup levels for regulatory purposes. However, alternate biological tests may be appropriate to conduct site evaluations if conditions warrant (Chapter 4 Section 4.2.3).

The standard sediment chemistry suite (Table 8-1) may be expanded to cover contaminants or characteristics that may be contributing to toxicity. Chapter 4, Table 4-1 includes a list of some chemicals and their potential sources that are not included in the SMS benthic chemical criteria. In some cases—or when chemicals of concern without SMS criteria are at the site—site-specific

conditions may require site-specific criteria or the selection of an alternative species or methods modification (Chapter 4, Table 4-4). Such changes are subject to Ecology's review and approval.

To retain consistency with the SMS, Ecology recommends use of the AET or FPM methods and the SMS biological criteria to develop site-specific chemical criteria for marine and freshwater sites, respectively. However, Ecology may consider other methods (such as logistic regression or the reference-envelope approach). Any of these methods require at least 30 synoptic chemical and biological sediment samples depending on the distribution of chemical concentrations, homogeneity of site conditions, and the numbers of bioassay exceedances results. For these types of sites, if the cleanup levels will be based on the bioaccumulative effects to higher trophic levels or human health, benthic biological testing may be a more effective approach than determining site-specific chemical benthic criteria.

See Chapter 4 Section 4.2.2 for further detail on the site-specific conditions that may warrant development of site-specific chemical criteria and Section 4.2.4 for further detail on assessing bioavailability of contaminants.

**Table 8-1.** Marine and freshwater sediment chemical criteria for protection of the benthic community.

| | SMS Freshwater Sediment[a] | | SMS Marine Sediment[b] | | Marine Sediment AETs[c,d] | |
|---|---|---|---|---|---|---|
| **Analyte** | **SCO** | **CSL** | **SCO** | **CSL** | **SCO** | **CSL** |
| **Conventional Pollutants** | **mg/kg dw** | | | | | |
| Ammonia | 230 | 300 | | | | |
| Total sulfides | 39 | 61 | | | | |
| **Metals** | **mg/kg dw** | | **mg/kg dw** | | **mg/kg dw** | |
| Arsenic | 14 | 120 | 57 | 93 | 57 | 93 |
| Cadmium | 2.1 | 5.4 | 5.1 | 6.7 | 5.1 | 6.7 |
| Chromium | 72 | 88 | 260 | 270 | 260 | 270 |
| Copper | 400 | 1200 | 390 | 390 | 390 | 390 |
| Lead | 360 | *> 1300* | 450 | 530 | 450 | 530 |
| Mercury | 0.66 | 0.8 | 0.41 | 0.59 | 0.41 | 0.59 |
| Nickel | 26 | 110 | | | | |
| Selenium | 11 | *> 20* | | | | |
| Silver | 0.57 | 1.7 | 6.1 | 6.1 | 6.1 | 6.1 |
| Zinc | 3200 | *> 4200* | 410 | 960 | 410 | 960 |
| **Organometallics** | **µg/kg dw** | | | | | |
| Monobutyltin | 540 | *> 4800* | | | | |
| Dibutyltin | 910 | 130000 | | | | |
| Tributyltin | 47 | 320 | | | | |
| Tetrabutyltin | 97 | *> 97* | | | | |
| **Organic Chemicals** | **µg/kg dw** | | **µg/kg dw (except *)** | | **µg/kg dw** | |
| 2,4-Dimethylphenol | | | 29 | 29 | 29 | 29 |
| 2-Methylphenol | | | 63 | 63 | 63 | 63 |
| 4-Methylphenol | 260 | 2000 | 670 | 670 | 670 | 670 |
| Benzoic acid | 2900 | 3800 | 650 | 650 | 650 | 650 |
| Benzyl alcohol | | | 57 | 73 | 57 | 73 |
| Dibenzofuran | 200 | 680 | 15* | 58* | 540 | 540 |
| Phenol | 120 | 210 | 420 | 1200 | 420 | 1200 |
| N-nitrosodiphenylamine | | | 11* | 11* | 28 | 40 |
| **Phthalates[d]** | **µg/kg dw** | | **mg/kg OC** | | **µg/kg dw[d]** | |
| Bis(2-Ethylhexyl)phthalate | 500 | 22000 | 47 | 78 | 1300 | 1900 |
| Butylbenzyl phthalate | | | 4.9 | 64 | 63 | 900 |
| Diethyl phthalate | | | 61 | 110 | 200 | *>1200* |
| Dimethyl phthalate | | | 53 | 53 | 71 | 160 |
| Di-n-butyl phthalate | 380 | 1000 | 220 | 1700 | 1400 | 1400 |
| Di-n-octyl phthalate | 39 | *> 1100* | 58 | 4500 | 6200 | 6200 |

**Table 8-1** (continued). Marine and freshwater sediment chemical criteria for protection of the benthic community.

| | SMS Freshwater Sediment[a] | | SMS Marine Sediment[b] | | Marine Sediment AETs[c,d] | |
|---|---|---|---|---|---|---|
| **Analyte** | **SCO** | **CSL** | **SCO** | **CSL** | **SCO** | **CSL** |
| **Pesticides and PCBs** | **µg/kg dw** | | **mg/kg OC** | | **µg/kg dw** | |
| beta-Hexachlorocyclohexane | 7.2 | 11 | | | | |
| Carbazole | 900 | 1100 | | | | |
| Dieldrin | 4.9 | 9.3 | | | | |
| Endrin ketone | 8.5 | ** | | | | |
| Total Aroclors[e] | 110 | 2500 | 12 | 65 | 130 | 1000 |
| Total o,p' and p,p' dichlorodiphenyldichloroethanes (DDDs) | 310 | 860 | | | | |
| Total o,p' and p,p' dichlorodiphenyldichloroethylenes (DDEs) | 21 | 33 | | | | |
| Total o,p' and p,p' dichlorodiphenyltrichloroethanes (DDTs) | 100 | 8100 | | | | |
| **Polycyclic Aromatic Hydrocarbons** | **µg/kg dw** | | **mg/kg OC** | | **µg/kg dw** | |
| Total PAHs | 17000 | 30000 | | | | |
| Total LPAH | | | 370 | 780 | 5200 | 5200 |
| Naphthalene | | | 99 | 170 | 2100 | 2100 |
| Acenaphthylene | | | 66 | 66 | 1300 | 1300 |
| Acenaphthene | | | 16 | 57 | 500 | 500 |
| Fluorene | | | 23 | 79 | 540 | 540 |
| Phenanthrene | | | 100 | 480 | 1500 | 1500 |
| Anthracene | | | 220 | 1200 | 960 | 960 |
| 2-Methylnaphthalene | | | 38 | 64 | 670 | 670 |
| Total HPAH | | | 960 | 5300 | 12000 | 17000 |
| Fluoranthene | | | 160 | 1200 | 1700 | 2500 |
| Pyrene | | | 1000 | 1400 | 2600 | 3300 |
| Benz[a]anthracene | | | 110 | 270 | 1300 | 1600 |
| Chrysene | | | 110 | 460 | 1400 | 2800 |
| Total benzofluoranthenes | | | 230 | 450 | 3200 | 3600 |
| Benzo[a]pyrene | | | 99 | 210 | 1600 | 1600 |
| Indeno[1,2,3-c,d]pyrene | | | 34 | 88 | 600 | 690 |
| Dibenzo[a,h]anthracene | | | 12 | 33 | 230 | 230 |
| Benzo[g,h,i]perylene | | | 31 | 78 | 670 | 720 |
| **Bulk Petroleum Hydrocarbons** | **mg/kg dw** | | | | | |
| TPH-Diesel | 340 | 510 | | | | |
| TPH-Residual | 3600 | 4400 | | | | |

**Table 8-1** (continued). Marine and freshwater sediment chemical criteria for protection of the benthic community.

| | SMS Freshwater Sediment[a] | | SMS Marine Sediment[b] | | Marine Sediment AETs[c,d] | |
|---|---|---|---|---|---|---|
| **Analyte** | **SCO** | **CSL** | **SCO** | **CSL** | **SCO** | **CSL** |
| **Chlorinated Organics** | **µg/kg dw** | | **mg/kg OC** | | **µg/kg dw** | |
| 1,2,4-Trichlorobenzene | | | 0.81 | 1.8 | 31 | 51 |
| 1,2-Dichlorobenzene | | | 2.3 | 2.3 | 35 | 50 |
| 1,4-Dichlorobenzene | | | 3.1 | 9 | 110 | 110 |
| Hexachlorobenzene | | | 0.38 | 2.3 | 22 | 70 |
| Hexachlorobutadiene | | | 3.9 | 6.2 | 11 | 120 |
| Pentachlorophenol | 1200 | *> 1200* | 360[f] | 690[f] | 360 | 690 |

a, All freshwater values are dry weight normalized.

b, Marine values are dry weight normalized for metals and polar organics and normalized to total organic carbon for nonpolar organics.

c, TOC normalized values and dry weight normalized AETs should be considered when total organic carbon is outside the recommended range of 0.5 – 3.5% for organic carbon normalization.

d, Dry weight AETs for phthalates are derived from Barrick et.al, 1988. The SCO is established as the lowest AET and the CSL is the 2nd lowest AET, consistent with the dry weight AETs for the other SMS chemicals. These differ from the DMMP values for phthalates which were updated in 2005, based on additional bioassay endpoints and synoptic chemistry/bioassay data. Bioassays may be used in place of these AETs if necessary.

e, Upon approval by Ecology on a case-by-case basis, Total PCB congeners may be analyzed to substitute for Total PCB Aroclors to verify compliance with the benthic criteria. When using Total PCB congeners in place of Total Aroclors to assess impacts to the benthic community, bioassays should be analyzed if the benthic SCO is exceeded.

f, µg/kg dry weight

> *Italicized blue* "greater than" value indicates that the toxic level is unknown, but above the concentration shown.

* mg/kg OC

** CSL criteria does not exist

When Total organic carbon values are high (e.g., ≥ 5%), analysis of total volatile solids is recommended.

**Table 8-2.** Marine biological criteria (SCO & CSL and performance standards) for each biological test. Adverse effects are defined when any of the biological tests show the following results:

| Biological Test Endpoint | Performance Standard | | SCO/SQS | CSL |
|---|---|---|---|---|
| | Control | Reference[a] | | |
| | | **Amphipod** | | |
| **10-Day mortality** | $M_C \leq 10\%$ | $M_R \leq 25\%$ | $M_T > 25\%$ Absolute *and* $M_T$ vs. $M_R$ SD ($p < 0.05$) | $M_T - M_R \geq 30\%$ *and* $M_T$ vs. $M_R$ SD ($p < 0.05$) |
| | | **Larval** | | |
| **Bivalve or echinoderm abnormality /mortality** | $N_C / I \geq 0.70$ | $N_R / N_C \geq 0.65$ | $N_T / N_R < 0.85$ *and* $N_T$ vs. $N_R$ SD ($p < 0.10$) | $N_T / N_R < 0.70$ *and* $N_T$ vs. $N_R$ SD ($p < 0.10$) |
| | | **Juvenile Polychaete** | | |
| ***Neanthes* 20-day growth[b]** | $M_C \leq 10\%$ *and* $MIG_C \geq 0.38$[c] mg/individual/day (or case-by-case) | $MIG_R / MIG_C \geq 0.80$ | $MIG_T / MIG_R < 0.70$ *and* $MIG_T$ vs. $MIG_R$ SD ($p < 0.05$) | $MIG_T / MIG_R < 0.50$ *and* $MIG_T$ vs. $MIG_R$ SD ($p < 0.05$) |
| | | **Microtox** | | |
| **Microtox decreased luminescence** | Case-by-case | Case-by-case | $ML_T / ML_R < 0.80$ *and* $ML_T$ vs. $ML_R$ SD ($p < 0.05$) | |
| **Benthic Community** | | | | |
| **Benthic Abundance** | See notes below | | $A_T / A_R < 0.50$ For any one of the three major taxa: Class Crustacea, Phylum Mollusca, or Class Polychaeta | $A_T / A_R < 0.50$ For any two of the three major taxa: Class Crustacea, Phylum Mollusca, or Class Polychaeta |

A = Abundance; C = Control; R = Reference; T = Test; F = Final; M = Mortality; N = Normal Survivorship expressed as actual counts; I = Initial count; MIG = Mean Individual Growth Rate expressed in mg/ind/day Ash Free Dry Weight; ML = Mean Light output; BLD = Blank Corrected Light Decrease; SD = Significantly Different.

This presentation of the criteria differ from Part V of the SMS rule. With the exception of the Larval test where statistical significance is set at $\alpha = 0.10$ (i.e., an exceedance of the criteria occurs when $p < 0.10$), they reflect the criteria in Part III of the SMS rule and represent the clearest interpretation of the criteria.

a, Carr Inlet is the preferred reference location. The area has different grain sizes available to match site samples or bracket the range. Other reference areas may be relatively free from anthropogenic impact but they tend to have elevated sulfide concentrations that may complicate results.

b, See Appendix B: 2013. DMMP/SMS Clarification Paper: Bioassay Endpoint Refinements: Bivalve Larval and *Neanthes* Growth Bioassays. *Neanthes arenaceodentata* is a sediment ingester and when the animals are dried and weighed at the end of the 20 day test, the inorganic sediments in the gut can contribute up to 30% of the weight of the animal, which interferes with test results. The use of Ash Free Dry Weight to more accurately reflect the increase in biomass over the test period was examined and determined to be an appropriate change, with the recognized need to review the performance standard for the negative control.

c, Ecology recommends 0.38 MIG AFDW as the performance standard for negative control. The former performance standard was 0.72 MIG with an allowance for case-by-case approval down to 0.38 MIG. A review of negative controls from all ten test batches from 2013 and later was reviewed. Ten of the 9 test batches met the 0.38 MIG and 8 were below the former performance standard of 0.72 MIG.

**Table 8-3.** Marine biological tests, species, and applicable endpoints.

| Class/Type | Species | Biological Test Endpoint | Acute Effects Test | Chronic Effects Test |
|---|---|---|---|---|
| **Amphipod** | • *Rhepoxynius abronius*<br>• *Ampelisca abdita*<br>• *Eohaustorius estuarius* | 10–Day Mortality | x | |
| **Larval** | • *Crassostrea gigas* (Pacific oyster)<br>• *Mytilus (edulis) galloprovincialis* (Blue mussel)<br>• *Strongylocentrotus purpuratus* (Purple sea urchin)<br>• *Dendraster excentricus* (Sand dollar) | Mortality / Abnormality | x | |
| **Juvenile Polychaete** | *Neanthes arenaceodentata* | 20–Day growth | | x |
| **Microtox** | *Vibrio fisheri* | • 15–Minute Exposure<br>• Decreased Luminescence | | x |
| **Benthic Infauna** | Three major taxa, including<br>• Class Crustacea<br>• Class Polychaeta<br>• Phylum Mollusca | | | x |

**Table 8-4.** Freshwater biological criteria (SCO/CSL and performance standards) for each biological test. Adverse effects are defined when any of the biological tests show the following results:

| Biological Test Endpoint | Performance Standard | | SCO[c] | CSL[c] |
|---|---|---|---|---|
| | Control[a] | Reference[b] | | |
| ***Hyalella azteca*** | | | | |
| **10-Day mortality** | $M_C \leq 20\%$ | $M_R \leq 25\%$ | $M_T - M_C > 15\%$ | $M_T - M_C > 25\%$ |
| **28-Day mortality** | $M_C \leq 20\%$ | $M_R \leq 30\%$ | $M_T - M_C > 10\%$ | $M_T - M_C > 25\%$ |
| **28-Day growth** | $MIG_C \geq 0.15$ mg/individual | $MIG_R \geq 0.15$ mg/individual | $MIG_T / MIG_C < 0.75$ | $MIG_T / MIG_C < 0.60$ |
| ***Chironomus dilutus*** | | | | |
| **10-Day mortality** | $M_C \leq 30\%$ | $M_R \leq 30\%$ | $M_T - M_C > 20\%$ | $M_T - M_C > 30\%$ |
| **10-Day growth[d]** | $MIG_C \geq 0.48$ mg/individual | $MIG_R / MIG_C \geq 0.8$ | $MIG_T / MIG_C < 0.8$ | $MIG_T / MIG_C < 0.7$ |
| **20-Day mortality** | $M_C \leq 32\%$ | $M_R \leq 35\%$ | $M_T - M_C > 15\%$ | $M_T - M_C > 25\%$ |
| **20-Day growth[d]** | $MIG_C \geq 0.48$ mg/individual | $MIG_R / MIG_C \geq 0.8$ | $MIG_T / MIG_C < 0.75$ | $MIG_T / MIG_C < 0.6$ |

M = Mortality; C = Control; R = Reference; T = Test; F = Final; MIG = Mean Individual Growth at time final; mg = milligrams.

a, These tests and parameters were developed based on the most updated American Society for Testing and Materials (ASTM International) protocols.

b, Reference performance standards are provided for sites where Ecology has approved a freshwater reference sediment site(s) and reference results will be substituted for control in comparing test sediment to criteria.

c, A statistical significance is set at $\alpha = 0.05$ (i.e., an exceedance of the criteria occurs when $p < 0.05$).

d, Results for *Chironomus dilutus* growth endpoint should be reported on an Ash Free Dry Weight basis.

**Table 8-5.** Freshwater biological tests, species, and applicable endpoints.

| Species/Endpoint | Acute effects biological test | Chronic effects biological test | Lethal effects biological test | Sublethal effects biological test |
|---|---|---|---|---|
| **Amphipod:** ***Hyalella azteca*** | | | | |
| 10-Day mortality | x | | x | |
| 28-Day mortality | | x | x | |
| 28-Day growth | | x | | x |
| **Midge:** ***Chironomus dilutus*** | | | | |
| 10-Day mortality | x | | x | |
| 10-Day growth | x | | | x |
| 20-Day mortality | | x | x | |
| 20-Day growth | | x | | x |

These tests and parameters were developed based on the most current American Society for Testing and Materials (ASTM International) and EPA protocols for establishing appropriate biological tests.

*This page intentionally left blank*

# Chapter 9
# Risk-Based Bioaccumulative Sediment Cleanup Standards
# WAC 173-204-561

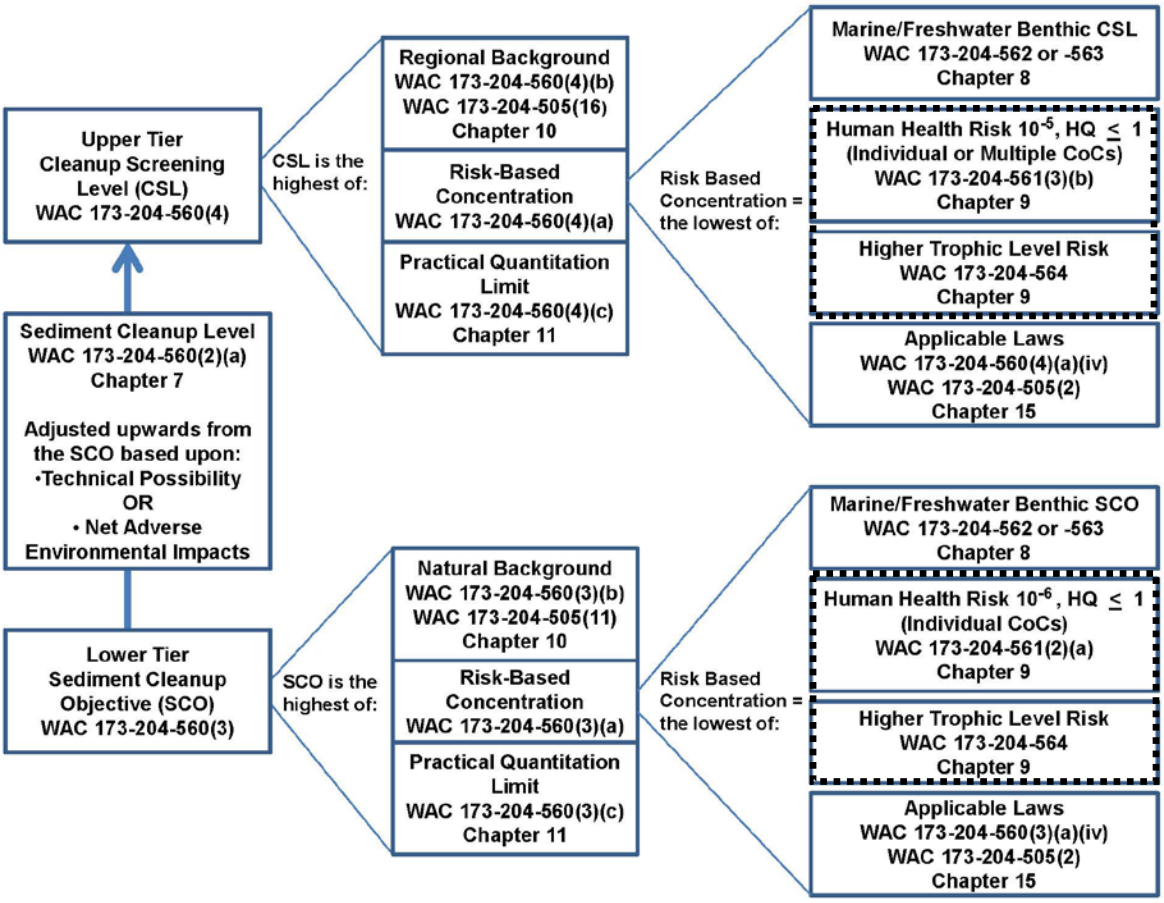



**Figure 9-1.** SMS framework for establishing sediment cleanup levels, WAC 173-204-560, Chapter 7.

## 9.1 Introduction

The focus of this chapter is on protection of human health and higher trophic levels through development of risk-based sediment concentrations for bioaccumulative chemicals, in order to establish sediment cleanup levels. If complete exposure pathways (e.g., fish consumption or dermal contact/sediment ingestion for humans) have been identified in the remedial investigation, risk based concentrations for bioaccumulative CoCs need to be established.

Once bioaccumulative risk-based concentrations are developed, they are compared to the benthic criteria (Chapter 8) to identify the lowest risk-based concentrations in sediment for each CoC. The risk-based concentration for each CoC is then compared to background concentrations and PQLs in order to establish the final SCO and CSL values (Figure 9-1 and Chapter 7, Section 7.2). However, if the exposure pathways are incomplete, then the benthic criteria should be compared to background concentrations and PQLs.

This chapter presents two approaches to address risks to human health and higher trophic levels, which includes establishing risk-based sediment concentrations for bioaccumulative chemicals:

- A simpler and more streamlined approach using only sediment data, described as Option 1 in Section 9.2.

- A more detailed, site-specific approach using site-specific sediment and tissue data, described as Option 2 in Section 9.3.

Both approaches meet the SMS requirements and represent an appropriate level of effort for most sites. Additional information on assessing risks to human health and higher trophic levels is provided in Appendix E. The information in Appendix E may be appropriate for more complex or unusual sites where Ecology determines that a more detailed evaluation is necessary, or where there is a specific higher trophic level receptor or human exposure pathway of concern that is not addressed by the methods below.

This section provides an overview of the two approaches for calculating risk-based concentrations in sediment. A spreadsheet is provided (see Appendix K) that may be used to calculate risk-based concentrations for sediment and tissue.

### 9.1.1 Approaches for addressing risk-based sediment concentrations for bioaccumulative chemicals

In terms of exposure to contaminants in sediment, the risks to humans and higher trophic levels occur primarily through consumption of fish/shellfish. Therefore, contaminant concentrations in tissue can play a critical role in assessing risks and establishing risk-based sediment concentrations. However, collecting tissue data can be a substantial effort that may not be necessary for smaller or less complex sites. Therefore, two options are available for determining risk-based sediment concentrations for bioaccumulative CoCs. Option 1 is simpler and generally results in lower values, while Option 2 is more detailed and site-specific and requires both tissue and sediment data (Figure 9-2).

#### 9.1.1.1 Option 1 – An approach using sediment data only

When only sediment data are available for the site, it is generally not possible to calculate site-specific risk-based sediment concentrations. This is because tissue data are needed to calculate site-specific biota-sediment accumulation factors (BSAFs), which are used to back-calculate from protective tissue concentrations to sediment concentrations (see Section 9.3.3 for discussion of alternatives to site-specific BSAFs). In these cases, Option 1 in Figure 9-2 may be selected. This is a simplified approach where the SCO and CSL are established at background (natural or regional, respectively) or the PQL, whichever value is higher (Chapter 7; Section 9.2.1). Option 1 can be a more cost-effective and efficient approach that is appropriate for:

- Smaller or simple sites.
- For sites where it is expected that risk-based sediment concentrations would be below background, which is the case for most bioaccumulative carcinogenic chemicals (e.g., dioxin/furan congeners, PCB congeners, and cPAHs).
- For sites where there is not enough data to calculate a site-specific BSAF and it has been determined this data collection is not necessary.

Even when tissue data are available, Option 1 may be an appropriate approach because it eliminates the need to back-calculate risk-based sediment concentrations from tissue concentrations. With Option 1, human exposure pathways that involve direct contact with, and ingestion of, sediment are also assessed using the equations provided in Section 9.2.2. These equations are included because this may be the only human exposure pathway that applies to some intertidal sediment areas. For more detailed information on Option 1, see Section 9.2.

#### 9.1.1.2 Option 2 – An approach using sediment and tissue data

Option 2 involves calculating a site-specific BSAF which is then used to develop risk-based sediment concentrations based on protective, risk-based tissue concentrations. Concentrations in tissue that are protective of human health and higher trophic levels are first determined (Section 9.3.1 and 9.3.2, respectively). These concentrations are then back-calculated to sediment using site-specific BSAFs to determine risk-based sediment concentrations (Section 9.3.3). In addition, direct contact pathways for human health should also be assessed using the equations provided in Section 9.2.2, as in Option 1. For more detailed information on Option 2, see Section 9.3.

WAC 173-204-560(7)(b) also allows for screening of bioaccumulative CoPCs by comparing site data to risk-based tissue concentrations and/or to natural background tissue concentrations. Therefore, if bioaccumulative compounds are significant CoPCs at a site and/or it is anticipated that Option 2 will be selected, it will be helpful to have a robust tissue data set for screening CoPCs and developing site-specific BSAFs.

### 9.1.2 Spreadsheet to calculate risk-based concentrations

A resource for calculating risk-based concentrations is available as an Excel spreadsheet in Appendix K. Using this spreadsheet, one can calculate:

- Risk-based sediment concentrations protective of human health and higher trophic levels using site-specific BSAFs (Option 2) (Figure 9-3).

- Risk-based sediment concentrations protective of human health using the direct contact with and incidental ingestion of sediment exposure pathways (Options 1 and 2).

- Risk-based tissue concentrations protective of human health and higher trophic levels using the consumption of fish/shellfish exposure pathway (Option 2).

These spreadsheets were used along with the recommended exposure parameters in Tables 9-1a, 9-1b, and 9-3 to calculate the risk-based values for sediment (for the ingestion/dermal contact exposure pathway) and tissue (for the fish consumption exposure pathway) presented in Table 9-2 and Table 9-4. The values for each exposure parameter can be modified to calculate site-specific values upon approval by Ecology, as discussed in Appendix E. In addition, the spreadsheet can be used to conduct a sensitivity analysis to determine the effect that varying specific parameters would have on the resulting tissue and sediment concentrations. Such an evaluation would be useful, for example, to determine whether risk-based sediment concentrations would be below background, regardless of how a particular parameter is modified and assuming a reasonable range.

## 9.2 Option 1: An Approach Using Sediment Data Only

This option has two parts and includes a) Part 1: Using sediment background concentrations (natural and regional) or b) Part 2: Calculating risk-based sediment concentrations based on secondary exposure pathways (direct contact with and incidental ingestion of sediment) as follows:

- Part 1: Using background sediment concentrations instead of back-calculating risk-based sediment concentrations from tissue concentrations (Section 9.2.1). This can be done instead of calculating site-specific sediment concentrations protective of human health and higher trophic levels based on the fish/shellfish consumption exposure pathway. This is appropriate since these risk-based sediment concentrations are frequently below background, resulting in the final SCO and CSL defaulting to background or PQL (Chapter 7). Even when risk-based sediment concentrations for consumption of fish/shellfish may be above background, use of background

concentrations will be protective as cleanup below background is not feasible. Therefore, this option may always be selected.

- Part 2: Calculating risk-based sediment concentrations based on secondary exposure pathways (Section 9.2.2). Secondary exposure pathways (e.g., direct contact with and incidental ingestion of sediment during activities such as beach recreation, clam-digging, or net-fishing; Section 9.2.2) typically result in higher risk-based concentrations than for the fish/shellfish consumption exposure pathway. If both exposure pathways (direct contact/incidental ingestion and fish/shellfish consumption) apply in the same areas for the same chemicals, then the fish/shellfish consumption exposure pathway likely represents the highest risk. In this case, calculation of risk-based sediment concentrations for both pathways calculations is not necessary. However, at some sites, there may be intertidal areas with entirely separate exposure areas or sediment management areas. In such cases, it may be appropriate to calculate risk-based sediment concentrations for both exposure pathways. Note that these two exposure pathways may have differing depths of exposure that would apply as the point of compliance.

### 9.2.1 Option 1, Part 1: Use of natural and regional sediment background

Under Option 1, risk-based sediment concentrations based on the consumption of fish/shellfish exposure pathway by human and higher trophic level receptors (e.g., fish-eating mammals and birds) can be assumed to be below background concentrations. In Ecology's experience, risk-based concentrations for the bioaccumulative chemicals that are typically found at cleanup sites (such as dioxins/furans, dioxin-like PCB congeners, chlorinated benzenes and phenols, pesticides [chlordane, lindane, DDTs, and dieldrin], and cPAHs) are below or near natural and regional background or PQLs, regardless of the specific exposure assumptions used. Therefore, it may be appropriate to default to background concentrations or PQLs. Since it is not feasible to clean up below background concentrations, Option 1, Part 1, represents a simpler, more practical, and protective approach.

Establishing background concentrations is discussed in Chapter 10. Use of Option 1 should follow the methods described in that chapter, including how the dioxin-like PCB TEQ can be combined with the dioxins/furans TEQ.

### 9.2.2 Option 1, Part 2: Use of risk-based sediment concentrations based on secondary exposure pathways

Under Option 1, background concentrations are used instead of calculating risk-based sediment concentrations based on consumption of fish/shellfish exposure pathway. This section

describes the calculation of risk-based sediment concentrations that are based on secondary exposure pathways (direct contact with and incidental ingestion of sediment). This route of exposure typically applies to sediment in intertidal areas. As noted above, site managers should consider whether these secondary pathways need to be assessed, depending on whether they represent a geographically separate exposure area from the fish/shellfish consumption exposure pathway, which would likely have more conservative risk-based concentrations.

#### 9.2.2.1 Human health

Equations 9-1(a,b) and 9-2 are used to calculate sediment risk-based concentrations based on direct contact with and incidental ingestion of sediment during activities such as beach play, clam digging, or net fishing. Key parameters in the equations are presented in Table 9-1a, including definition, units, and recommended or default values. Key parameters are detailed in Appendix E, including when site-specific adjustments to the default parameters can be made.

The EPA has determined benzo[a]pyrene is mutagenic—or causes cancer through induction of increased mutations—and that exposure during early life stages has greater potential to cause cancers even though these may not be manifest until years later. The EPA recommends using Age-Dependent Adjustment Factors for calculating risk of excess cancers for benzo[a]pyrene, which are applied to the TEQ derived for the group of cPAHs. The equations for this special case can be found in 9-1b/9-5b and age-dependent adjustment factors in Table 9-1b.

**Equation 9-1a:** Sediment cleanup levels for carcinogens for sediment ingestion/dermal contact exposure pathways.

$$SCL_{Cancer} = \frac{ACR \times BW \times AT_{cr} \times UCF}{EF \times ED \times [(IR \times AB \times CPF_o) + (SA \times AF \times ABS \times CPF_d)]}$$

**Equation 9-2b:** Sediment cleanup levels for carcinogenic chemicals that have a mutagenic mode of action (e.g., cPAHs) for sediment ingestion/dermal contact exposure pathways. This includes age dependent adjustment factors for early life exposure (Table 9-1b).

$$IRF_{child\text{-}adj}\ (mg/kg) = \frac{IRF_{0\text{-}2} \times ED_{0\text{-}2} \times EF_{0\text{-}2} \times ADAF_{0\text{-}2}}{BW_{0\text{-}2}} + (2\text{-}6yr, 6\text{-}16yr, 16\text{-}70yr)$$

$$DF_{child\text{-}adj}\ (mg/kg) = \frac{SA_{0\text{-}2} \times ED_{0\text{-}2} \times EF_{0\text{-}2} \times AF_{0\text{-}2} \times ADAF_{0\text{-}2}}{BW_{0\text{-}2}} + (2\text{-}6yr, 6\text{-}16yr, 16\text{-}70yr)$$

$$SCL_{mutagen}\ (mg/kg) = \frac{ACR \times AT_{cr} \times UCF}{[(IRF_{child\text{-}adj} \times AB \times CPF_o) + (DF_{child\text{-}adj} \times ABS \times CPF_d)]}$$

Where:

AB = gastrointestinal absorption factor (unitless)
ABS = dermal absorption factor (unitless)
ACR = acceptable cancer risk (unitless; 1 in 1,000,000)
ADAF = Age-dependent adjustment factor (unitless)
AF = sediment-to-skin adherence factor ($mg/cm^2 \cdot day$)
AT = averaging time (70 x 365 days/year)
BW = body weight (kg)
$CPF_o$ = oral cancer potency factor $(mg/kg \cdot day)^{-1}$
$CPF_d$ = cancer potency factor adjusted for dermal exposure $(mg/kg \cdot day)^{-1}$
$DF_{Child\text{-}adj}$ = child mutagenic dermal factor – age adjusted (mg/kg)
EF = exposure frequency (day/year)
ED = exposure duration (year)
$IRF_{Child\text{-}adj}$ = Age adjusted child ingestion factor (mg/kg)
IR = ingestion rate (mg/day)
SA = dermal surface area ($cm^2$)
SCL = risk-based sediment cleanup level concentration (mg/kg dry weight)
UCF = unit conversion factor (1,000,000 mg/kg)

**Equation 9-3:** Sediment cleanup levels for non-carcinogens for sediment ingestion/dermal contact exposure pathways.

$$SCL_{NonCancer} = \frac{HQ \times BW \times AT_{nc} \times UCF}{EF \times ED \times [((1/RfD_o) \times (IR \times AB)) + ((1/RfD_d) \times (SA \times AF \times ABS))]}$$

Where:

SCL = risk-based sediment cleanup level concentration (mg/kg dry weight)
HQ = hazard quotient (unitless)
$RfD_o$ = oral reference dose (mg/kg·day)
$RfD_d$ = reference dose adjusted for dermal exposure (mg/kg·day)
All other terms are the same as in Equation 9-1

In Equations 9-1(a,b) and 9-2, the $CPF_d$ and $RfD_d$ are derived from the $CPF_o$ and $RfD_o$ rather than being independent parameters, as follows:

**Equation 9-4:**

$$RfD_d = RfD_o \times GI$$

**Equation 9-5:**

$$CPF_d = CPF / GI$$

Where:

$CPF_o$ and $RfD_o$ are as defined in Appendix E, Section E.2.1.1

GI = Default of 0.2 for inorganic hazardous substances
Default of 0.8 for volatile organic compounds and mixtures of dioxins/furans
Default of 0.5 for other organic hazardous substances

Alternatively, chemical-specific GIs may be used when known and available in the literature. Table 9-2 includes risk-based sediment concentrations for the direct contact with, and incidental ingestion of, sediment exposure pathways that were calculated using the above equations and the recommended exposure parameters in Table 9-1. These values may be used as a guide to understand how they compare to sediment background and risk-based sediment and tissue concentrations based on the fish/shellfish consumption exposure pathway.

### 9.2.2.2 Higher trophic levels

Although sediment ingestion is one pathway by which aquatic-dependent wildlife can be exposed to bioaccumulative chemicals in sediment, the dietary pathway tends to be the dominant source (Bridges et al. 1996). Therefore, at most sites, this pathway does not need to be evaluated separately nor as part of the streamlined approach used under Option 1.

# 9.3 Option 2: An Approach Using Sediment and Tissue Data

This option has three steps and includes back calculating risk-based sediment concentrations from risk-based tissue concentrations based on the fish/shellfish consumption exposure pathway as follows:

Step 1: Determine the lowest risk-based concentration in tissue for each CoPC. See Section 9.3.1 to identify risk-based tissue concentrations for human health, and Section 9.3.2 to identify risk-based tissue concentrations for higher trophic level ecological receptors. The lowest of these bioaccumulative risk-based tissue concentrations should be identified for each CoPC.

Step 2: If sufficient tissue data are available for the site, compare the tissue concentrations measured at the site to these risk-based tissue concentrations. Some chemicals may be screened out at this stage at the site manager's discretion, if they do not exceed risk-based tissue concentrations or are not above natural or regional background tissue concentrations (which have not yet been established by Ecology). For bioaccumulative CoPCs, this comparison is conducted using the mean or area-weighted mean over the exposure area (Chapter 6, Section 6.3).

Step 3: Determine a site-specific BSAF and apply that BSAF to back-calculate risk-based sediment concentrations from the lowest risk-based tissue concentrations for each CoPC (or CoC, if screening has been conducted as described above) (Section 9.3.3).

Option 2 is data-intensive and is recommended when there is reason to believe that the resulting risk-based sediment concentrations for bioaccumulative chemicals will be above background concentrations and PQLs.

## 9.3.1 Calculating tissue concentrations protective of human health

Risk-based tissue concentrations protective of human health are calculated using the following acceptable risk levels and approaches:

- Calculate risk-based tissue concentrations for individual bioaccumulative chemicals at acceptable risk levels for carcinogens and non-carcinogens by using Equations 9-5 and 9-6:
    - Carcinogens: The risk-based tissue concentration should be calculated using a cancer risk level of $1\times10^{-6}$ for the SCO and $1\times10^{-5}$ for the CSL. These risk levels correspond to one additional case of cancer in a population of one million, or one in one hundred thousand, respectively.

- Noncarcinogens: The tissue risk-based concentration should be calculated using a hazard quotient (HQ) of 1.

- Adjust risk-based concentrations for individual bioaccumulative chemicals downward. The risk-based concentrations for individual bioaccumulative chemicals should be adjusted based on multiple exposure pathways and multiple hazardous substances. This step is designed to ensure that site risks do not exceed total acceptable risk levels.

  - Carcinogens: If multiple complete exposure pathways or multiple carcinogenic chemicals are present at the site, then the risk-based concentrations for those carcinogens should be adjusted downward as necessary to ensure that the total site excess cancer risk does not exceed $1\times10^{-5}$ (WAC 173-204-561(2)(a)(ii)).

  - Noncarcinogens: If multiple complete exposure pathways or multiple non-carcinogenic contaminants are present at the site that:

    a) Exhibit toxicity on the same target organ (e.g., hepatic, renal, respiratory, cardiovascular, etc.), or
    b) Exhibit toxicity for a common endpoint (e.g., developmental, immunological, reproductive, neurological, etc.), or
    c) Exhibit toxicity via a common mode of action, then
    d) The risk-based concentrations for these chemicals should be adjusted downward to ensure that the hazard index (HI) does not exceed 1 (WAC 173-204-561(2)(a)(i)).

Equations 9-5(a,b) and 9-6 should be used to develop risk-based tissue concentrations based on the consumption of fish/shellfish exposure pathway for carcinogens and noncarcinogens, respectively. Key exposure parameters in the equations are presented in Table 9-3, including definition, units, and recommended values. Several key parameters are discussed further in Appendix E, including when site-specific adjustments to the recommended exposure parameters can be made.

**Equation 9-6a:** Risk-based tissue concentrations for carcinogens for the fish consumption exposure pathway.

$$RBC_{cancer} = (ACR \times BW \times AT_{cr} \times UCF) / (CPF_o \times FCR \times FDF \times EF \times ED)$$

**Equation 9-7b:** Risk-based tissue concentrations for carcinogenic chemicals that have a mutagenic mode of action (e.g., cPAHs) for fish consumption exposure pathways. This includes age dependent adjustment factors for early life exposure (Table 9-1b).

$$FCR_{child\text{-}adj}\ (mg/kg) = \frac{FCR_{0\text{-}2} \times ED_{0\text{-}2} \times EF_{0\text{-}2} \times ADAF_{0\text{-}2}}{BW_{0\text{-}2}} + (2\text{-}6yr,\ 6\text{-}16yr,\ 16\text{-}70yr)$$

$$RBC_{mutagen}\ (mg/kg) = (ACR \times AT_{cr} \times UCF) / (CPF_o \times FCR_{child\text{-}adj} \times FDF)$$

Where:

$RBC_{cancer}$ = risk-based tissue concentration (mg/kg)
ACR = acceptable cancer risk (unitless)
BW = body weight (kg)
AT = averaging time (day)
UCF = unit conversion factor (1000 g/kg)
$CPF_o$ = oral cancer potency factor $(mg/kg \cdot day)^{-1}$
FCR = fish/shellfish consumption rate (g/day)
FDF = fish diet fraction (unitless)
EF = exposure frequency (day/year)
ED = exposure duration (year)

**Equation 9-8:** Tissue concentrations for non-carcinogens for the fish consumption exposure pathway.

$$RBC_{Noncancer} = (HQ \times BW \times AT_{nc} \times UCF \times RFD_o) / (FCR \times FDF \times EF \times ED)$$

Where:

HQ = hazard quotient (unitless)
$RfD_o$ = oral reference dose (mg/kg·day)
All other terms are the same as in Equation 9-3.

Table 9-4 includes risk-based tissue concentrations protective of the fish/shellfish consumption exposure pathway that were calculated using the above equations and the recommended exposure parameters shown in Table 9-3. These values may be used as a guide to understand how they compare to background (Chapter 10, Table 10-1 for natural background values) and other risk-based concentrations, such as the benthic criteria (Chapter 8, Table 8-1).

The fish consumption rate (FCR) exposure parameter should be established by working with the affected tribes and stakeholders on a site-specific basis. For illustration purposes in Table 9-4, tissue concentrations based on three representative FCRs based on tribal subsistence fish consumption (Ecology 2013b) are shown. See Appendix E for a discussion of alternative FCRs where tribal scenarios are not applicable.

## 9.3.2 Calculating tissue concentrations protective of higher trophic levels

There are three broad categories of higher trophic levels that may be appropriate to consider at sediment cleanup sites: 1) fish, 2) birds (aquatic, terrestrial fish-eating, and shorebirds), and 3) fish- and shellfish-eating mammals. For most species, ecological risk is assessed at the population level by considering endpoints that may affect the overall population such as growth, mortality, and reproduction. For ESA-listed species, ecological risk is assessed on an individual level and may include additional endpoints, such as behavioral or sublethal.

### 9.3.2.1 Higher trophic level ecological risk screening

Higher trophic level species such as birds and mammals are similar to humans where the greatest risks are associated with consumption of fish/shellfish. Therefore, concentrations in fish/shellfish are recommended to assess risks. Ecological benchmarks and exposure factors are less standardized than for human health—plus, there are more species to assess. In general, the high fish/shellfish consumption rates and the RME exposure factors for individual humans will also be protective of most of the higher trophic level species at the population level. Additionally, for those chemicals that might pose greater risks to higher trophic levels, many risk-based sediment concentrations may be below background.

Therefore, a three-part screening assessment can be employed to determine whether higher trophic levels need to be assessed, or whether other values (such as human health risk-based, background, etc.) will be protective of these receptors:

1. Identify chemicals at the site that may pose greater risks to higher trophic level receptors than to humans. Screen out chemicals that pose greater risks to humans (Section 9.3.1).

2. Identify chemicals at the site for which higher trophic level risk-based tissue or sediment concentrations may be below background or PQL. Default to these values for those chemicals below background or PQL. Retain only those chemicals whose risk-based values may be above background or PQL (see Chapter 10, Table 10-1 for natural background information and Chapter 11, Table 11-1 for PQL information).

3. Identify any resources of special concern that may warrant specialized field investigations, modeling, and/or literature-based assessments.

With this assessment, simpler approaches can be used for chemicals that pose greater risks to human health or those with risk-based concentrations below background, while the more complex ecological assessments can be reserved for those chemicals and organisms of special concern.

There are several bioaccumulative chemicals that may pose greater risks to higher trophic levels than to human health (when higher trophic level risk-based concentrations are lower than human health risk-based concentrations.) These chemicals are:

- Lead
- Mercury
- Selenium
- Tributyltin (TBT)
- Pentachlorophenol (PCP)
- Pyrene and fluoranthene.

For other chemicals, risk-based concentrations for higher trophic level receptors are typically higher than for human health and the risks may not need to be calculated separately. Higher trophic level risk-based concentrations for dioxins/furans are likely to fall below background concentrations and PQLs, while this is less likely for other CoPCs.

To evaluate whether special assessments need to be conducted for resources of particular concern and potentially unusual exposure pathways, see Appendix E.

#### 9.3.2.2 Selection of indicator species

Once the screening process has been conducted and it has been determined that assessment of certain chemicals/receptors is needed, indicator species for the site should be selected. Table 9-5 lists example aquatic and aquatic-dependent higher trophic level receptors for freshwater and marine systems. Aquatic receptors include fish and invertebrates that may experience acute or chronic effects due to concentrations in their tissues. The aquatic-dependent species listed in Table 9-5 are considered representative or indicator wildlife receptors for Washington State sites based on feeding guilds, including several avian and mammalian species that

consume large amounts of fish and/or shellfish. Except where noted, most of these receptors are found in both freshwater and marine environments. Depending on the type of waterbody and the location of the sediment cleanup site, shorebirds (such as the stilt, avocet, or sandpiper) may also serve as representative receptors. These birds typically consume aquatic invertebrates including insects and crustaceans, which may bioaccumulate metals and metalloids to a higher degree than fish consumed by predominantly fish-eating birds. Mammals that commonly feed on crustaceans and fish in watersheds include river otter, sea otter, and mink.

Not all of these species will be appropriate to select as an indicator species at any given site, and other species might be present that are of particular concern. Several (2 – 4) indicator species found in Table 9-5, or other species appropriate to the site, should be selected for calculation of risk-based tissue concentrations. The species should be representative of feeding guilds at the site and (if known), selected for their sensitivity to the bioaccumulative CoCs being assessed.

#### 9.3.2.3 Calculation of higher trophic level risk-based tissue concentrations for mammals and birds

Ecological risk assessment is an evolving field. Many different approaches have been proposed to calculate protective levels in tissue, including using toxicity reference values (TRVs), species sensitivity distributions (SSDs), and equilibrium partitioning-based approaches derived from water quality criteria. Of these, use of TRVs is the most straight-forward, as these values represent a dose in food (or the concentration in the fish/shellfish tissue) that is considered safe for the species consuming the fish and shellfish. This approach is therefore recommended, although other approaches may be proposed and used with Ecology's approval.

A substantial amount of ecotoxicology data is available online from federal and state agencies. A summary of many of these databases can be found at the California Office of Environmental Health Hazard Assessment's Toxics Directory at http://oehha.ca.gov/public_info/TDecotox.html#ecotox_database. Other resources are listed in relevant sections below. If a TRV is available in the literature for the actual indicator species being assessed, it can be used directly as the risk-based concentration in tissue. However, most often this is not the case, and the TRV would need to be adjusted for the body weight and ingestion rate of the indicator species compared to the test species, as follows:

**Equation 9-9:**

$$TSL = TRV_{test} \times (FIR_{test} / BW_{test}) \times (BW_{ind} / FIR_{ind})$$

Where:

TSL = higher trophic level risk-based tissue concentration for the indicator species (mg/kg lipid)

$TRV_{test}$ = toxicity reference value from the test (mg/kg lipid)

$FIR_{test}$ = food ingestion rate of the test organism (kg/day)

$FIR_{ind}$ = food ingestion rate of the indicator species (kg/day)

$BW_{test}$ = body weight of the test organism (kg)

$BW_{ind}$ = body weight of the indicator species (kg)

TRVs, food ingestion rates, and body weights for site-specific wildlife species of interest can be determined from many literature sources, including EPA's *Wildlife Exposure Factor Handbook* (USEPA 1993), EPA's ECOTOX database (http://cfpub.epa.gov/ecotox/), and the Oak Ridge National Laboratory's Ecological Risk Analysis tools and guidance page (http://www.esd.ornl.gov/programs/ecorisk/ecorisk.html). Site-specific species that have a higher food ingestion rate to body weight ratio than that of the test species would have a lower risk-based concentration in tissue, and vice versa. Alternatively, allometric scaling for the TRV may be applied to account for differences in body weight. This scaling method can also be found in USEPA (1993).

Some chemicals such as DDE, PCBs, dioxin/furans, and dioxin-like PCB congeners (USEPA 2003), mercury, and selenium (Fairbrother et al. 1999; Adams et al. 2003) have demonstrated effects on avian development at the egg level. In these cases, developing tissue risk-based concentrations based on eggs is more appropriate than the dietary pathway, because the reproductive effects and corresponding TRVs are based on concentrations in bird eggs rather than in the diet. Higher trophic level risk-based tissue concentrations can be calculated for this

**Equation 9-10**

$$TSL = TRV_{egg} / BMF_{egg}$$

Where:

TSL = higher trophic level risk-based tissue screening level (mg/kg lipid)

$TRV_{egg}$ = egg-based toxicity reference value (mg/kg)

$BMF_{egg}$ = biomagnification factor from prey to egg (unitless)

**Equation 9-11**

$$TSL = TRV_{egg} / BMF_{egg}$$

Where:

TSL = higher trophic level risk-based tissue screening level (mg/kg lipid)
$TRV_{egg}$ = egg-based toxicity reference value (mg/kg)
$BMF_{egg}$ = biomagnification factor from prey to egg (unitless)

The $BMF_{egg}$ can be derived from site-specific data (if available) or from the literature. Examples of site-specific derivation of BMFs can be found in Henny et al. (2003), USFWS (2004), and Braune and Norstrom (1989). Other methods for estimating BMFs can be found in USFWS (1994).

### 9.3.2.4 Calculation of higher trophic level risk-based tissue concentrations for fish and invertebrates

The toxicity of bioaccumulative CoCs to fish and invertebrates can be evaluated using the tissue residue approach (TRA). By associating the toxic response of aquatic biota with the tissue concentration of the chemical causing the effect, complicating factors associated with exposure media can largely be eliminated. Toxic effects can then be directly expressed as a function of tissue residues. Elimination or minimization of confounding factors such as bioavailability has the great advantage of using tissue residues to evaluate toxicity of environmental contaminants, rather than using chemical concentrations in water, sediment, or diet.

TRA is used to generate critical body residues (CBRs), such as $LR_{50}$s, $LR_{10}$s, or lowest observed effect residues (LOERs), for a given toxicant with relatively low variability among species. Because data from a variety of taxa are used to generate the CBRs and corresponding tissue concentrations, for most contaminants, the CBRs will be the same for fish and invertebrates. Not all CBRs will have broad taxonomic application and exceptions will occur (e.g., TBT). However, for most chemicals, the species sensitivity distributions (SSDs) for fish and invertebrates largely overlap.

SSDs are most commonly expressed as cumulative distribution functions (CDFs) of the toxicity of a chemical to a set of species. When toxicity data (such as a set of $LC_{50}$ values for a number of species) are rank ordered from low to high (or high to low), generation of the SSD as a cumulative distribution function permits identification of a concentration at which a defined proportion of the species comprising the SSD is not adversely affected. Tissue concentrations

derived from SSDs that contain larger amounts of toxicity data are more likely to accurately define tissue residues that, if not exceeded, are protective of fish.
A potential difficulty with measured residue-effects data at this time is data availability. There is less information available in the literature on tissue residues associated with toxicity than there is on water column or sediment concentrations associated with toxicity. This does not preclude the use of literature data to derive risk-based fish tissue concentrations, but the limited available information for many chemicals will curb both the number and reliability of these values. ERED, available at http://el.erdc.usace.army.mil/ered/ (Bridges and Lutz 1999, as updated in 2011), and Jarvinen and Ankley (1999), are the primary sources of residue-effects information that can be used to develop SSDs.

Risk-based tissue concentrations derived using the TRA approach for RSET are being reviewed by the agencies and may be updated in the future. Existing values are not currently recommended. Additional information will be provided as these values are reviewed and updated.

### 9.3.3 Calculating risk-based sediment concentrations from risk-based tissue concentrations

The final step in calculating risk-based sediment concentrations for bioaccumulative CoCs is to apply site-specific BSAFs to risk-based tissue concentrations in order to back-calculate sediment concentrations. BSAFs for organic chemicals based on equilibrium partitioning theory and project-specific field-derived BSAFs are widely available in the literature and in databases. However, in practice, BSAFs are highly site-specific. They are affected by a variety of factors, including but not limited to: a) species present, b) food web structure, c) habitat availability and use by biota, d) nonlinearity of uptake by species, e) nonequilibrium environmental conditions, f) congener mixtures, g) seasonal variations, h) sediment organic carbon source, and i) species-specific lifecycle effects. For all of these reasons, site-specific and species-specific BSAFs for the same chemical or chemical class can vary over several orders of magnitude. Therefore, Ecology recommends developing site-specific BSAFs to implement Option 2 or use Option 1 in Section 9.2 rather than setting risk-based sediment concentrations.

The general equation for calculating risk-based sediment concentrations from risk-based tissue concentrations for human health or higher trophic levels is as follows:

**Equation 9-12:**

$$RBC = \frac{TSL}{BSAF \times SUF}$$

Where:

RBC = risk-based sediment concentration (mg/kg OC or dry weight)
TSL = lowest risk-based tissue screening level for a bioaccumulative CoC (mg/kg lipid-normalized or wet weight)
BSAF = biota-sediment accumulation factor (mg/kg tissue/mg/kg sediment)
SUF = site use factor (unitless where 1 = 100%)

The BSAF and RBC may be in different units for different chemicals, as follows:

- For nonpolar organic chemicals, the tissue concentration used to calculate the BSAF is lipid-normalized and the sediment concentration is OC-normalized, because these chemicals are primarily found in fatty tissue and the organic fraction of sediment. Therefore, the final RBC will be an OC-normalized sediment concentration.
- For polar organics or metals the tissue concentration used to calculate the BSAF is not lipid-normalized and the sediment concentration is in dry weight. In this case, the final RBC will be a dry weight sediment concentration.

Back-calculation of tissue concentrations to sediment concentrations also involves consideration of the site use factor (SUF), discussed in Section 9.3.3.2. Finally, there are cases where the BSAF approach is not applicable, such as for PAHs in fish tissue, since PAHs are metabolized by fish. An alternative approach for this case is described in Section 9.3.3.3.

If the final RBC is an OC-normalized value, it will need to be compared to the PQL and background concentration to determine which is highest to set the cleanup level. However, the PQL and background concentrations will generally be in units of dry weight. To compare them directly, they will all need to be converted to the same units, either dry weight or OC-normalized.

Ecology recommends using the TOC data for the site to determine a natural TOC range (0.5 – 3.5% for marine sediment) for the area and using that to convert the OC-normalized RBC to a range of dry weight-equivalent concentrations for comparison to the PQL and background. In establishing the natural TOC range for comparison, areas that are impacted by *anthropogenic*

TOC (e.g. a site contaminated with woodwaste or fishwaste; black carbon from anthropogenic sources—this exclusion will be determined on a site-specific basis) from the site or with unusually low TOC concentrations (< 0.5%) should not be included.

If an OC-normalized RBC is the highest of the three values and may be established as the SCO or CSL, site sediment data should generally be compared to the RBC on an OC-normalized basis to identify areas that exceed the standard. However, as above, areas that are impacted by anthropogenic TOC or with unusually low TOC concentrations should be compared on a dry weight basis, converting the RBC to a dry weight value based on a natural TOC concentration for the area. A mean or area-weighted mean TOC could be used for this conversion since bioaccumulative standards are applied on an area-weighted basis.

#### 9.3.3.1 Biota-sediment accumulation factor (BSAF)

This section describes methods for developing a site-specific BSAF, including Ecology's preferred field-based method and alternative modeling approaches. If a BSAF has already been developed for a nearby site or for the region as a whole, Ecology may allow use of that BSAF at the site manager's discretion.

The BSAF represents the relationship of the chemical concentration in biota with the chemical concentration in sediment. As noted above, lipid and organic carbon normalization are used for nonpolar organic chemicals, because these chemicals reside primarily in the organic compartments of the sediment or tissue and this normalized value has smaller variation that non-normalized values. For polar organics or metals, non-normalized tissue and sediment concentrations should be used.

Generally speaking, the BSAF is not a linear relationship between concentrations in sediment and tissue and should not be considered a simple ratio. Sufficient data should be collected to obtain a tissue-sediment regression curve (at least 10 paired tissue-sediment concentrations). Samples should span as wide a range of concentrations as possible to best define the shape of the curve. Special care should be taken to collect both tissue and sediment data at concentration ranges as near the risk-based tissue concentration as possible, with the recognition of the limitations that risk-based concentrations may be below analytical sensitivity and natural background.

The regression should not be assumed to be linear or to pass through the origin, as this may result in substantial errors. The appropriate BSAF to use when back-calculating the sediment concentration is the slope of the curve at the point that corresponds to the risk-based tissue concentration. The error in the BSAF should be estimated through the use of 95% confidence bands, either on the original curve or on a BSAF vs. sediment concentration curve.

BSAFs can be measured or estimated on a site-specific basis using a variety of methods. These methods typically require a considerable amount of data and may not be cost-effective for smaller sites:

- Field-collected spatially-paired sediment and tissue concentrations. This approach is most appropriate when the organisms are stationary and in close association with the sediment, such as bivalves. Mobile fish or shellfish that have well-characterized home ranges smaller than the total area of the site can also be used. For example, this approach has been used to characterize individual river stretches at large sites. In cases like this, both tissue concentrations and sediment concentrations in each area are averaged or composited, and each area is considered one paired data point on the curve. Sediment data should be area-weighted before averaging, when appropriate.

- Laboratory bioaccumulation testing. Contaminated sediment from the site is sampled and brought to a laboratory, where organisms are exposed to the contaminated sediment under controlled conditions. The species are then harvested and both tissue and sediment concentrations are calculated for each sample. This approach is useful if it is suspected that non-sediment sources may be contributing to tissue burdens at the site (Chapter 4, Section 4.2.5).

- *In situ* bioaccumulation testing. *In situ* bioaccumulation testing is designed to provide realistic exposures that preserve the natural setting in which the organisms live. Abiotic elements (e.g., light, temperature, currents, etc.) that are lost during laboratory testing can be maintained *in situ*. During *in situ* bioaccumulation testing, organisms are placed in or just above contaminated sediment at the site for a period of time long enough to achieve equilibrium with the environment. Their body burden is determined upon harvest (Chapter 4, Section 4.2.5) and co-located sediment samples are also collected.

- Using BSAFs for larger sites. Modeling approaches to developing BSAFs can be resource- and data-intensive. They are unlikely to be used at any but the largest sites, but have been included here as an option, upon approval by Ecology. Food web modeling predicts the bioaccumulation of contaminants in food webs. Approaches for developing food web models are discussed in detail in Gobas (1993, 2008) and can be used to back-calculate risk-based sediment concentrations that will result in no greater than the risk-based tissue concentrations in target organisms. Food web models must be calibrated to the site to avoid large errors, and therefore generally require at least as much field data as the above approaches, including additional types of data that affect partitioning through the various media. Once calibrated, they offer potential advantages in the ability to predict the effects of cleanup action alternatives or proposed cleanup standards on a variety of trophic levels over time.

- Using BSAFs for smaller sites. For smaller sites or sediment cleanup units, if BSAFs have been developed for the same chemicals at neighboring sites or for the region as a whole, and there is reason to believe they would similarly apply at the site or sediment cleanup unit, such BSAFs may be adopted at the site manager's discretion. In addition, smaller sites or sediment cleanup units may combine data for the same chemical to calculate an area-wide BSAF, if the sites are within similar habitat and have similar receptor species.

Before calculating a BSAF, relevant factors should be considered, such as: treatment of non-detects; model selection criteria; shape of the relationships; validity of the data; and the potential presence of more than one population (Judd et al. 2013). Some of the more important considerations include:

- Multiple routes of exposure. Organisms are exposed to bioaccumulative chemicals directly from the sediment, the water, and prey. Therefore, assuming that sediments are the only source of contaminants to the organism may result in an overestimate of the BSAF and an overly conservative risk-based sediment concentration. For this reason, the regression curve should not be forced through the origin, as this represents an inherent assumption that the only source of the contaminant is site sediment (i.e., when the sediment concentration is zero, the tissue concentration will also be zero). Instead, the curve should be allowed to pass through the y-axis. The magnitude of its intersection with the y-axis is an indication of degree to which water- or food-borne sources may be important at the site. This is valuable information for assessing the degree of source control, as well as the maximum amount of improvement in tissue concentrations that can be expected through sediment cleanup.

- Nonlinearity. Many factors cause contaminant uptake to be non-uniform, resulting in nonlinearity in the BSAF curve. These factors include, but are not limited to, the concentration of the contaminant in sediment and/or tissue; the species, age, health, and reproductive status of the organism; and geochemical factors affecting bioavailability (e.g., salinity, pH, dissolved oxygen, alkalinity, temperature, etc.). In particular, empirical data has shown that the BSAF tends to decline with increasing sediment concentration. BSAF curves may be best fit by exponential or other functions, and it is important to fit the BSAF data as a curve rather than a line to avoid substantial potential errors in calculating the slope.

- Lipid content of organisms. Different organisms (e.g., different ages, life stage, sex, and species) have varying amounts of lipid content in their tissue. When conducting lipid normalization, using a single, default lipid content value for all fish/shellfish results in uncertainty in the BSAF. Therefore, lipid content should always be measured when sampling tissues. Other factors should be noted where relevant, such as age, life

history stage, sexual maturity, and condition. Tissue samples should be lipid-normalized on a sample-specific basis, in the same manner that sediment samples are organic carbon-normalized on a sample-specific basis. Sampling should be avoided during spawning season or other times when the lipid content and contaminant burden might be rapidly changing.

- Tissue processing and analysis. The methods used to process tissue samples prior to analysis may result in biased and highly uncertain BSAFs if standard method(s) are not employed. For example, standard methods such as purging of gut sediment from worms and shellfish, or sampling outside of spawning periods, should be applied in order to minimize bias and uncertainty.

- Confounding factors. It is important to recognize that test organisms, water, and control and reference sediments may contain measurable concentrations of bioaccumulative COCs, particularly at low detection limits. Test organisms in particular may contain PCBs and other chemicals in their bodies due to chemicals in feed, or paint and caulk in rearing areas, etc. Test organisms and other potential pre-existing sources of chemicals should be analyzed before any bioaccumulation tests are conducted, to provide a baseline for comparison to after-test results.

- Migratory fish species. As noted previously, use of migratory fish species or any organisms with home ranges that are large relative to the site may result in significant uncertainty in the BSAF, which is typically indicated by poor correlations. Use of such species should be avoided when calculating BSAFs (see Chapter 3, Section 3.4.2).

Additional guidance materials, and reviews of BSAFs and regressions, include:

- USEPA BSAF database: http://www.epa.gov/medatwrk/Prods_Pubs/bsaf.htm
- USEPA guidance (Burkhard 2009b)
- Judd et al. (2013)

#### 9.3.3.2 Site use factor

The site use factor is the percentage of time an organism is in contact with contaminants at the site, relative to the organism's home range. There are significant uncertainties associated with estimating home ranges relative to the site and the relationships between sediment contamination and fish/shellfish tissue concentrations. Ecology therefore recommends:

1) Selecting resident species at the site for calculating the BSAF;
2) Calculating a site-specific BSAF that inherently incorporates home range exposure issues; and
3) Using a site use factor of 1.

This is a health-protective approach given the uncertainties in estimating home ranges and BSAFs. This approach is also consistent with approaches used to establish surface water quality standards and surface water cleanup levels.

Some species of salmon and other anadromous species spend considerable portions of their life cycle in the open ocean and can obtain much of their body burden of bioaccumulative chemicals outside of Washington waters. However, some species of salmon also obtain a substantial amount of their body burden from Puget Sound waters or contaminated estuaries draining to Puget Sound (O'Neill 2009a,b). In addition, salmonid contaminant body burdens differ based on: a) marine distribution (reproductive life history); b) where salmonids live (marine habitats, proximity to urbanized areas as sources, migration residency times); c) reproductive life history (gender and number of reproductive cycles); d) trophic level; and e) diet (O'Neill 2009a,b). For these reasons, use of salmonids and other highly migratory species is not recommended in calculating site-specific BSAFs. Instead, resident fish, epibenthic, or benthic species should be used to ensure high site fidelity and a strong relationship between tissue concentrations and sediment concentrations at the site. See Chapter 3, Section 3.4.2 for further guidance on the design of bioaccumulation evaluations.

As discussed above, the initial SUF for all sites should be 1 (or 100%). In general, proper selection of species and study design should eliminate the need to calculate a SUF. However, the SUF may be reduced to reflect site-specific conditions and higher trophic level receptors in unusual circumstances. For example, a species of special concern may be present that is not fully resident at the site. In this case, the SUF may be reduced to reflect the species' relative exposure to the site. Adjacent sediment cleanup units that are being remediated for the same chemical within a site should be considered as a whole in this calculation.

There are multiple methods that can be used to calculate a SUF. Some of these include, but are not limited to, the following:

- Divide the contaminated area represented by the site and/or adjacent sediment cleanup units by the area of the home range of the fish/shellfish being consumed.

- Divide the time the fish spends at the site by the lifetime of the fish (if a seasonal or migratory species).

- Area-weight the home range by the habitat preference of the species prior to either of the above calculations.

#### 9.3.3.3 Risk-based PAH concentrations in sediment for protection of fish

For most contaminants, sediment concentrations protective of fish and fish-eating birds and mammals can be back-calculated from protective tissue concentrations using BSAFs, as

described above. However, because fish metabolize PAHs, the back-calculation approach cannot be used for PAHs. Instead, more direct approaches have been developed by NOAA that compare PAH concentrations in field-collected sediment to adverse effects in fish, including mortality, growth, and reproductive endpoints. These values may be particularly important to include when ESA-listed fish species are present at or transit through the site. The research cited below focuses specifically on juvenile salmonids for that reason. The Regional Sediment Evaluation Team (RSET) agencies are considering draft PAH values for protection of fish that were proposed by NOAA in 2014. These draft PAH values and the basis for them can be found at: http://www.nwd.usace.army.mil/Portals/25/docs/RSET/RSET-WP-PAH_fish.pdf.

Final values may be incorporated into this manual if adopted by RSET and after review by Ecology.

**Table 9-1a.** Recommended exposure parameters for calculating human health risk-based concentrations for ingestion of sediment and direct contact with sediment. See Table 9-1b for parameters based on early life exposure.

| Abbrev | Parameter Name | Units | These parameters are provided for informational purposes only and represent Ecology policy only when stated. The exposure parameters presented in this table should be used at all SMS sites unless site-specific information indicates they are inappropriate. See Appendix E Section E.2.2 for more information on site-specific adjustments. | | |
|---|---|---|---|---|---|
| | | | **Beach Play Child** | **Subsistence Clam Digging Adult** | **Subsistence Net Fishing Adult** |
| ACR | Acceptable cancer risk | unitless | $1\times10^{-6}$ for individual carcinogens; $1\times10^{-5}$ for multiple carcinogens or exposure pathways | | |
| HQ | Hazard quotient | unitless | 1 | | |
| EF | Exposure frequency | day/year | 41<br>May be adjusted based on site-specific data | 120<br>May be adjusted based on site-specific data | 119<br>May be adjusted based on site-specific data |
| ED | Exposure duration | year | 6<br>May be adjusted based on site-specific data | 70[a]<br>May be adjusted based on site-specific data | |
| IR | Ingestion rate | mg/day | 200<br>(USEPA 2014) | 100<br>(USEPA 2014) | 50 |
| AB | Gastrointestinal absorption factor (soil) | unitless | Default is 1, or 0.6 for dioxins/furans[b]<br>(see WAC 173-340-745, Equation 745-5) | | |
| $CPF_o$ | Cancer potency factor (oral) | $(mg/kg\cdot day)^{-1}$ | Chemical-specific | | |
| $RfD_o$ | Reference dose (oral) | mg/kg·day | Chemical-specific | | |
| $CPF_d$ | Cancer potency factor (dermal) | $(mg/kg\cdot day)^{-1}$ | Chemical-specific | | |
| $RfD_d$ | Reference dose (dermal) | mg/kg·day | Chemical-specific | | |
| SA | Dermal surface area | $cm^2$ | 2,378 | 3,212 | |
| AF | Sediment-to-skin adherence factor | $mg/cm^2\cdot day$ | 0.2 | 0.6 | 0.02 |
| ABS | Dermal absorption factor | Unitless | Chemical-specific | | |
| BW | Body weight | kg | 15 | 75<br>(see Section E.2.1.4) | |
| AT | Averaging time | day | 2,190 (6 year) – noncancer<br>25,550 (70 year) – cancer | 25,550 (70 year) – noncancer<br>25,550 (70 year) – cancer | |

a, ages 0-6 years is not included in the 70-year exposure

b, When the MTCA Science Advisory Board reviewed this value for dioxins/furans, it applied only to carcinogenic congeners. However, subsequent research suggests that it may also be applicable to noncarcinogenic congeners.

**Table 9-2b.** Risk parameters and exposure pathways used for calculating risk-based sediment concentrations for early life exposure to cPAHs.

| | **Life Stages (Age Groups, years)** | | | |
|---|---|---|---|---|
| **Risk Parameters** | 0-2 | 2-6 | 6-16 | 16-70 |
| Age Dependent Adjustment Factor for cPAHs (unitless) | 10 | 3 | 3 | 1 |
| Body Weight[a] (kg) | 10 | 17 | 44 | 81 |
| Dermal Exposure Areas[a] | 1952cm$^2$ | 2591cm$^2$ | 2161cm$^2$ | 3407cm$^2$ |
| Fish Consumption Rate Factor | 0.4 | 0.4 | 1 | 1 |
| **Exposure Pathways** | | | | |
| Fish/Shellfish Consumption | X | X | X | X |
| Beach Play, Child (Dermal & Incidental Ingestion | X | X | | |
| Clam Digging, Subsistence (Dermal & Incidental Ingestion)[b] | b | b | X | X |
| Net Fishing (Dermal & Incidental Ingestion)[b] | b | b | X | X |

Values subject to confirmation of site-specific RME input parameters
a, 2011 EPA Exposure Factors Handbook Publication EPA/600/R-090/052F
b, Tribal subsistence fisher assuming a 70-year exposure; clam digging and net fishing direct contact exposure scenarios assume child beach play from 0 - 6 years, and clam digging or net fishing from 6 – 70 years.

**Table 9-3.** Human health risk-based sediment concentrations for ingestion of sediment and direct contact with sediment (calculated using the spreadsheets in Appendix K and the recommended exposure parameters in Table 9-1a).

| Chemical | Beach Play (Child) | Subsistence Clam Digging (Adult) | Subsistence Net Fishing (Adult) |
|---|---|---|---|
| Arsenic (inorganic) (mg/kg) | 4.8 | 0.96 | 3.0 |
| Cadmium (mg/kg) | 610 | 1300 | 4400 |
| Methylmercury (mg/kg) | 67 | 230 | 460 |
| Tributyltin-oxide (mg/kg) | 160 | 230 | 1200 |
| Carcinogenic PAHs TEQ* (µg/kg) | 900 | 320 | 680 |
| DDTs (µg/kg) | 21000 | 4300 | 13000 |
| Dioxins/Furans and Dioxin-like PCB Congeners TEQ (ng/kg) | 89 | 15 | 55 |

These calculated values are made available as a guide to understand how they compare to sediment background values (Chapter 10), PQL (Chapter 11), and other risk-based sediment concentrations when establishing sediment cleanup levels.

*****Early life exposure for cPAHs incorporated to recognize the carcinogenic and mutagenic modes of action.

.

**Table 9-4**. Recommended exposure parameters for calculating human health risk-based tissue concentrations for consumption of fish/shellfish.

| Abbrev | Parameter Name | Units | These parameters are provided for informational purposes only and represent Ecology policy only when stated. The exposure parameters presented in this table should be used at all SMS sites unless site-specific information indicates they are inappropriate. See Appendix E Section E.2.1 for more information on site-specific adjustments. |
|---|---|---|---|
| | | | **Recommended value** |
| ACR | Acceptable cancer risk | unitless | $1\times10^{-6}$ for individual carcinogens; $1\times10^{-5}$ for multiple carcinogens or exposure pathways |
| HQ | Hazard quotient | unitless | 1 |
| BW | Body weight[a] | kg | 75 weighted average (by duration) of the mean body weight of males and females combined from ages 6 to 7)(USEPA 2011, Ecology 2013b) |
| AT | Averaging time | days | Cancer: 25,550 (70 year); Noncancer: 25,550 (70 year)<br>(WAC 173-340-730 Equation 730-2, may be adjusted on a site-specific basis) |
| UCF | Unit conversion factor | g/kg | 1000 |
| $CPF_o$ | Cancer potency factor (oral) | $(mg/kg\cdot day)^{-1}$ | Chemical-specific (Source: WAC 173-340-708) |
| $RfD_o$ | Reference dose (oral) | mg/kg·day | Chemical-specific (Source: WAC 173-340-708) |
| FCR | Fish consumption rate[a] | g/day | To be established on a site-specific basis in consultation with affected tribes. For example, Ecology (2013b) includes rates for establishing the tribal adult RME scenario that include Suquamish, Tulalip and Columbia River tribal fish consumption rates. |
| FDF | Fish diet fraction | unitless (0 –1) | 1<br>May be adjusted based on site-specific data. |
| EF | Exposure frequency | day/year | 36 |
| ED | Exposure duration | year | 70 |

a, Fish consumption rates and body weights can be obtained from Ecology (2013b). See Appendix C of that document for fish/shellfish consumption rates and Appendix D for body weights.

**Table 9-5.** Human health risk-based tissue concentrations for consumption of fish/shellfish (calculated using the spreadsheets in Appendix K and the recommended exposure parameters in Table 9-3 and fish consumption rates at the 90 percentile from Ecology 2013b).

| Chemical | Suquamish Tribal Adult | Tulalip Tribal Adult | Columbia River Tribal Adult |
|---|---|---|---|
| Arsenic (inorganic) (mg/kg)[a] | 0.0001 | 0.00026 | 0.00038 |
| Cadmium (mg/kg) | 0.15 | 0.39 | 0.58 |
| Methylmercury (mg/kg) | 0.015 | 0.039 | 0.058 |
| Tributyltin (mg/kg) | 0.046 | 0.12 | 0.17 |
| Carcinogenic PAHs TEQ (µg/kg) | 0.059 | 0.15 | 0.22 |
| DDTs (µg/kg) | 0.45 | 1.1 | 1.7 |
| Dioxins/Furans and Dioxin-like PCB Congeners TEQ (ng/kg) | 0.0012 | 0.003 | 0.0044 |

These calculated values are made available as a guide to understand how they compare to tissue background values, PQL (Chapter 11), and other risk-based tissue concentrations.

a, Much of the arsenic in fish and shellfish is in the organic form, so either arsenic speciation should be conducted or a default proportion should be applied to estimate the amount of inorganic arsenic.

*This page intentionally left blank*

**Table 9-6.** Aquatic-dependent wildlife representing indicator higher trophic level receptors.

| Common Aquatic-dependent Wildlife Receptors in Freshwater and Marine Systems | Scientific Name | Dominant Food Items |
|---|---|---|
| **Birds** | | |
| Great Blue Heron | *Ardea herodias* | Fish, crustaceans, small mammals |
| Belted Kingfisher | *Ceryle alcyon* | Fish and crayfish |
| Hooded Merganser | *Mergus serrator* | Small fish and invertebrates |
| Black-necked Stilt | *Himantopus mexicanus* | Aquatic (including emergent) insects, small fish |
| American Avocet | *Recurvirostra americana* | Mostly crustaceans and insects (including emergent) |
| Spotted Sandpiper | *Actitis macularia* | Aquatic insects, mollusks, worms, crustaceans |
| Bald Eagle | *Haliaeetus leucocephalus* | Fish, fish-eating and non-fish eating birds, some mammals |
| Osprey | *Pandion haliaetus* | Fish |
| **Mammals** | | |
| North American River Otter[a] | *Lutra canadensis* | Fish predominantly; also crustaceans (crayfish) |
| American Mink[a] | *Mustela vision* | Crustaceans (crayfish), fish |
| Northern Sea Otter[b] | *Enhydra lutris* | Marine shellfish and invertebrates |
| Harbor Seal[b] | *Phoca vituluna* | Marine fish, salmon, macroinvertebrates |
| Orca Whale[b] | *Orcinus orca* | Fish, marine mammals |

a, Predominantly a freshwater species.
b, Predominantly a marine species.

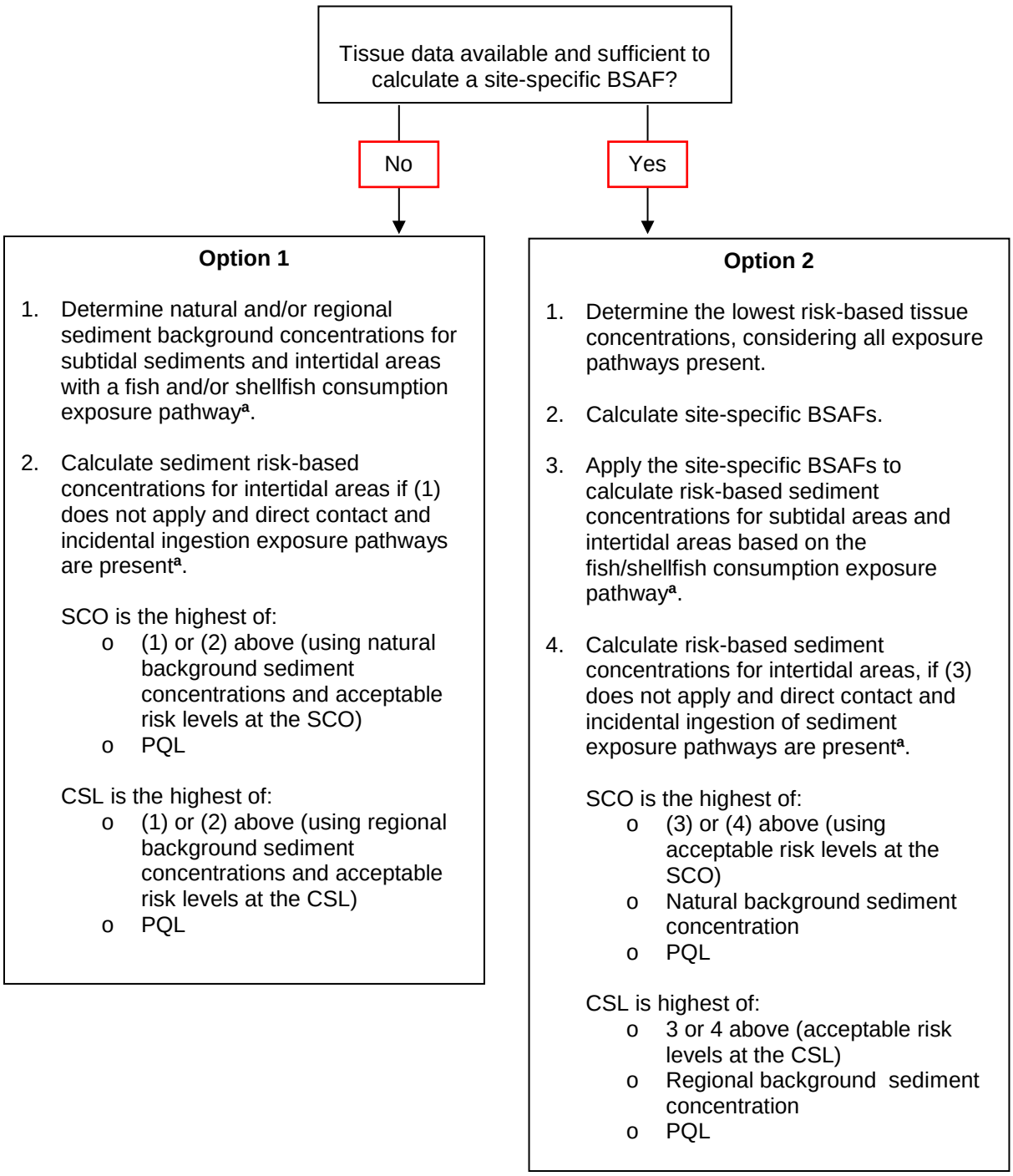



**Figure 9-2.** Development of tissue and sediment concentrations based on bioaccumulative risks to higher trophic level species and human health.

a, The assumption is that the human health or higher trophic level risk-based sediment concentrations for bioaccumulative CoCs are below the benthic criteria for the same CoC.

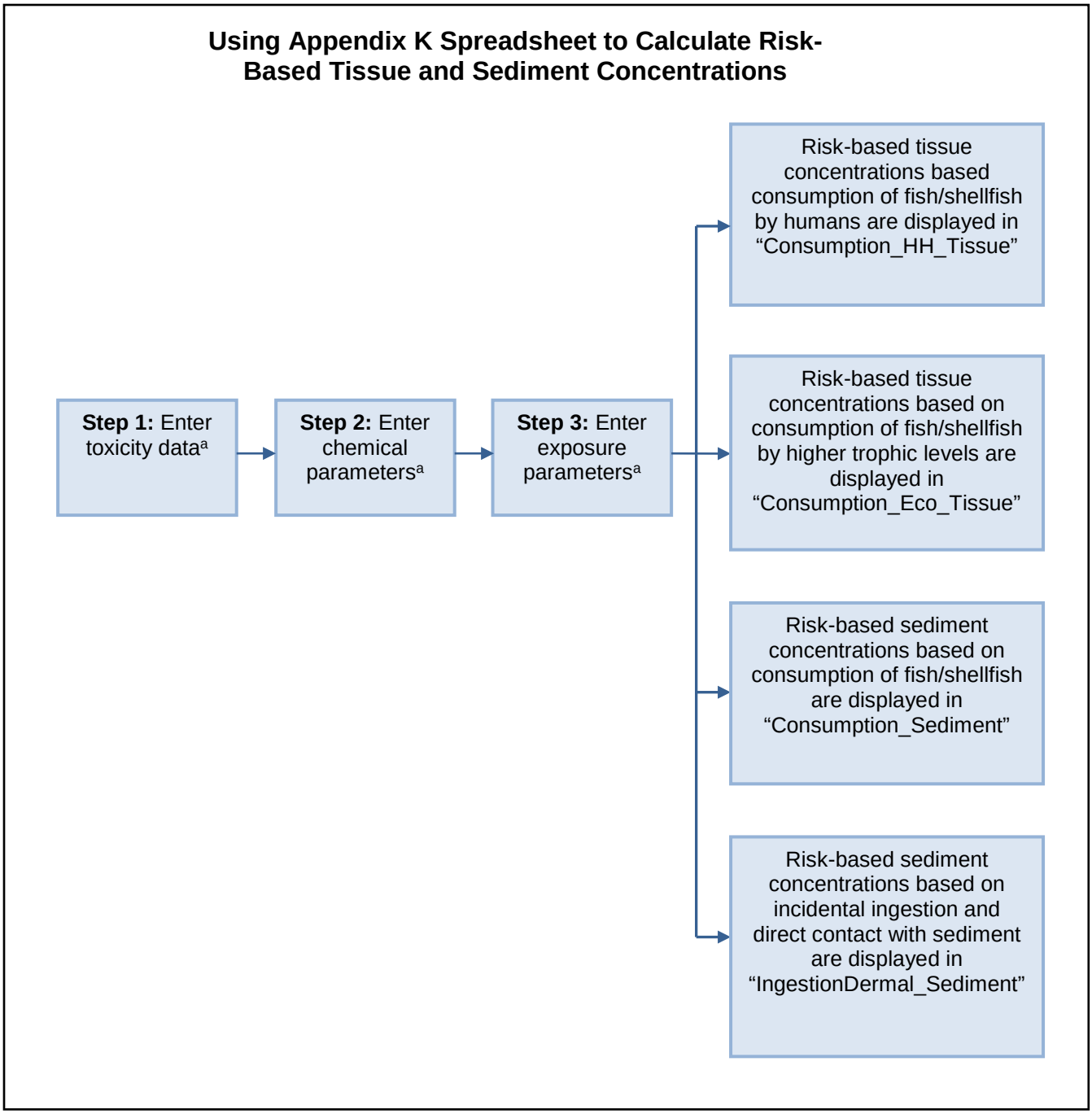



**Figure 9-3.** Directions for using the spreadsheets in Appendix K.

a, These values can be used or changed on a site-specific basis using the shaded cells in the spreadsheets in Appendix K.

*This page intentionally left blank*

# Chapter 10
# Natural and Regional Background
# WAC 173-204-505 and 173-204-560

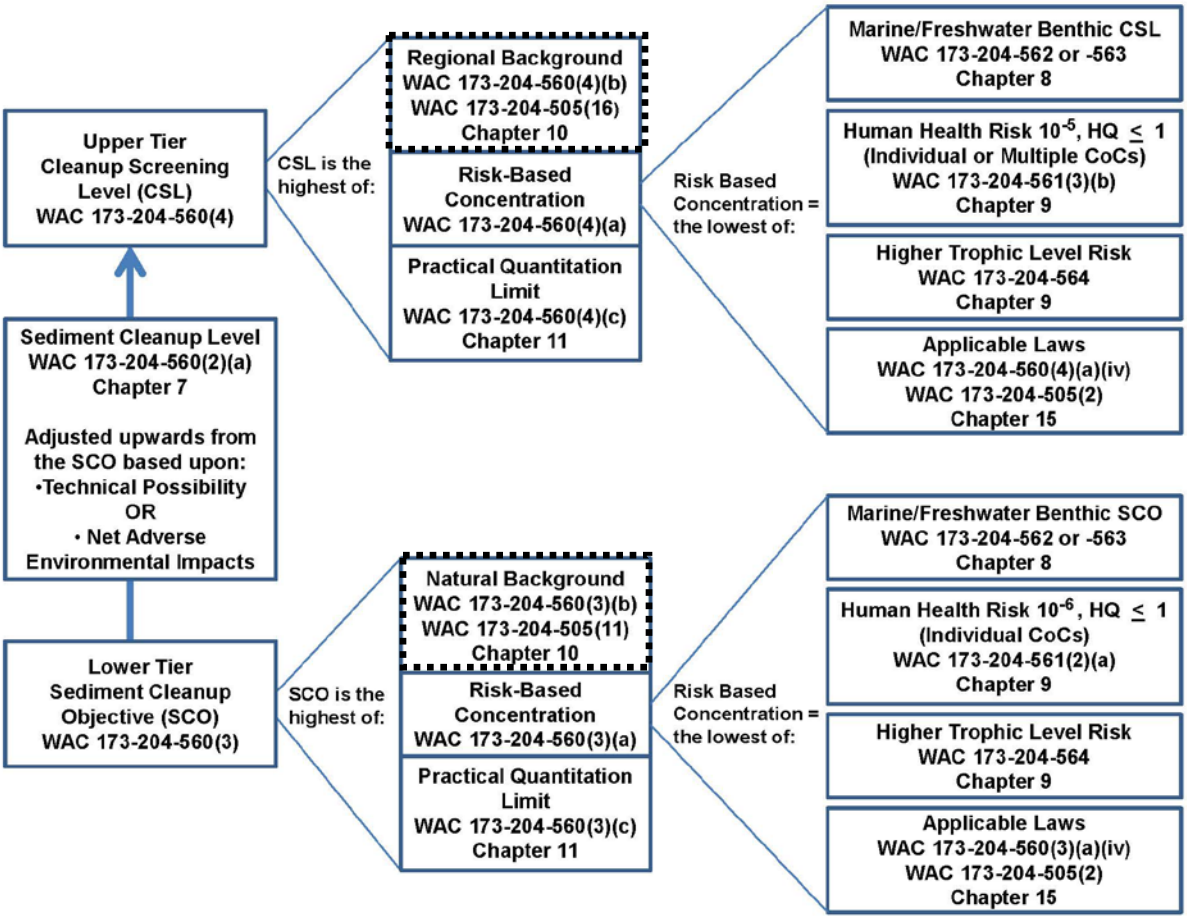



**Figure 10-1.** SMS framework for establishing sediment cleanup levels, WAC 173-204-560 (Chapter 7). Natural and regional background criteria are highlighted.

## 10.1 Introduction

This chapter presents methods for determining natural and regional background that are used throughout the cleanup process. The SMS rule allows the SCO and CSL to be established at natural and regional background, respectively, if the risk-based concentration and PQL are lower than background. The SCO and CSL are threshold or bright line values, so a background-based SCO or CSL would be treated as such. To develop cleanup levels, background sediment

concentrations will need to be established based on the processes outlined in Section 10.2, unless Ecology has already developed or approved natural or regional background concentrations for the area.

### 10.1.1 Definitions of natural and regional background

**Natural background** is defined in the SMS rule (WAC 173-204-505(11)):

> *Natural background means the concentration of a hazardous substance consistently present in the environment that has not been influenced by localized human activities. For example, several metals and radionuclides naturally occur in the bedrock, sediment, and soil of Washington state due solely to the geologic processes that formed these materials and the concentration of these hazardous substances would be considered natural background. Also, low concentrations of some particularly persistent organic compounds such as polychlorinated biphenyls (PCBs) can be found in surficial soils and sediment throughout much of the state due to global distribution of these hazardous substances. These low concentrations would be considered natural background. Similarly, concentrations of various radionuclides that are present at low concentrations throughout the state due to global distribution of fallout from bomb testing and nuclear accidents would be considered natural background.*

Below are examples of some scenarios that may contribute to natural background in sediment:

- Arsenic concentrations are widely elevated in sediment and other media in western Washington due to naturally high concentrations in the Cascade Mountains. Natural concentrations of arsenic in these media are frequently above risk-based concentrations.

- PAHs may occur due to certain natural and anthropogenic (e.g., combustion of motor vehicles) sources and can be globally distributed. Natural sources can include, but are not limited to, forest fires and natural petroleum and coal deposits.

- Atmospheric distribution of synthesized chemicals such as PCBs, dioxins/furans, pesticides, and other persistent pollutants has been documented worldwide, even in remote areas where these chemicals have never been used.

The concept of regional background is unique to the SMS rule. Regional background differs from natural background (WAC 173-204-505(11)) in that it is intended to include concentrations of chemicals that are primarily from diffuse sources such as stormwater and atmospheric deposition.

**Regional background** is defined in the SMS rule in WAC 173-204-505(16):

> *Regional background means the concentration of a contaminant within a department-defined geographic area that is primarily attributable to diffuse sources, such as atmospheric deposition or storm water, not attributable to a specific source or release.*

The concept of regional background differs from MTCA area background (WAC 173-340-200). Regional background is not intended to include the direct influence from localized, specific (identifiable) sources or releases. Regional background concentrations can include some influence from these specific sources but not the direct influence. For example, an area beyond the immediate depositional zone of an outfall may be considered for sampling to establish regional background.

The intent of regional background is to address the issue of ubiquitous chemicals that are continuously entering the environment, and:

a) Are not able to be controlled or eliminated through traditional source control programs. These are area-wide sources better addressed through larger pollution-prevention and toxics reduction initiatives. Such examples include contaminants from vessel traffic, automobiles, and contaminants in the atmosphere from diffuse, un-definable sources.

b) Are not able to be controlled or eliminated in any practicable or timely manner. Such examples include contaminants in stormwater that cannot be treated with current technology (due to the type of contaminant, load, volume of stormwater, inordinate cost) or contaminants from orphan pilings. However, sampling within the immediate depositional zone of an outfall would not be allowed to establish regional background.

## 10.1.2 How natural and regional background can be used

Once background-based concentrations are established, they are compared to risk-based concentrations and the PQL to establish the final SCO and CSL (Chapter 7). When background concentrations are discussed throughout this document, they are used as threshold or bright line values.

**Natural background can be used for the following purposes**:

- Identifying clusters of low concern that do not need further investigation or evaluation. Sediment natural background concentrations are used for this step (WAC 173-204-510 and 173-204-520; Chapter 2).

- Screening chemicals of concern at a cleanup site. Both sediment and tissue background concentrations can be used for this step (WAC 173-204-560(7); Chapter 3).

- Establishing the SCO if the natural background concentration is higher than the risk-based concentrations and PQL (WAC 173-204-560(3)(b); Chapter 7).

**Regional background can be used for the following**:

- Identifying clusters of potential concern as potential sediment cleanup sites or areas for potential further investigation and evaluation. Sediment background concentrations can be used at this step along with risk-based concentrations (WAC 173-204-510 and 173-204-520; Chapter 2).

- Establishing the CSL if the regional background concentration is higher than risk-based concentrations and PQL (WAC 173-204-560(4); Chapter 7).

- If there is no elevated regional background concentration in the area for a particular chemical or if the regional background concentration is unknown, natural background is used at the SCO level (WAC 173-204-560(5)(c)). In this case, a background-based CSL is not established.

# 10.2 Establishing Natural Background Concentrations

This section includes recommendations for establishing natural background in marine and freshwater sediment, and will be updated as new data and information becomes available.

## 10.2.1 Establishing natural background for marine sediment

Ecology has determined that a collective data set (referred to as Bold Plus) is appropriate to establish natural background for marine sediment. This Bold Plus data set includes:

1. The OSV Bold Survey (DMMP 2009) dataset. This data can be downloaded from EIM (Study ID = BOLD 2008).

2. A data set from Ecology approved reference areas. This data can be accessed in Appendix I, Appendix I: Table I-1 through Table I-3.

3. A data set from additional areas Ecology considers similar to reference areas (collectively referred to as Bold Plus). This data can be accessed in Appendix I, Tables I-1 through I-3.

Table 10-1 includes the calculated natural background values for select chemicals from the Bold Plus data set. Ecology recommends using this data to establish natural background for Puget Sound, as well as other marine areas on a case-by-case basis.

It may be appropriate to use a subset of local stations for specific areas, with sufficient scientific justification, upon approval by Ecology. The number of stations must be sufficient to provide a statistically robust estimate of the mean and upper percentiles (approximately 25 stations). Ecology will also consider new data for calculating natural background as it becomes available.

To establish the natural background-based SCO (Chapter 7) and for compliance evaluations (Chapter 13), Ecology recommends using the 90/90 Upper Tolerance Limit (90/90 UTL) calculated from the natural background population. This 90/90 UTL is also the bright-line criterion specified in Section 10.1 and can be used to determine the SCO.

### 10.2.2 Establishing natural background for freshwater sediment

To date, Ecology has not conducted studies to establish natural background for freshwater sediment. This section will be updated as background studies are completed. Some options for gathering data to establish natural background for freshwater sediment include the following, all of which must be approved by Ecology (Ecology will consider other proposals):

- Using existing data or collecting new data from reference locations.
- Using existing data from studies or sampling stations that are not directly influenced by identified sites or sources.
- Collecting new data from sampling stations that are upstream of a site and are not directly influenced by identified sites or sources.

## 10.3 Establishing regional background concentrations

This section of the guidance will be periodically updated to reflect new background work, data, and conclusions as regional background studies are completed. See Table 10-2 for more information on regional background that has been established. Regional background work conducted by other parties is encouraged by Ecology. Prior to starting any work, early engagement with Ecology is important. Ecology will decide if regional background should be established and, if so, determine appropriate requirements. Regional background may be established using several methods below, all of which must be approved by Ecology on a case-by-case basis:

- Using values derived from Ecology-led regional background studies conducted specifically for the purpose of establishing regional background for defined geographic areas (see Section 10.3.1).

- Using values derived from Ecology-led regional background studies as a surrogate for another geographic area (see Section 10.3.2).

- Using newly collected data from a geographic area using the approach outlined in Section 10.3.1.
- Using existing data from a geographic area (see Section 10.3.2)
- Using a pooled data set from similar geographic areas (see Section 10.3.2).

### 10.3.1 Ecology-led regional background studies

Ecology is engaged in efforts to establish regional background for a select number of areas around Puget Sound (Table 10-2). Below are references to case studies that are intended to be site-specific examples of how regional background is being established in select areas of Puget Sound. Ecology expects that certain areas of both marine and freshwater environments will require unique, site-specific approaches for establishing regional background, which may differ from these case studies.

- Port Gardner/Snohomish River Estuary (Ecology 2014).
- Bellingham Bay (Ecology 2015).
- North Olympic Peninsula (Ecology 2016).
- Lake Washington Area (Ecology 2017b).
- South Puget Sound (Ecology 2018).

The long-term goal is to continue establishing regional background for Puget Sound and in freshwater rivers where applicable throughout the state, while providing examples that others could use to develop background concentrations for areas not yet addressed.

The following guiding principles were incorporated into the regional background study designs for both Port Gardner and Bellingham Bay. See links above for more detailed information on the bay-specific study designs. Ecology will continue using these guiding principles, with bay or site-specific modifications where appropriate, to conduct or approve future regional background studies.

1. <u>Rationale and conceptual bay model</u>. Examination of the selected analytes and existing data to support the rationale to develop the sampling area and sampling method(s). These choices should be based on a conceptual bay model developed for the study and the key features that influenced these decisions that include:

    a. Known sites and sources
    b. Existing chemistry data

c. Existing modeling information
d. Hydrodynamic information
e. Bathymetry

2. Determining areas of primary influence. The area where sampling will occur must be consistent with the SMS definition of regional background (WAC 173-204-505(16)). This could entail sampling areas near the shoreline, sources, and sites, while remaining outside areas of direct influence. Bay- (or area-) specific information should be used where available to determine areas directly associated with depositional zones of outfalls or other point sources and areas directly affected by sites.

3. Differentiating from natural background. Existing data should be examined to identify areas that are within the range of natural background concentrations as defined in Chapter 10, Table 10-1. These areas should be excluded from sampling and calculation of regional background.

4. Differing areas of interest for different analytes. Different analytes may be elevated above natural background in different areas of the bay. For example, in Bellingham Bay, it was determined that cPAHs were elevated over a larger area than other chemicals. Therefore, a larger area of interest (AOI) was used for sampling regional background concentrations of cPAHs.

5. Sampling and sources. Regional background includes chemical concentrations in sediment from diffuse sources. Diffuse sources include such things as stormwater and air deposition that are not primarily attributable to specific sources, such as an identifiable stormwater pipe.

   To ensure that regional background does not include the direct influence from specific sources, Ecology recommends avoiding sampling within:

   a. The immediate depositional zone of any active or historical outfalls, if such a zone exists. (For example, an exclusionary buffer was added to the diffuser outfall in Bellingham Bay. Data for certain CoCs existed that did not show elevated values. However, because existing data did not include all CoCs, a 75-meter buffer was added as a conservative measure.) Existing data or models can be used to generally define the immediate depositional zone. Models have been developed (for example, in King County) that show concentrations declining within a few hundred feet of a stormwater or combined sewer overflow outfall. This range could generally be considered the immediate depositional zone for such outfalls.

b. The boundaries of established cleanup sites as follows:

i. Cleanup sites that have not undergone remediation and have not met cleanup standards.

ii. Cleanup sites that have not naturally recovered.

iii. Cleanup sites for CoCs that are of concern for regional background. For example, Bellingham Bay is a very large cleanup site for mercury. However, for the Bellingham Bay regional background study, Ecology sampled within this mercury site for other CoCs (dioxins/furans, cPAHs, etc.) since they were not identified CoCs for that site.

iv. Existing RI data can be used to define a sampling exclusion zone around existing cleanup sites. See the Bellingham Bay regional background study design for further information on how the exclusion zone can be established.

c. Areas directly influenced by active, historic, or suspected shoreline sources.

d. Dredged material disposal sites (excluded because they may be atypical of the surrounding area in terms of both grain size and chemistry).

e. Areas at or below -6 feet MLLW, for logistical sampling reasons and to avoid intertidal areas.

6. Sample independence and spatially-balanced random sampling. A representative, random, and independent set of samples spatially balanced within the background area will be the simplest and most efficient design to generate appropriate background statistics. To ensure independent results between sampling locations, a minimum distance between locations should be established. This distance will depend on the size and sediment dynamics within each regional background sampling area. Distances between 250 to 500 meters have been used in the Ecology-led regional background studies. However, smaller distances between samples may be required to achieve the desired sample size for smaller sampling areas. A spatially balanced random sample should be collected using appropriate statistical methods. Examples might include a stratified random design with one random sample per stratum in equally-sized strata, or an ArcGIS model such as the Reverse Randomized Quadrant-Recursive Raster (RRQRR) algorithm. In order to evaluate the chemical concentration distributions and estimate summary statistics with reasonable precision, Ecology recommends a minimum of 20 to 30 observations with a sufficient number of detected values to estimate the required

statistics. Therefore, laboratory DQOs should be sufficiently stringent to achieve low detection limits.

7. Chemicals of concern. The focus for regional background is on bioaccumulative chemicals but may include others as deemed appropriate. The following are typically analyzed if the CoCs are suspected to be elevated above natural background:

    a. Metals (arsenic and mercury)
    b. Carcinogenic polycyclic aromatic hydrocarbons
    c. Dioxin/furan congeners
    d. Polychlorinated biphenyl congeners
    e. Grain size
    f. Total organic carbon
    g. Total solids.

8. QA/QC. Data should undergo an independent quality assurance review and data validation at the QA2/EPA Stage 4 level in order to use the data for regulatory decisions.

9. Statistical metrics and statistical evaluations. Ecology recommends using the 90/90 UTL calculated from the regional background population to establish the regional background-based CSL (Chapter 7), assuming an appropriate distribution and level of precision. This 90/90 UTL is also the bright-line criterion specified in Section 10.1 and can be used to determine the CSL and identify potential cleanup sites (Chapters 2 and 7). In areas where there is not an elevated regional background signal, the natural background threshold concentration should be used.

### 10.3.2 Other approaches for establishing regional background

Ecology's preferred approach for establishing regional background is described in Section 10.3.1, that is, implementing a study specifically designed to collect new data for the purpose of establishing regional background following the recommendations in Section 10.3.1. However, this approach can be expensive as well as time- and labor-intensive. Ecology will consider other approaches detailed below:

- Use of regional background studies as surrogates.
- Use of newly (non-Ecology) collected data.
- Use of existing data.

#### 10.3.2.1 Use of regional background studies as surrogates

Ecology-led or approved regional background studies can be used as surrogates for another geographic area where regional background has not been established. To determine if this is appropriate, Ecology will consider if the geographic areas have similar:

1. Geologic origins to ensure that naturally occurring chemical concentrations are similar.
2. Fate and transport and biological activities.
3. Chemical signatures or concentrations.
4. Grain size, TOC, conventional chemistry, etc.
5. Physical characteristics and land use patterns, which may include:
    a. A similar degree of urbanization, e.g., if the geographic areas have similar populations.
    b. A similar degree and type of waterfront development, e.g., if the geographic areas have similar residential and industrial development.

#### 10.3.2.2 Use of newly collected data

Newly collected data can be used from the geographic area where the site(s) is located. Ecology's recommended approach detailed in Section 10.3.1 should be followed. If a person or PLP is interested in leading the development of regional background, Ecology should be consulted well ahead of developing a sampling and analysis plan to ensure that the approach is consistent with Ecology's recommendations and Ecology can approve the work.

#### 10.3.2.3 Use of existing data or pooled existing data

Existing data can be used from the geographic area where the site(s) is located or existing data can be pooled from geographic areas similar to the geographic area where the site(s) is located. If a person or PLP is interested in leading the development of regional background, Ecology should be consulted ahead of developing the proposal to ensure it can be approved.

This section includes Ecology's recommended approach to developing regional background values using existing data. This approach was developed based on the Lake Washington area effort (Ecology 2017b) and South Puget Sound (Ecology 2018) regional background studies, but Ecology recognizes that other geographic areas may warrant departures from the approach described below, based on area-specific conditions and the nature and quality of the existing

data. Similar to the approach Ecology has developed for new sampling data, this approach using may evolve over time based on public comment and experience with implementation.

#### 10.3.2.3 Similarities to developing regional background using new data

Section 10.3.1 includes details of the approach to establish regional background values using new data, consistent with the SMS rule. Many of the same steps and guiding principles should be used when calculating regional background based on existing data, for example:

- Develop a conceptual site model that guides the area from which existing sediment data will be selected. As part of the model, describe relevant features of the water body, including land use, bathymetry, hydrology, grain size, TOC, known sites and sources, and presence of bioaccumulative chemicals.

- Once the overall area of interest has been selected, exclude areas near known sites and sources with high potential to directly influence sediment concentrations. This step will require best professional judgement, but should be based generally on decreasing concentrations away from the identified source and whether values closer to the source are outliers or are in the upper tail of the distribution and appear to be a different population.

- Exclude areas that are considered natural background, have unusually high TOC, or are otherwise unrepresentative of the water body as a whole.

- Determine whether different areas of interest should be identified for different chemicals or whether different samples should be included for different chemicals.

- Ensure that the data are of acceptable quality, screening out data of unacceptable quality.

- Identify the sample independence distance and ensure that the data retained for analysis meet this criterion to avoid sample bias (especially important for existing data sets).

- Conduct an outlier analysis and remove outliers as appropriate (Section 10.3.3).

- Calculate and report precision for the final data set, screening out analytes that do not meet precision targets or screening out samples that unduly degrade precision.

- Use the 90/90 UTL to calculate regional background (but see Representativeness and Precision discussions below).

Several of these steps require modification to work with existing data sets and some additional steps are needed, discussed below.

#### 10.3.2.3 Additional or modified steps to develop regional background using existing data

The following includes additional or modified steps that may be necessary when using existing data to calculate regional background.

1. Minimum Data Requirements. Data for the area of interest may be downloaded from EIM or other available sources. The chemicals for which regional background can be calculated will depend on the availability of sufficient data once all screening steps have been completed. When calculating regional background based on new data, Ecology estimated that at least 25 samples were preferred, with an equal number of samples archived in case additional data were needed to fill in part of the distribution. However, data sets as small as the dataset used for the Lake Washington area (Ecology 2017) could be sufficient if the data were generally well behaved (symmetric and with adequate precision) and/or appeared to be representative of the regional background population of interest.

   Furthermore, the data set should:

   - Encompass the range of concentrations found in the water body away from sites and sources, to adequately define the 90/90 UTL.
   - Be of adequate quality.
   - Be geographically representative of the water body, to the degree possible.
   - Not include anomalous samples or data sets that are distinctly different from the rest of the distribution.

   It may be helpful to conduct additional statistical analyses to determine whether multiple distributions are present in the data set, since conceptually, regional background would be a single population. This may assist in determining whether certain samples should be included or excluded. Statistical evaluation of excluded data should be accompanied by a clear rationale that provides a logical explanation for why the samples are different.

   For the Lake Washington area, initially there were substantially more than 25 samples in the data set. However, distributional and precision analysis indicated that the data set contained several distinct distributions. These distributions were carefully analyzed to select data that were considered most representative of the geographic area as a whole, represented a single distribution, and had good precision. As a result, the final data set had fewer than the expected minimum number of samples, but met all of the other conceptual, regulatory, and statistical requirements for regional background and had the appropriate precision. Therefore, the recommended minimum number of samples of 25 is considered ideal, but is not a hard and fast rule as long as other requirements are met.

2. Pooling Regional Data. In cases where the data from a single water body are insufficient or unduly affected by larger sites and sources, it may be possible to pool data from

multiple areas to obtain a large enough data set to calculate regional background. The factors described in Section 10.3.2.1 should be considered in determining whether it is appropriate to pool data from adjacent areas. Regional background calculated from pooled data sets may be considered to apply to all areas from which the data were pooled, as well as such other neighboring areas as Ecology may deem appropriate. In such cases, it will be especially important to evaluate the data set to ensure that it represents a single distribution and that precision is acceptable.

3. Evaluation of Older Data. A recency cutoff for the data set should be established to ensure that the calculated regional background represents relatively current conditions, to the extent possible. A default recency cutoff for the Puget Sound region is generally considered to be 10 years, but can be modified to be somewhat more or less, depending on the availability and quality of data. Selection of the recency cutoff should include consideration of:
    - The conceptual model for the area, e.g., the sedimentation rate compared to the depth of the samples.
    - Other changes that may have occurred in the area, such as source control efforts.
    - Changes in analytical methods that may have affected the existing data values.
    - Data quality and the ability to obtain backup documentation of methods and quality assurance.
    - The results of any statistical evaluations showing breakpoints in the data set.

    In many cases, older data will be co-located with or nearby more recent data. In all such instances, the more recent data should be used unless there is a specific reason for excluding the more recent data.

4. Sample Depths. A cutoff should similarly be established for sample depth. This will depend in part on the conceptual model for the area. Samples should not be used with depths that extend well below relatively recent sediments, as determined by the sedimentation rate and the date of sampling. However, samples need not necessarily be limited to 2 to 10 cm in depth, as this may limit the amount of useable data in many areas.

5. Data Quality. Under the SMS, regional background can define the CSL, which is considered regulatory criteria. Therefore, it is important that data used to calculate regional background be of good quality. Ideally, data will have undergone QA2 review (also known as EPA Level III/IV, Chapter 5) prior to or as part of the regional background calculation. However, Ecology will use professional judgment in accepting data that have undergone QA1 review (also known as EPA Level I/II, Chapter 5) if there is no evidence of bias or concern.

6. Representativeness. Representativeness is a challenge when working with existing data, as most existing data sets were not collected with the goal of evenly characterizing general conditions in a water body. Best professional judgment will need to be used along with the conceptual model to evaluate potential biases in the data set. If those biases are substantial enough, then collection of new data may be preferable to fill important data gaps. A population separation analysis to obtain a distribution representative of regional background may be necessary.

   For example, in Lake Washington, it is generally believed that deeper sediments are finer-grained and likely serve as the ultimate sink for chemicals entering the lake. Ideally, characterization of regional background would include deeper lake samples. However, relatively recent data were limited in these areas. It is therefore possible that the existing data set is biased low in terms of characterizing the entire lake. On the other hand, using primarily shoreline samples collected closer to sites and sources could introduce unrepresentative high concentrations and increase the variability in the data set, thus increasing the 90/90 UTL. Careful screening of the data and confirming data independence were relied on to ensure that high-concentration samples and proximity to sources did not bias the data high. Similarly, unrepresentative samples at swimming beaches that were coarser and cleaner than others were clearly identified as a different population and removed. The limited number of deeper lake samples remains a concern, offset by the reality that regional background would apply to sites predominantly located at the shoreline, where the majority of the data to establish regional background were collected.

7. Data Independence. Data independence is especially important for existing data sets. Many existing data sets were designed for biased sampling of sites and sources. This presents several problems. First, the data may be biased toward areas with higher concentrations. Second, the data may be too close together and not independent of one another. Together, these challenges contribute to an overall lack of representativeness of the water body as a whole, particularly in those areas that would meet the SMS definition of regional background.

   Therefore, an evaluation of the autocorrelation distance should be conducted as described in Section 3.5 and Appendix B of the Lake Washington report (Ecology 2017). Once the autocorrelation distance is determined, it should be applied to the screened data set to further remove (or average) any samples that are too close together, minimizing the bias toward heavily sampled areas.

   Decision rules may need to be developed to determine which samples to remove. Older samples should in general be removed first. However, clusters of samples may remain

that were sampled at the same time. For the Lake Washington area data set, simulations were used to determine the effect of randomly selecting stations from clusters for removal. These simulations showed that due to the heterogeneity of the data, the specific samples retained could have a substantial effect on the 90/90 UTL. Therefore, clusters of autocorrelated samples were identified and concentrations within the same subpopulation were averaged, but kept separate from autocorrelated samples from different subpopulations. Other alternatives could be considered in areas with different data distributions.

8. Precision and Distributional Analysis. Precision is a measure of the spread of the data set. If precision is poor (% is high), the 90/90 UTL will be higher than if precision is good (% is low). Because compilations of existing data sets have been collected for varying purposes, they will likely have poorer precision than those that are synoptically collected and analyzed for a specific purpose. Therefore, it is particularly important to calculate precision for existing data sets and evaluate whether it is sufficiently low to be useable. The target Ecology has established for the purpose of establishing regional background with synoptically collected data sets is 25%. Existing data sets may or may not be able to meet this target, but it should serve as a goal to ensure that regional background values calculated for various geographic regions have a similar degree of conservativism regardless of the type of data set used.

   The various screening steps described above have a substantial effect on precision. If the decision is uncertain, it can be helpful to calculate precision throughout the process to evaluate the appropriateness of screening data. If precision is substantially improved by screening out specific data, it is likely that these data were unrepresentative of the rest of the population or introduced substantial variability into the data set.

   It may be the case, as with Lake Washington area data set, that the data set is made up of several different clearly identifiable distributions, reducing the precision and increasing the variability of the overall data set (even when none of the individual values qualifies as an outlier in the combined data set). Where this is the case, the individual distributions should be carefully evaluated for screening, both at the low and high end. The goal of this screening is to obtain a data set that is:

   - Representative of the geographic area being evaluated.
   - Consistent with the SMS definition of regional background.
   - Represents a single statistical distribution with reasonably good precision.

   If all of the above screening steps have been attempted and precision is still very high, it may be appropriate to reconsider whether the data set is usable for this purpose.

### 10.3.3 Identifying and addressing outliers

Ecology has formulated a weight of evidence approach to identify and evaluate potential outliers and determine whether they should be excluded from the calculation of regional background. The recommended steps for this approach are as follows:

1. The bay- (or area-) specific distribution should be compared to the natural background distribution, both visually for the entire distribution and with respect to the calculated 90/90 UTLs for the bay- (or area-) specific and natural background distributions. See Chapter 10, Table 10-1 for marine sediment natural background values.

2. If the bay- (or area-) specific distribution for an analyte is within the natural background distribution, the analyte and any potential outliers associated with it do not need further evaluation and may be excluded from the calculation of regional background. Alternatively, if the bay-specific distribution for an analyte appears to exceed natural background, any potential outliers within that distribution should be evaluated further.

3. A statistical analysis should be conducted on the remaining data set to identify potential statistical outliers. This analysis can include a variety of techniques such as Q-Q plots, box plots, and univariate outlier tests appropriate to the distribution. Bivariate and multivariate outlier analyses may also be performed to identify samples with different chemical fingerprints that may indicate unexpected sources, even if these samples do not have elevated individual concentrations. These analyses can include scatterplots of chemical concentrations against percent fines or total organic carbon, and Mahalanobis distance evaluations.

4. If statistical outliers are identified, those specific analytes and stations should be evaluated to determine whether they appear to be directly influenced by a current or historical source. If so, such outliers should be excluded from the calculation of regional background.

5. If an outlier is identified that does not appear to be directly impacted by a current or historical source, other factors that may explain the elevated value(s) should be considered, including:

    a. Gradients or patterns in the data set for that analyte, or lack thereof.
    b. Correlations with natural geologic factors such as grain size or TOC.
    c. Sediment transport processes.
    d. Potential gaps in the upper tail of the data distribution that could cause the appearance of an outlier.

6. If deemed necessary, the 90/90 UTL of the data set can be calculated with and without any identified outliers. If the resulting 90/90 UTL calculated values are within the range of analytical variability and not substantially different from one another, it may be appropriate to retain the elevated concentrations to calculate regional background. However, if the 90/90 UTL values are significantly affected by statistically identified outliers, the outliers should be removed from the data set.

### 10.3.4 Use of ProUCL to calculate statistics

Ecology will make a case-by-case determination whether existing data are sufficient to establish background. After this has been established, regional background data sets should be evaluated and summarized using the process in this section.

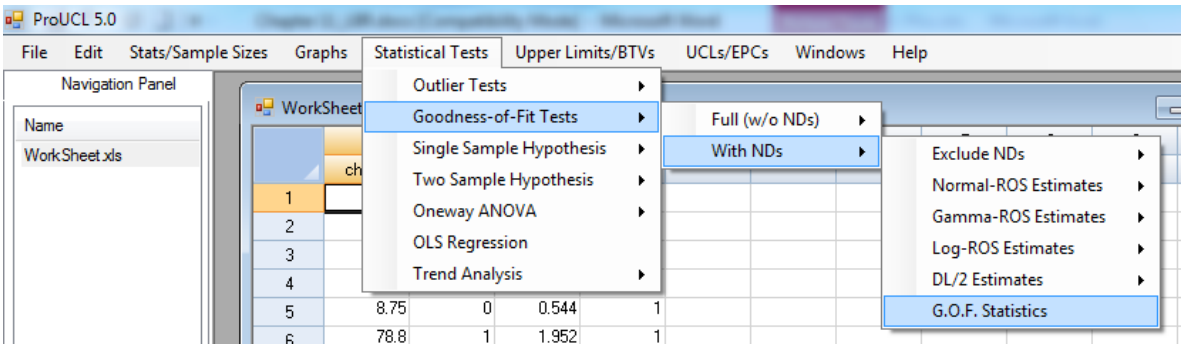
Appropriate statistical methods and software should be used to evaluate the concentration distributions, identify outliers, calculate statistics, and address non-detects as described in Chapter 6 and Appendix F. The latest version of ProUCL may be used for many of the calculations (see Section 10.3.4 for examples). However the user should be sufficiently versed in the statistical methods to appropriately interpret the ProUCL output. ProUCL users should be aware that several issues with ProUCL methods have been noted, including a) inaccurate reporting of some p-values; b) the reliance on low power goodness-of-fit tests (i.e., Lilliefors and Kolmogorov-Smirnov tests) for distributional recommendations; and c) the choice of computational algorithm for percentiles and non-parametric UTLs that results in lower values than produced by other algorithms. The Kaplan-Meier method for computing a sum may be accomplished using a) available tools such as ProUCL after transposing the dataset; b) the NADA package (Lee 2013) for R (R Core team 2014); or c) EPA's Excel TEQ calculator found here: (http://www.epa.gov/superfund/health/contaminants/dioxin/dioxinsoil.html).

For the following examples in ProUCL, selected procedures/parameters are shown in parentheses.

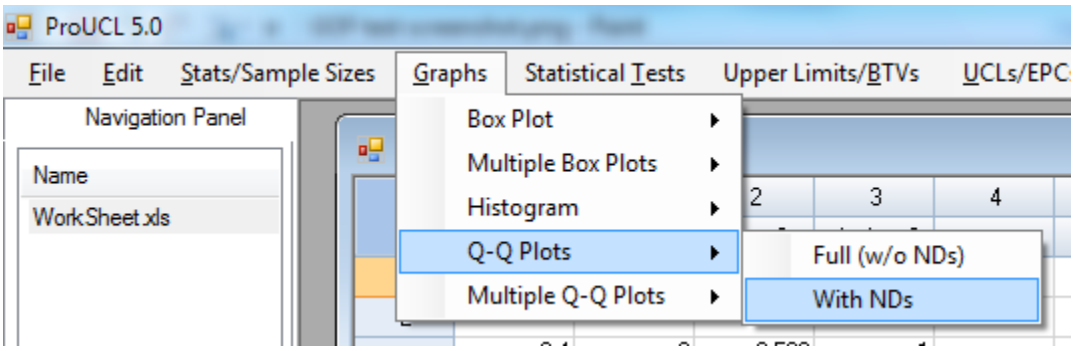
***Step a.*** Using ProUCL (or other industry-vetted statistical software such as R, SAS, SPSS, MATLAB, among others), evaluate:

i. The distributional form of the background data set(s). Use the goodness-of-fit tests within ProUCL (Statistical Tests > Goodness-of-Fit Tests > G.O.F. Statistics) in conjunction with graphical displays (Q-Q plots and histograms). These plots provide valuable information about the data distribution and can highlight if there is bi-modality in the data set and whether the left or right tail are more heavily populated than expected for one of the theoretical data distributions. Results of the goodness-of-fit tests should be based on the Shapiro-Wilks and Anderson-Darling tests rather than the low power Lilliefors and Kolmogorov-Smirnov tests. Note that the assumption of normal (lognormal) distributed data is rejected when the Shapiro-Wilks

test value is less than the critical value. By comparison, the assumption of gamma distributed data is rejected when the Anderson-Darling test value is greater than the critical value provided.

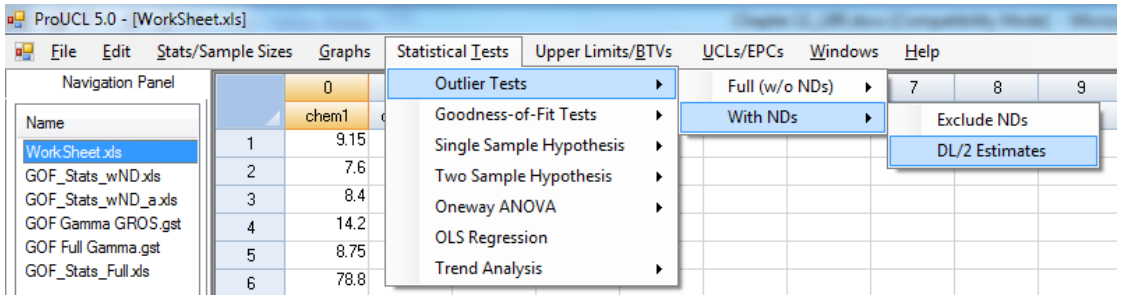



ii. Look for unusual data points or outliers. Evaluate the graphical displays (Graphs > Q–Q Plots > With non-detects (NDs), and Graphs > Box Plot > With NDs), and apply formal outlier tests where applicable (Statistical Tests > Outlier Tests). If NDs are present, the influence of the NDs on the data distribution should be considered before using the results of an outlier test. The formal outlier tests currently available in ProUCL only apply to data that follow a Normal distribution.



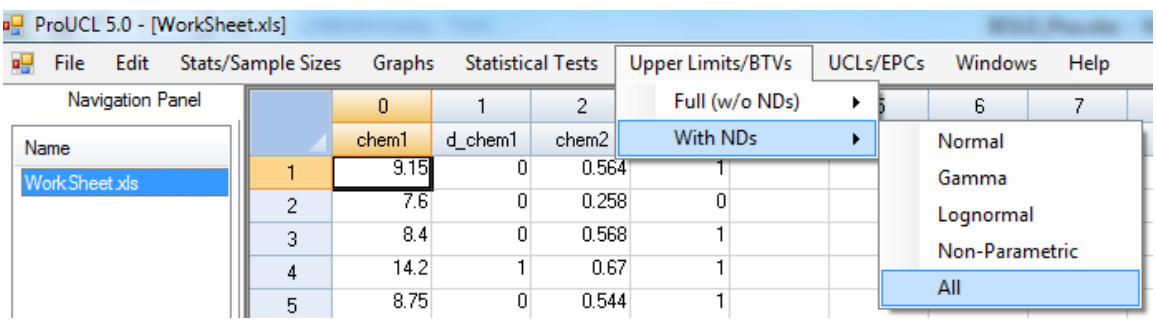

***Step b***. Any extreme values identified should be critically evaluated as they can greatly influence the background summary statistics. However, it is important to note that extreme values are simply values that do not follow the assumed (normal or lognormal) distribution. Extreme values are not intrinsically bad—they may simply represent a part of the concentration distribution that has not been adequately represented. The decision to include extreme values may be made when the value(s) are believed to be representative of the background area but sampling was insufficient to capture the full range of values. This may occur if the extreme values are within the range of other similar or comparable background data sets. The decision to exclude extreme values may be made when the value(s) are unprecedented, the suspect value(s) are from stations that may have derived

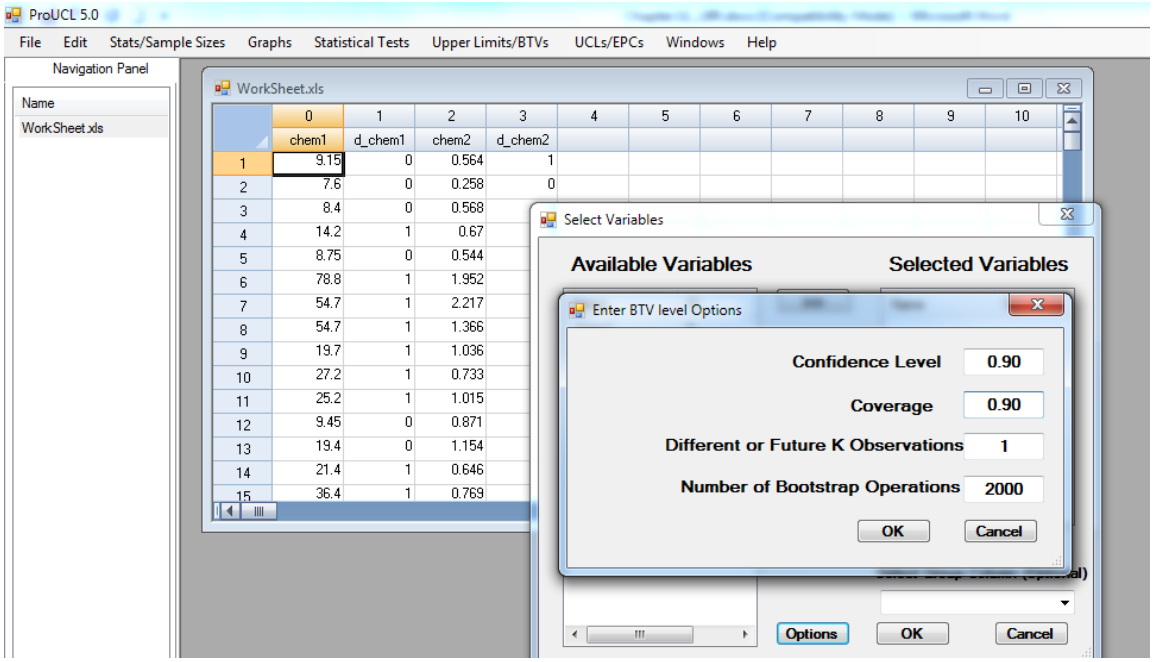
from a possible historical source, and the policy choice is to err on the conservative side (i.e., lower concentrations).




***Step c.*** For a natural or regional background data set:

i. Calculate the 90/90 upper tolerance limit (UTL) (i.e., the 90% upper confidence limit on the 90$^{th}$ percentile) using the most appropriate parametric or non-parametric option (Upper Limits/BTVs > With NDs > All; with options: Confidence Level = 0.90, Coverage = 0.90, k values = 1, bootstrap = 2000). Choose the parametric UTL based on the best fit distributional assumption (from Step a) or alternatively, one of the non-parametric UTLs.






ProUCL should only be used for data sets that represent an independent random sample from a single population. If the background data set is not a single population and/or includes spatially auto-correlated samples that are not independent, then a more involved background evaluation should be used. This might involve using stratified methods to describe population characteristics for a mixture population (e.g., when regional background is described by multiple embayments with distinct, but overlapping, chemical characteristics). If autocorrelation is present in the data, the autocorrelation range may be estimated from the data. The dataset may also be sub-sampled to include only samples that are beyond this estimated autocorrelation range. Ecology is currently evaluating options for conducting such evaluations.

**Table 10-1.** Calculated values (90/90 UTL) for marine sediment natural background from the data sets in Appendix I and Bold study (DMMP, 2009).

| Chemical | Natural Background 90/90 UTL (dry weight) |
|---|---|
| **Dioxins / Furans**[a] (ppt [ng/kg] sum TEQ) | 4 |
| **Dioxin-Like Polychlorinated Biphenyl Congeners**[b] (ppt [ng/kg] sum TEQ) | 0.2 |
| **Total Polychlorinated Biphenyl Congener**s[c] (ppt [ng/kg]) | 3500 |
| **Carcinogenic Polycyclic Aromatic Hydrocarbons**[d] (ppb [µg/kg] sum TEQ) | 21 |
| **Arsen**ic (ppm [mg/kg]) | 11 |
| **Cadmiu**m (ppm [mg/kg]) | 0.8 |
| **Chromium** (ppm [mg/kg]) | 62 |
| **Copper** (ppm [mg/kg]) | 45 |
| **Lead** (ppm [mg/kg]) | 21 |
| **Mercury** (ppm [mg/kg]) | 0.2 |
| **Nickel** (ppm [mg/kg]) | 50 |
| **Silver** (ppm [mg/kg]) | 0.24 |
| **Zinc** (ppm [mg/kg]) | 93 |

This table is intended as a guide for marine sediment natural background values. The values calculated are from Appendix I using the process recommended in this chapter.

a, Chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans congeners. See Table 6-2, Chapter 6 for the specific congeners and TEFs used. See Chapter 6, Section 6.3.4, and Appendix F for Kaplan-Meier summing.

b, See Table 6-3, Chapter 6 for the specific dioxin-like PCB congeners and TEFs used. See Chapter 6, Section 6.3.4, and Appendix F for Kaplan-Meier summing. See Section 6.3.3 and 10.1.1 for combining dioxin-like PCBs and dioxins/furans TEQs.

c, Total PCB congener sum represents the 209 congeners from the Bold study (DMMP, 2009). Ecology recommends the use of dioxin-like PCB congeners to assess bioaccumulative risks and establish cleanup levels, see Chapter 6.

d, See Table 6-1, Chapter 6 for the specific carcinogenic PAHs and TEFs used for calculations.

**.Table 10-2.** Calculated values (90/90 UTL) for marine and freshwater sediment regional background.

| Regional Background 90/90 UTL (dry weight) | | | | | | |
|---|---|---|---|---|---|---|
| **Chemical** | **Geographic Area** | | | | | |
| | **Port Gardner Bay** | **North Olympic Peninsula** | **Port Angeles** | **Bellingham Bay** | **South Puget Sound** | **Lake Washington Area** |
| **Dioxins Furans** (ppt [ng/kg] sum TEQ) | 3.9 | 5 | 5 | 15 | 19[c] | N/A[b] |
| **Dioxin-Like Polychlorinated Biphenyls** (ppt [ng/kg] sum TEQ) | 0.38 | 0.21 | 0.21 | 0.21 | N/A[b] | N/A[b] |
| **Total PCB Congeners** (ppt [ng/kg]) | | 5300 | 5300 | | N/A[b] | N/A[b] |
| **Carcinogenic Polycyclic Aromatic Hydrocarbons** (ppb [µg/kg] sum TEQ) | 56 | 31 | 64 | 86 | 78[c] | 210 |
| **Cadmium** (ppm [mg/kg]) | 0.52 | 2.4 | 2.4 | | N/A[b] | N/A[b] |
| **Mercury** (ppm [mg/kg]) | 0.14 | 0.13 | 0.13 | | N/A[b] | N/A[b] |
| **Lead** (ppm [mg/kg]) | N/A[a] | N/A[a] | N/A[a] | 16 | N/A[b] | N/A[b] |
| **Arsenic** (ppm [mg/kg]) | 12 | 14 | 14 | | N/A[b] | N/A[b] |

All footnotes in Table 10-1 apply to this table. If regional background is not established for a geographic region, or if regional background is lower than natural background for a CoC, then natural background will be used.

a, Regional background was equivalent to natural background value (Table 10-1).

b, There was insufficient data to establish regional background for this chemical.

c, South Puget Sound regional background for cPAHs and dioxins/furans apply to Budd Inlet and Shelton Harbor in Oakland Bay. For Oakland Bay outside of Shelton Harbor, regional background for dioxins/furans applies but regional background for cPAHs does not apply. Site-specific decisions will be made by Ecology for other areas in South Puget Sound as to the applicability of regional background.

# Chapter 11
# Practical Quantitation Limit-Based Sediment Cleanup Standards
# WAC 173-204-560

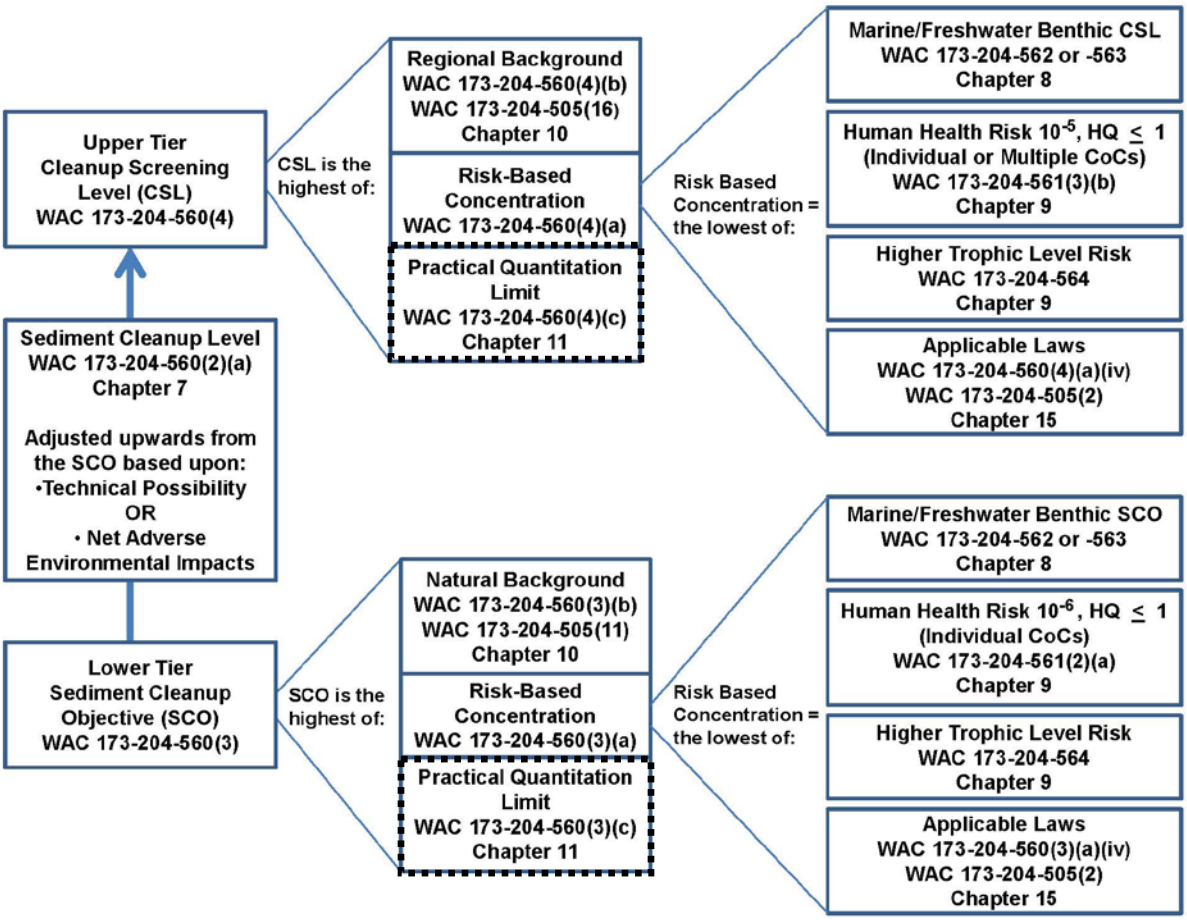



**Figure 11-1.** SMS framework for establishing sediment cleanup levels, WAC 173-204-560. PQL criteria are highlighted.

## 11.1 Introduction

The purpose of this chapter is to present the process for developing the SCO/CSL based on the practical quantitation limit (PQL). For the PQL-based SCO and CSL, the value will be the same. For cleanup, once the PQL-based SCO/CSL is established, it should be compared to other

risk-based concentrations and background to establish the final SCO and CSL (Figure 11-1, Chapter 7). Once the final SCO and CSL are established, they may become sediment cleanup levels based on the process detailed in Chapter 7.

### 11.1.1 Definition of PQL

The PQL is defined as:

> *The lowest concentration that can be reliably measured within specified limits of precision, accuracy, representativeness, completeness, and comparability during routine laboratory operating conditions, using department approved methods. When the limit for an analytical method is higher than the concentrations based on protection of human health or the environment, the department may require the use of another method to lower the practical quantitation limit.* (WAC 173-204-505(15))

In addition, where the PQL is used as a cleanup level, it must meet the more stringent of the following conditions (WAC 173-340-707(2)(a) and (b)):

- The PQL is no greater than ten times the method detection limit (MDL).
- The PQL is no greater than that established by the U.S. EPA and used to establish requirements in 40 CFR 136, 40 CFS 141-143, or 40 CFR 260-270.

Laboratories have varying definitions of reporting limits that are not necessarily consistent with the SMS definition. Ecology plans to work with local labs, and will consider new guidance that may be published by the EPA, to determine if future updates to the SMS definition are warranted.

### 11.1.2 Use of PQLs

This chapter details programmatic and site-specific approaches for establishing the PQL-based SCO/CSL (Section 11.2). However, the guidance is not intended to limit the selection of individual laboratories or PQLs during RIs, or during compliance monitoring for purposes of analysis, quality assurance, and data interpretation on a site-specific basis. Analytical PQLs used during RIs or monitoring may need to differ from the PQL-based SCO/CSLs. Below are two examples of when it may be necessary to use the lowest achievable PQL for analytical purposes:

- Compliance monitoring. Non-detects at or near background levels or PQL may result in failure to meet cleanup levels if a few stations are above background or PQL and the rest are non-detected at the PQL. The likelihood of attaining cleanup levels is greater when a lower PQL is used during laboratory analysis.

- Establishing background. If using the programmatic PQL results in less than half the samples detected, the preferred statistical approach for establishing background cannot be applied.

## 11.2 Approaches to Establishing a PQL-Based SCO/CSL

The following approach is recommended to identify, select, and apply the PQL-based SCO/CSL at sediment cleanup sites under the SMS.

### 11.2.1 Identifying current laboratory PQLs

To identify the commercially available range of PQLs from which the PQL-based SCO/CSL is established, Ecology will periodically survey Ecology-accredited laboratories for specific chemicals. Ecology will request that method-specific MDLs and PQLs be provided that represent what the laboratory can routinely achieve using each method. When conducting surveys of laboratories, Ecology will identify the lowest chemical concentration that each laboratory can reliably quantify on a method-specific basis, rather than selecting a contract-required or a sample-specific reporting limit. In general, analytical PQLs should be reviewed approximately every 5 years to ensure accuracy. See Appendix D for Ecology's latest PQL laboratory survey. This appendix will be updated as new surveys are completed.

### 11.2.2 Programmatic approach for establishing the PQL-based SCO/CSL

Ecology will review the available PQLs (Appendix D) and identify a representative value that is reasonably achievable and reliably attainable by most accredited laboratories using appropriate analytical methods. Ecology may choose to remove particularly high PQLs (e.g., that represent EPA CLP contract-required reporting limits) or particularly low PQLs (e.g., that only a few specialty or research labs can achieve) from the distribution of PQLs in Appendix D. For chemicals that Ecology identifies as having high human health or ecological risks at natural background or PQL concentrations, a more sensitive commercially available method may be used to establish the distribution of PQLs.

To select a specific PQL-based SCO/CSL, a central tendency value (median of the distribution in Appendix D with the high and low values removed if necessary) is recommended, which should be rounded to one significant digit. For compound classes that are normally reported as TEQs (e.g., dioxins/furans, coplanar PCBs, carcinogenic PAHs) the PQL-based SCO/CSL will also be reported as TEQs. See Chapter 6 for TEQ summing requirements.

As required by MTCA, the PQL-based SCO/CSL will be no more than 10 times the MDL and no higher than the EPA CLP. However, it may not always be possible in practice for the PQL to be 10x the MDL, particularly given the evolving nature of these definitions in the industry. The

lower level of quantitation (LLOQ; EPA SW-846 method) is comparable to the PQL and Ecology recognizes EPA SW-846 no longer includes MDLs (Chapter 5, Section 5.1.1.4). However, since this is a requirement in MTCA, Ecology requires MDLs to also be reported. The PQL-based SCO/CSL for such chemicals would be developed on a case-by-case basis using the latest available science. An example of the programmatic approach for setting PQLs is provided in Appendix D, Section D.6. Table 11-1 provides the calculated PQLs for compounds that have calculated natural background values (metals and bioaccumulative chemicals of concern).

### 11.2.3 Site-specific approach for selecting a PQL-based SCO/CSL

The final PQL-based SCO/CSL and sediment cleanup levels are selected at the end of the RI process and do not necessarily reflect the PQLs used during the RI for analytical purposes. Site managers may require site-specific PQLs during the RI for the purposes of laboratory selection, data analysis, quality assurance, and data evaluation. Such analytical PQLs may be higher or lower than the PQL-based sediment cleanup level, depending on the conceptual site model and other site-specific considerations.

There may be circumstances in which a site manager needs to select a site-specific PQL-based SCO/CSL that is different from the programmatic PQL-based level. For example:

- If a new method or improvement to a method comes into widespread commercial use.
- If the existing programmatic PQL-based SCO/CSL for a chemical is more than 5 years old (Appendix D).
- If a PQL-based SCO/CSL has not been developed for a chemical of concern at the site.
- If the sediment matrix at the site is sufficiently unusual to affect the achievable PQL.
- The conditions in WAC 173-340-830(2)(e) apply.

### 11.2.4 Comparison of background or risk-based concentrations to PQLs

To determine if the final SCO/CSL is based on PQLs, the site manager will determine whether the risk-based concentration and/or the natural/regional background concentrations are below the programmatic PQL (Figure 11-1, Chapter 7). These comparisons will be based on bright-line values rather than distributions. For example, natural and regional background would be established using the 90/90 UTL metric as the SCO and CSL, respectively. These are then compared to the PQL-based SCO/CSL to determine which value is higher to establish the final SCO/CSL.

## 11.3 Using the PQL-Based SCO/CSL as a Sediment Cleanup Level

The MTCA rule requires that sites at which the cleanup level was set at the PQL shall undergo periodic reviews, and that the availability of improved analytical techniques should be considered during the periodic review (WAC 173-340-707(4)).

To avoid the need for reconsideration during periodic review, a site manager may wish to set a sediment cleanup level below the PQL on a site-specific basis, if it would provide greater finality or protectiveness (e.g., based on human health risk, protection of endangered species, or background).

Site managers should carefully consider the implications of selecting a PQL-based sediment cleanup level, including the possibility that the PQL may fall below natural background or risk-based levels over time. An understanding of how decisions or actions could change if this occurs during the periodic reviews would be important to reach in cooperation with the PLP(s) prior to finalizing the Cleanup Action Plan.

Before the Cleanup Action Plan is finalized, it is important to reach an understanding with PLP(s) that decisions or actions may change if periodic reviews find that PQL levels have fallen.

Once established, PQLs are treated like any other bright-line site-specific sediment cleanup level, with the exception of the 5-year periodic review. See Chapter 13, Section 13.6 for a discussion of methods for evaluating compliance with PQL-based sediment cleanup levels

**Table 11-1.** Programmatic sediment and tissue PQLs used to establish the PQL-based SCO and CSL.

| Chemical | Sediment (dry weight) | Tissue (wet weight) |
|---|---|---|
| **Dioxins / Furans**[a] (ppt sum TEQ) | 5 | 1 |
| **Dioxin-Like Polychlorinated Biphenyl Congeners**[b] (ppt sum TEQ) | 0.7 | 1 |
| **Carcinogenic Polycyclic Aromatic Hydrocarbons**[c] (ppb sum TEQ) | 9 | 10 |
| **Arsenic** (ppm) | 0.3 | 0.5 |
| **Cadmium** (ppm) | 0.07 | 0.05 |
| **Chromium** (ppm) | 0.2 | 0.2 |
| **Copper** (ppm) | 0.1 | 0.2 |
| **Lead** (ppm) | 0.1 | 0.08 |
| **Mercury** (ppm) | 0.02 | 0.01 |
| **Nickel** (ppm) | 0.2 | 0.2 |
| **Silver** (ppm) | 0.1 | 0.06 |
| **Zinc** (ppm) | 1 | 1 |

The PQL values in this table are intended to be used as a guide for establishing the SCO and/or CSL. They represent sum TEQ PQLs calculated using the recommended approach in this chapter for the purpose of establishing sum TEQ cleanup levels. See Appendix D for individual congener data that was used to calculate the sum TEQs.

a, Chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans congeners. See Table 6-2 in Chapter 6 for the specific congeners and TEFs used for calculations.

b, See Table 6-3, Chapter 6 for the specific dioxin-like PCB congeners and TEFs used for calculations.

c, See Table 6-1, Chapter 6 for the specific carcinogenic PAHs and TEFs used for calculations.

The final programmatic PQL for each CoC listed has been rounded to one significant figure for organics and two significant figures for metals. The chemicals in this table are included if Ecology had sufficient data to calculate a programmatic PQL. See Appendix D for further detail on data used to calculate these PQLs.

# Chapter 12
# Feasibility Study, Selecting Cleanup action Alternatives, Cleanup Action Plan
# WAC 173-204-550(7), 173-204-570, 173-204-575

## 12.1 Introduction

As part of the feasibility study (FS) report, cleanup action alternatives are developed and evaluated for use at the site. This chapter describes a) the FS report and remedy selection requirements; b) alternatives and technologies available for cleanup of contaminated sediment; and c) factors that may affect the alternatives.

## 12.2 Feasibility Study Report Requirements

The FS report requirements are found in WAC 173-204-550(7) and discussed here. The report's scope of information and analysis depends on factors such as: a) the nature and extent of contamination; b) the exposure pathways of concern; c) the natural resources potentially impacted by the contamination; d) the characteristics of the site or sediment cleanup unit; and e) the types of cleanup actions being evaluated. More complex sites will require more details, while feasibility studies for simpler cleanups can be significantly streamlined. In all cases, however, sufficient information must be collected, developed, and evaluated to enable Ecology to establish sediment cleanup standards and select cleanup actions that meet the requirements of the SMS rule.

The following major components should be included in the Feasibility Study Report:

- A summary of the Remedial Investigation (RI) results. The summary should include a discussion of which contaminants have been selected as indicator chemicals and the reasons for their selection (see WAC 173-340-703).
- A summary of the results of any investigations or technology evaluations conducted after the RI report was completed.
- A description and discussion of the future uses of the property.
- Identification and evaluation of a reasonable number of cleanup action alternatives.

- Identification of eliminated cleanup action alternatives that did not meet the requirements of WAC 173-204-570.
- Documentation of the cleanup action alternative's evaluation process including:
    - The location and estimated amount of CoCs removed, treated, or confined by the alternative, and the estimated timeframe for completion.
    - The location, estimated amount, and estimated distribution of remaining CoCs above the proposed sediment cleanup levels after the alternative cleanup action is implemented.
    - Costs associated with each cleanup action alternative that meets minimum cleanup criteria.
- The proposed preferred remedy and basis for selection. This includes how the preferred remedy meets the threshold criteria requirements in WAC 173-204-570(3) for protectiveness, permanence, and long-term effectiveness (e.g., resilience to climate change impacts such as sea level rise, flooding, wildfire, and landslide; For detail on how to evaluate these impacts see Ecology 2017a).
- Applicable laws specific to the proposed preferred remedy, including a description of all permits and approvals required to implement the remedy.
- Identification of any proposed sediment recovery zones and the basis for proposal.
- The proposed monitoring plan to implement the proposed preferred remedy, including both compliance monitoring and performance monitoring—especially when monitored natural recovery is part of a selected remedy. See Chapter 13 for more detail on monitoring.
- Sufficient information to fulfill the requirements of Chapter 43.21C RCW, State Environmental Policy Act (SEPA), for the proposed preferred remedy. At a minimum, this should include a completed SEPA checklist.
- Any other information that Ecology identifies is needed. Typically this will be identified in early review comments on the RI or FS.

## 12.3 Sediment Cleanup Units and Sediment Management Areas

In order to conduct a feasibility study, it is necessary to establish the boundaries of the site or the sediment cleanup unit as well as any sediment management areas (SMAs). The boundaries of the site or sediment cleanup unit could include all areas that exceed the site-specific cleanup standards, or the CSL (for example, regional background) if it is higher (see Chapter 7). Within these site boundaries, the site may be further divided into separate areas as follows:

- Sediment cleanup units. In 2013, the SMS was revised to address management of larger sites by delineating *sediment cleanup units.* Due to the presence of ubiquitous, bioaccumulative chemicals in sediment, the size of sites can be too large to effectively clean up as one site ((WAC 173-204-500(4)(a)). If the PLPs choose to settle their responsibilities separately from the larger site, they may do so by establishing a sediment cleanup unit within the larger site. This can be done either before or after the larger site boundaries have been established.

    - A sediment cleanup unit is an area within a cleanup site that may be remediated separately from other areas of the site and/or may have different cleanup standards. A separate RI/FS may be completed for a sediment cleanup unit and cleanup may be conducted separately from the larger site.

    - WAC 173-204-505(20) defines "sediment cleanup units" as:

        > *…a discrete subdivision of a sediment site designated by the department for the purpose of expediting cleanups. A sediment cleanup unit may be established based on unique chemical concentrations or parameters, regional background, environmental, spatial, contaminant source characteristics, future site use needs such as increased draft depth etc. or other characteristics determined appropriate by the department. Examples of development related cleanups include but are not limited to cleanups under piers, cleanup in eelgrass beds and cleanup in navigational lanes.*

- Sediment management areas. SMAs are similar to sediment cleanup units in terms of how they can be delineated (discussed below). However, SMAs differ from sediment cleanup units in that they are areas within the larger site that can be managed differently in terms of the remedy and monitoring, but are treated as part of the larger site. For more detail on SMAs, see Chapter 3.

Interpretation of the rule language for sediment cleanup units is simplified and demonstrated in this chapter. The decision to divide a site into sediment cleanup units or SMAs can be based on

a) physical, chemical, and biological factors that affect the practicality and implementability of the cleanup action alternatives; b) the cost of the cleanup action alternatives; c) the environmental benefits of restoration; d) the adverse environmental impacts of active cleanup; e) the potential risks to human health and the environment; and d) future site use. Each of these factors is discussed below, followed by an example to show how these factors can be used to identify sediment cleanup units or SMAs. Sediment cleanup units and SMAs preliminarily identified in the RI may be further refined in the FS after more detailed analysis.

### 12.3.1 Physical factors

Physical factors at a site, such as structures, water depth, and sediment dynamics, may influence the range of cleanup action alternatives that are practicable and implementable.

- Structures. Areas containing structures such as piers, riprap, and bulkheads are potentially more difficult to remediate because these structures may interfere with equipment used in dredging and capping sediment. Conversely, these structures may provide physical support for nearshore fill alternatives. Underground structures such as bridge supports, sewer lines, gas lines, and communications cables can also limit dredging alternatives. Physical debris, such as logs or sunken metal debris, may need to be removed before dredging can be performed or during dredging, and may limit the choice of dredging technologies (e.g., debris, such as that found at wood waste (Ecology 2013a) cleanup sites, may make hydraulic dredging infeasible). The presence or continued use of structures should not preclude cleanup under or around them, and cleanup may require temporary or partial demolition and reconstruction, or a choice of alternate cleanup technologies for that area.

- Water depth. Water depth is also an important factor that affects the technical feasibility of certain cleanup action alternatives. For example, dredging alternatives may be limited to depths of 200 feet or less. Alternatives that include habitat mitigation may be most appropriate for intertidal or nearshore areas. Finally, navigation lanes or small ship and boat traffic passing through the site may preclude alternatives that use sediment caps due to the potential to affect the cap's integrity.

- Sediment dynamics. Another factor that should be considered when developing sediment cleanup units is the depositional or dispersive nature of the site. Dispersive or erosional environments with high-velocity currents or turbulence (either natural or created by ship traffic) are less appropriate candidates for capping than non-dispersive areas. Depositional environments may allow capping, but may also interfere with habitat mitigation by altering the shape of the shoreline or by depositing fine particles onto coarser grained substrate. Alternatively, high depositional areas may be good candidates for monitored natural recovery as a cleanup action alternative.

- Water dynamics. Similar to the erosional and depositional nature of sediments described above, wave and fluvial energy often have significant effects on both the distribution of contaminants and appropriate alternatives. The type of dredging equipment and shoreline configurations (softened, hardened or protected shorelines) should be considered. A wave/flow energy dynamic modeling approach may be necessary to determine the most effective post-cleanup site configuration. In fluvial systems, capping is often not appropriate, since water depth and current can vary greatly, causing extremes in scouring and deposition on a seasonal basis.

### 12.3.2 Chemical factors

At an otherwise uniform site, differing levels of chemical contamination may require different cleanup action alternatives. This may be particularly true when the CoCs are primarily bioaccumulatives, although other CoCs must also be considered—particularly when they co-occur. Isolated areas of high contamination may be actively remediated (possibly using treatment), while larger surrounding areas of low contamination may be allowed to recover naturally. Areas that are chosen to be actively remediated may also be based on bioaccumulative chemical concentrations associated with unacceptable risks to human health or the environment. These risks and associated cleanup standards may vary in different parts of the site, if the site is divided into sediment cleanup units or SMAs. Examples might be intertidal areas where people may be exposed directly to sediment or where sedentary organisms such as shellfish live, versus subtidal areas where exposure is primarily through ingestion of fish. Finally, the options for disposal of dredged sediment may vary depending on the level of contamination in the sediment.

### 12.3.3 Biological factors

Biological resources within the site are important considerations for identifying sediment cleanup units or SMAs. Certain habitats and biological resources such as eelgrass beds and rocky bottom habitats may be very slow to recover following an active cleanup method like dredging, or may not be completely restorable at all. In these areas, the adverse environmental impacts of cleanup may outweigh the environmental benefits. After considering environmental impacts and benefits, Ecology may decide to let these areas recover naturally, rather than impact them through active cleanup.

Other areas that might recover quickly or could be restored to their original state may be considered for active cleanup and/or habitat restoration. Additionally, those areas in which humans or aquatic life are more likely to be exposed to high levels of contaminants (therefore the risk is higher) may be remediated differently from those areas where the risk is lower. For example, areas that provide habitat for juvenile salmonid prey or areas where humans come into physical contact with sediment may require special attention.

Areas may be selected for more timely or active remediation based on the consideration of different or compounding effects. For example, a site may have three areas of concern: 1) an

area where bioassay exceedances occur; 2) a focused area exceeding acceptable risks to higher trophic levels and human health; and 3) a larger area with widespread lower level exceedances above regional or natural background. These different areas with different levels of risk may be divided into sediment cleanup units or SMAs to address these varying levels of effects. There may be greater emphasis on resolving cleanup in the short term, employing more aggressive or permanent active measures where the adverse effects are compounded, or where the risks, adverse biological effects, and/or concentrations are higher. Alternatively, measures such as enhanced or monitored natural recovery may be implemented for areas that have lower risks, adverse biological effects, and/or concentrations.

### 12.3.4 Example of identifying sediment cleanup units or sediment management areas

Figure 12-1 shows an example of a relatively complex site where it would be appropriate to divide the site into sediment cleanup units or SMAs. Sediment Cleanup Unit #1 is a nearshore area under and around a pier to which access is difficult. Sediment Cleanup Unit #2 is a navigation lane, in which capping alternatives would not be feasible. Sediment Cleanup Unit #3 is a nearshore environment with a thriving eelgrass bed, in which capping or dredging alternatives may cause significant long-term adverse environmental impacts. Sediment Cleanup Unit #4 is soft-bottom, subtidal habitat between 20 and 200 feet deep, which could be considered the baseline condition for sediment sites and does not have any special restrictions on cleanup alternatives. Sediment Cleanup Unit #5 is a shellfish bed with potential human health risk via the seafood ingestion pathway, but also through direct human contact with the sediment and ingestion of the sediment.

## 12.4 Remedy Selection Process

The remedy selection process includes:

- Identify goals of the cleanup action beyond compliance with the SMS.
- Select a range of cleanup action alternatives from the least to the most permanent alternative. See Sections 12.4.3 and 12.4.4 for further detail.
- Screen the alternatives against a set of minimum requirements, WAC 173-204-570(3), Section 12.4.2.
- Evaluate the screened alternatives based on criteria to determine their relative environmental benefits, WAC 173-204-570(4)(b) and WAC 173-340-360(3)(f), Section 12.4.4.

- Conduct a disproportionate cost analysis on the screened alternatives to determine whether a more permanent alternative is impracticable based on the relative cost – benefit considerations, WAC 173-340-360(3), Section 12.4.5.

- More complex sites will likely require evaluation of a wider range of alternatives and a disproportionate-cost analysis. However, simpler sites or cleanups can be significantly streamlined and may only require evaluation of one to a few alternatives, depending on their level of permanence and feasibility based on site-specific circumstances.

- See Appendix H that includes case studies of how the remedy selection process can work at a sediment site. The case studies address simple and complex sites, with different options for evaluating and ranking alternatives.

### 12.4.1 Cleanup expectations

Ecology expects that sediment remedies will consist of actions that will achieve cleanup standards as soon as practical to minimize impacts to aquatic organisms, habitat, and human health. Recognizing that the following expectations may not apply to all sites, Ecology expects the remedy selection process (as described in WAC 173-204-570 and this chapter) to likely yield these results:

- For sites with a limited areal extent of contamination, it is expected the remedy will focus on the use of active cleanup actions to achieve sediment cleanup standards quickly, and will minimize the need for long-term maintenance and monitoring. Active cleanup actions are those that require physical construction such as dredging, capping, treatment, and/or enhanced natural recovery.

- For sites with more wide-spread contamination, where sediment cleanup standards may not be practical to achieve using only active cleanup actions, it is expected the remedy will typically consist of active cleanup actions in areas of higher contamination. Cleanup will be followed by the use of enhanced or monitored natural recovery to achieve cleanup standards for the remainder of the site as soon as practical.

### 12.4.2 Minimum requirements

The minimum requirements that must be met for sediment cleanup actions are (WAC 173-204-570(3)):

- Protection of human health and the environment.

- Compliance with all applicable laws as defined in WAC 173-204-505(2). See Chapter 15 for more detail.

- Compliance with sediment cleanup standards established in WAC 173-204-560 through 173-204-564, including time required to attain cleanup standards.
- Use of permanent solutions to the maximum extent practicable in WAC 173-204-570(4). See Section 12.4.5 for further detail.
- A reasonable restoration timeframe with preference for alternatives that restore the site sooner in WAC 173-204-570(5). See Section 12.5 for further detail.
- Source control measures, if applicable, with preference for source control measures more effective at minimizing future accumulation of contaminants in sediment caused by discharges.
- Issuance of a sediment recovery zone if the restoration timeframe is greater than 10 years after the cleanup action's active components are constructed, per WAC 173-204-590. See Section 12.6 and Chapter 14 for more detail.
    - Cleanup actions shall not rely exclusively on monitored natural recovery or institutional controls when it is technically possible to implement a more permanent cleanup action. Where institutional controls are used, they must comply with WAC 173-340-440. The department must consider the aquatic state land use classification under Chapter 332-30 WAC when establishing such controls. Preference must be given to institutional controls with a demonstrated ability to control exposures and ensure the integrity of the cleanup action.
    - An opportunity for affected landowners and the public to review and comment must be provided.
    - Compliance monitoring to ensure the effectiveness of the cleanup action. Preference will be given to alternatives with a greater ability to monitor the effectiveness of the cleanup action.
    - Provide for periodic review to determine the effectiveness and protectiveness of the remedy. Periodic reviews are required for remedies that use a) containment, b) enhanced natural recovery, c) monitored natural recovery, d) institutional controls, e) sediment cleanup levels based on practical quantitation limits, or f) a sediment recovery zone. These reviews must follow the process and requirements specified in WAC 173-340-420.

If none of the technologies and alternatives can meet the applicable cleanup standards, then it will be considered an interim action.

### 12.4.3 Elements of a remedy

Major elements of a cleanup action for sediments typically include:

- Source control measures to reduce or eliminate ongoing releases of substances and to prevent recontamination of sediment after cleanup.
- Active cleanup actions such as dredging, capping, treatment, sequestration, confined disposal, and enhanced natural recovery.
- Natural recovery of areas of the site with relatively low levels of contamination in which active cleanup actions are not practicable, through chemical degradation and deposition of clean sediment.
- Site-use restrictions and institutional controls (such as lease restrictions or no-anchor zones).
- Maintenance and monitoring to characterize the effectiveness of source control, active cleanup, and natural recovery.

This is not an all-inclusive list. Other remedies may be used, especially as new technologies and methods are developed over time (see Section 12.8 for references).

Cleanup action alternatives for sediment cleanup are generally composed of a combination of one or more of the above cleanup technologies. These technologies are combined to form an overall cleanup action alternative for a site or sediment cleanup unit. For example, a common alternative is dredging areas of highly contaminated sediment, followed by enhanced natural recovery in areas with lower contamination.

Cleanup action alternatives should address the interrelationship of these remedy elements, particularly with respect to timing. For example:

- Site use restrictions and institutional controls should be in place by the end of the active cleanup, and should continue as long as contaminants are left onsite that pose risks to human health and the environment. Where exposures during cleanup are a concern or where a cleanup takes multiple construction seasons, it may be necessary to implement institutional controls sooner than at the end of active cleanup.
- Source control should be timed to ensure that sediments are not recontaminated above cleanup standards after active cleanup and that natural recovery can proceed.

- Sediment monitoring should continue as long as sediment remains contaminated above the site-specific cleanup standards or contamination is left in place (i.e., containment remedy).

- The cleanup action should include contingency plans that describe what corrective actions will be taken if the selected remedy does not meet key project milestones within the expected timeframe, areas within the site become recontaminated from on-site sources, or the remedy is impaired due to a natural disaster (e.g., erosion from a severe storm event). A broad evaluation of available applicable cleanup technologies should be conducted before identifying applicable cleanup technologies for the site. Site-specific conditions greatly influence the number of cleanup technologies that will be effective at a particular site. The hierarchy of technologies used to assess long-term effectiveness (Section 12.4.5.1) should be considered as a guide. Cleanup technologies may be eliminated from further consideration on the basis of technical implementability, or their environmental impact and effectiveness. In general, technologies that clearly cannot be implemented at the site or that cannot meet the cleanup standards for the site should be screened out. This screening step relies on information obtained during the RI and considers the following information:

- Natural physical or biological environment. Natural recovery may not be possible in areas that receive little or no natural sedimentation—particularly for persistent, bioaccumulative contaminants. Dredging may not be appropriate for areas with sensitive biological resources (e.g., productive shellfish beds, eelgrass beds) that would be harmed by the action, would not recover quickly, and where mitigation is not feasible. Certain types of capping may not be appropriate for intertidal areas vulnerable to sea level rise and resulting storm events with increased severity.

- Human-made physical environment. Dredging may not be possible where permanent structures cannot be practically removed or replaced. Similarly, capping is not feasible where it would impair navigation or prop wash would impact the integrity of the cap.

- Contaminant concentrations and distribution. Large volumes of low-level contamination are not as amenable to treatment or dredging as are localized areas of high-level contamination.

- Types of contaminants. A treatment method for binding one type of contaminant may increase the bioavailability or mobility of other contaminants.

Once technology screening is conducted, several different cleanup action alternatives should be assembled from the remaining technologies for each site or sediment cleanup unit, ranging from active cleanup methods (such as dredging) to passive cleanup methods (such as natural

recovery). This allows a complete evaluation and comparison of the benefits, technical practicability, and costs for a wide variety of alternatives at each area of the site.

The following sections describe technologies that have been used for cleanup actions at contaminated sediment sites. This is not intended to be a comprehensive discussion of all available technologies. New technologies are emerging as more experience is gained in sediment cleanup. Several sources to consult for a discussion of new cleanup technologies are included in Section 12.8.

#### 12.4.3.1 Source control

Source control, in combination with other cleanup technologies, is a necessary and critical part of any sediment cleanup action alternative where sources have not already been eliminated or controlled. In general, the PLP conducting a cleanup is responsible only for 1) historic sources for which they are a PLP and that contributed to the sediment contamination, and 2) ongoing sources that are within the PLP's responsibility and authority to control. The RI or FS should describe these sources, as well as other sources outside the responsibility of the PLP doing the cleanup. See Chapter 13 for information on source control monitoring. Examples of sources to be addressed include:

- Historic upland contamination (i.e., the cleanup site) and potential contaminant migration pathways to sediment such as:
    - Contaminated groundwater discharging to surface water (either directly or indirectly through storm/foundation drains).
    - Contaminated soils leaching to groundwater, which then discharges to surface water.
    - Surface water runoff discharging to surface water (either from ongoing active operations or erosion/seeps from closed areas).
    - In fluvial systems, upstream sources of contamination via downstream sediment movement, or either regulated or unregulated upstream discharges.
    - Airborne contaminants (either through wind erosion or through emissions).
- Ongoing point source discharges, permitted or unpermitted.
- Ongoing sources of spills and waste material discharges, such as refueling, bulk loading, and log rafting areas.
- Existing creosote pilings and structures.

### 12.4.3.2 Dredging and disposal

Removal of sediment from the aquatic environment is a common approach to address contaminated sediment that requires cleanup action. Removal of subtidal sediment is typically conducted with a barge-mounted clamshell dredge, while intertidal sediment can be excavated under lower-tide conditions using upland-based equipment. Removal of sediment from a riverine system is often done with shore-based backhoes fitted with extended booms that can reach out into the river, although use of a clamshell dredge may be possible in larger rivers.

One option in riverine systems is to periodically dredge locations where contaminated sediments accumulate from upstream areas. This could be a natural slack water area or a sediment trap constructed specifically to capture such sediments. This, in combination with upstream source control measures, can be an effective cleanup action at some sites.

A number of site-specific operational conditions influence the effects of environmental dredging of contaminated sediment on aquatic systems. Re-suspension of contaminated sediment generally occurs during dredging and may result in a temporary spike in tissue concentrations and temporary water quality impacts. Contaminated sediment residuals will remain following operations, which can affect the magnitude, distribution, and bioavailability of contaminants. Dredging residuals have been shown to be particularly problematic at sites with considerable debris (Patmont and Palermo 2007).

When dredging is anticipated, *residuals management strategies*, or management of sediment contamination left behind after cleanup, should be considered. Extensive experience from previous dredging projects shows that the dredging equipment selected and the method used to control the depth and location of a dredge can greatly affect the efficiency of contaminant removal. Furthermore, the historical approach of using multiple cleanup passes to address residuals may not always be effective. More recently, dredging remedies have incorporated a residuals management strategy that entails placement of a post-dredge clean cover, such as a nominal 6-inch-thick layer of clean sand.

Due to the uncertainty often associated with the depth of cut needed for full removal of contaminated material, it is appropriate and consistent with current practice to build in an uncertainty factor when estimating dredge volumes for a feasibility study. Based on a review of historical sediment cleanup projects, an uncertainty factor of 1.5 – 2 times the best estimate or "neatline" estimate of dredge volumes appears to be reasonable. Removal volume estimates should also include a 1-foot overdepth allowance. A further uncertainty factor of 1.5 to accommodate engineering design considerations, such as side slope volumes and undulating sediment surface, may also be appropriate (Palermo et al., 2008). The combination of these factors could increase the overall project uncertainty factor to 2 – 3 times "neatline" calculations. In situations where controlling volumes and costs is more critical, even more accurate estimates can be acquired through additional sampling during the engineering design study. In such cases,

however, the costs of sampling and capabilities of dredging equipment need to be weighed against the benefits of improving volume estimates.

Dredged sediments may be managed and disposed of in a variety of ways. Under the SMS, beneficial reuse is the preferred option, followed by treatment, upland disposal, and open-water disposal. Cleanup actions that involve dredging and open-water disposal of sediments should be developed and performed in coordination with the Dredged Material Management Program.

***Beneficial Reuse***

Beneficial reuse opportunities for certain types of waste or sediment occasionally exist, such as upland soil amendment or construction fill. In the case of wood waste (Ecology 2013a) and prior to its upland reuse, debris needs to be screened out, larger pieces chipped, and—for marine sediment—the salt rinsed from the material (i.e., sparged). Some sediment may have levels of contamination low enough that they could be beneficially reused as fill material in upland areas without exceeding upland cleanup standards or local regulations. However, if this is done with marine sediment, the potential impacts of saltwater on the groundwater, soils, sediment, and surface water at both the fill site and the sparge site will need to be considered. Another option may be wet-screening fines to reduce contaminant concentrations and create a clean gravel substrate for in-water habitat enhancement. Approval from local authorities may be required for beneficial reuse in upland areas.

***Ex Situ Treatment***

*Ex situ* or upland treatment options for dredged sediments are limited, particularly due to complicating factors such as salt in marine sediment, the need for dewatering, and the frequent presence of debris such as sandblast grit or wood waste (Ecology 2013a). *Ex situ* treatment of wood waste using relatively low-cost sparging technologies has been demonstrated as a method to remove salt from the material and facilitate the beneficial reuse of these materials. However, in order to be cost-effective, *ex situ* treatment by sparging requires a significant upland space available adjacent to the project site for up to 1 year while sparging is performed.

For some sediments and disposal options, dewatering or stabilizing this material using agents such as fly-ash may facilitate certain handling or confinement options. While other cleanup technologies such as thermal desorption, incineration, and stabilization could potentially be applied to contaminated sediment, such technologies are substantially more expensive than off-site landfill disposal. Many of these technologies have limited effectiveness for sediment.

***Upland Disposal***

For debris and sediments that are not suitable for open-water disposal, upland disposal at a new or existing permitted municipal or landfill may be necessary. Sediments excavated using water-based equipment could be directly loaded onto a barge or barge-truck-rail transloading facility

and shipped to a landfill. Alternatively, if space permits, an on-site offloading and staging area could be set up to process sediment and debris. The material could then be loaded onto trucks or rail cars for off-site transport and disposal.

Sediments are typically dewatered on barges before upland disposal. Where marine sediments are handled upland, the design needs to address protection of groundwater from salts and other contaminants that are draining and leaching from the dredged sediment.

***Confined Aquatic Disposal/Nearshore Fill***

Confined aquatic disposal (CAD) is the containment of sediment within a defined area in the waterbody. At Commencement Bay in Tacoma, for example, an unused waterway was isolated from the bay and used for deposition of contaminated sediment dredged from other nearby waterways. Important considerations for using a CAD are the current habitat quality in the proposed location and the final use of the land.

A nearshore fill is typically an upland area located next to the surface water where sediment can be pumped directly into settling lagoons for dewatering and ultimate disposal.

***Open-Water Disposal***

For sediment determined by the DMMP to be suitable for open-water disposal, the sediment may be transported by bottom-dump barge for disposal at an unconfined open-water disposal site. DMMP testing and suitability determinations are generally required during remedial design to verify the suitability of materials for open-water disposal, even if core sampling has previously been conducted.

#### 12.4.3.3 *In situ* treatment

*In situ* treatment entails the direct application or placement of amendments into the sediment and/or adding mixing reagents with the sediment cap substrate. This reduces the bioavailability of specified contaminants. Selection of appropriate *in situ* treatment requires evaluating available options to determine which amendments and distribution methods are likely to be most effective for reducing bioavailability of the selected CoCs residing within the site sediment. Typical applications involve the placement of activated carbon or other types of reagents that bind certain organic and/or metal contaminants. *In situ* treatment has been employed at sediment cleanup sites using one of five process options at the field pilot scale, including:

- Mechanical mixing of amendments into shallow sediment.
- Slurry placement of the amendments onto the sediment surface.
- Mixing amendments with sand, and placing the blended materials using methods similar to the containment technology discussed above, or the Enhanced MNR discussed below.

- Sequentially placing amendments under a thin sand cover.

- Broadcast application of amendments in a pelletized form to improve settling characteristics (e.g., SediMite™). The pellet matrix subsequently degrades, allowing the amendment to slowly mix into surface sediment through bioturbation.

Of the amendments available, activated carbon has received more testing and evaluation than other materials such as organoclays, particularly with respect to sediment remediation. This is because the activated carbon sorption capacities for PAHs, dioxin/furans, and other organic chemicals are at least an order of magnitude higher than other sorbents.

To determine the appropriateness of any type of amendment, impacts to aquatic resources should be considered such as:

- Potential bioavailability of carbon-sequestered contaminants to benthic infauna. While carbon sequestration may limit the bioavailability of contaminants to higher trophic levels, it may not be as effective for protection of the benthic community. The stomach acidity in some sediment ingestors or deposit feeders may be sufficient to de-sorb the contaminants in the gut, which may result in toxicity.

- Potential impacts on the bioavailability of other contaminants in the sediment matrix. Testing and monitoring should address not just the target contaminants but others that could be mobilized as a result of the treatment.

- Quality of habitat. The amendment should provide appropriate habitat for recruitment and growth of the benthic community in the long-term. -Amendments may affect suitability of the substrate for ŧ a typical benthic community through altering grain size or preventing access to organic deposits by strongly binding organic nutrients. Use of amendments should consider balancing such effects against short- or long-term effectiveness.

- Long-term impacts on the benthic community. Benthic community monitoring greater than 5 years is recommended.

*In situ* treatment as described above is an evolving science and new and potentially more effective methods may arise. If results from an emerging technology appear promising, Ecology encourages investigation on a pilot scale which should include initial field applications with enhanced monitoring.

For more information on assessing bioavailability of contaminants in sediment see Chapter 4. For more information on alternative technologies, see the references in Section 12.8.

#### 12.4.3.4 Engineered containment (capping)

Engineered containment for sediment involves placing a suitable cap to provide chemical confinement, and physically isolating contaminated material to protect the biological receptors of interest (e.g., benthic infauna, forage fish, crabs). In the aquatic environment, the cap must be designed to contain contaminants and prevent migration via porewater. It must also withstand erosive forces generated by wave action, currents, and propeller wash. It must be thick enough and have appropriate physical properties to support a productive benthic community and provide adequate isolation from the material contained by the cap.

An engineered cap will include a surface layer of material (typically 1- 3 feet thick, depending on location-specific biological requirements) that isolates deeper burrowing organisms from potentially contaminated sediment. Caps in nearshore areas should be designed to be compatible with habitat goals for the site (such as elevation and surface substrate). Aggregate caps (e.g., with a gravel surface) may potentially be appropriate for consideration in sediment areas with high potential for disturbance (such as from propeller wash or wind-generated wave forces).

Sediment caps should be constructed of clean silt/sand and/or sand and gravel materials that are selected to provide the necessary physical and hydrogeologic confinement of contaminants. A cap can be placed by a number of mechanical and hydraulic methods. Cap material can either be provided from a beneficial reuse dredging project or from an upland borrow source, such as a commercial quarry (when beneficial reuse material would not provide the appropriate grain size). Grain size requirements are determined during remedial design based on a) consideration of chemical and hydrologic confinement; and b) finishing or surface layers selected to address erosive forces (e.g., wind/wave, propeller wash); and c) habitat compatibility. These requirements would likely vary depending on elevation and location.

Cap design criteria can be found in EPA and Corps design guidance, including EPA (2005) and Palermo et al. (1998a,b). These guidance documents provide detailed procedures for cap design, cap placement operations, and monitoring of engineered caps, and have been relied upon extensively for successful cap designs at sediment cleanup sites. Caps designed according to the EPA and Corps guidance have been demonstrated to be protective of human health and the environment (EPA 2005).

#### 12.4.3.5 Enhanced monitored natural recovery

Enhanced monitored natural recovery (EMNR) involves active measures, such as the placement of a thin layer of suitable sand or sediment, to accelerate the natural recovery process. EMNR is often applied in areas where natural recovery may appear to be an appropriate remedy, yet the rate of sedimentation or other natural processes is insufficient to reduce potentially unacceptable risks within an acceptable timeframe (EPA 2005), and/or the chemicals present are persistent and not expected to degrade. The acceleration of natural recovery most often occurs due to burial and/or incorporation and mixing of the clean material into the contaminated surface sediment

through bioturbation and physical mixing processes. Other recovery processes can also be conducted, such as a) binding contaminants to organic carbon in the clean material, particularly if the material is from a clean sediment source with naturally occurring organic carbon; or b) using a geotextile fabric. Placement of such EMNR materials differs from capping because it is not designed to provide long-term isolation of contaminants. Clean sand or sediment can be placed in a relatively uniform thin layer over a contaminated area, or placed in berms or windrows that allow natural sediment transport processes to distribute the clean material over wider areas. As with MNR, EMNR includes both monitoring and contingency plan components to verify that recovery is occurring as expected, and to respond accordingly if it is not.

Ideally, EMNR sediment would be obtained from a clean beneficial reuse sediment source (typically navigational dredging) to ensure maximum compatibility with, and the quickest recovery of, the benthic community. The availability of clean material from beneficial reuse projects changes over time, and thus the availability of sources must be evaluated during remedial design. If material is only available on a limited basis each year, this may extend the implementation timeline of projects that require larger volumes of EMNR sediment.

#### 12.4.3.6 Monitored natural recovery

Natural processes fundamental to the recovery of contaminants in sediments include sedimentation and biodegradation. The monitored natural recovery (MNR) remedy relies on these processes to reduce risks to acceptable levels following source control, while monitoring recovery over time to verify success (Magar et al. 2009). The CSM (Chapter 3) depicts how specific natural recovery processes operate at the site to reduce risk, and forms the basis for evaluating natural recovery processes during remedy selection.

MNR lines of evidence can be developed from rigorous analyses of site data (e.g., laboratory and field studies, modeling, and other activities) that define the role of natural processes in reducing risk. Key factors for determining whether MNR is an appropriate remedy include the ability to achieve and sustain an acceptable level of risk reduction through natural processes within an acceptable period of time. Predicting future natural recovery rates requires site-specific inputs to models, such as the net sedimentation rate or chemical degradations rates, to quantify the processes described in the CSM. Numerical models can be used to develop estimates of recovery time using baseline data to determine likely effectiveness of MNR implementation.

Natural recovery processes operate regardless of the selected remedy. Effective sediment remedies may incorporate MNR in combination with approaches such as capping and dredging. Factors particularly favorable to selecting MNR include a) evidence that natural recovery will effectively reduce risks within an acceptable time period (such as a high sedimentation rate); b) the ability to manage risks during the recovery period; and c), (where physical isolation is important) a low potential for exposure of buried contaminants.

Under the SMS, a 10-year timeframe is normally considered acceptable for natural recovery. Where natural recovery timeframes are expected to be greater than 10 years, a technical practicability evaluation is required in the FS.

#### 12.4.3.7 Institutional controls

For any aquatic construction project such as dredging, environmental reviews are conducted by permitting agencies including the Corps, Ecology, and other resource agencies. The process involves reviewing site data and imposing requirements to manage dredged sediment appropriately and protect water quality. These requirements are incorporated into the permit and typically address those conditions and requirements that apply during the cleanup action.

However, long-term institutional controls may be necessary, depending on the preferred cleanup action alternative. These controls could include a) restrictive covenants for platted tidelands; b) use authorizations for state-owned aquatic lands; c) documenting the cleanup action in Corps and regulatory agency's permit records, as well as records maintained by the Department of Natural Resources for state-owned aquatic lands; and d) fish consumption advisories and restrictions.

Institutional controls can be effective, implementable, and cost-effective provided that the cleanup action is consistent with marine land and navigation uses and tribal fishing treaty rights. In cases where the proposed cleanup action is incompatible with tidal land use or navigation uses, conflicts can result that can jeopardize the effectiveness of institutional controls. Aquatic area use is more difficult to restrict than upland land use, since many water and shoreline uses are open to the public and cannot be easily restricted. In addition, many or most areas of Puget Sound and rivers are within Usual and Accustomed fishing or shell fishing areas for one or more tribes. Their rights to collect fish and shellfish in these areas are guaranteed by treaty.

The SMS (WAC 173-204-570(3((h)) does not allow cleanup actions at the site to rely exclusively institutional controls and monitoring. However, institutional controls may be appropriate in combination with other cleanup actions such as source control or capping.

### 12.4.4 Identifying and evaluating cleanup action alternatives

Sediment cleanup (remedial) actions may be selected for an entire sediment site, sediment cleanup units, or sediment management areas within the sediment site. Sediment cleanup actions may consist of one or more components, such as capping, source control, and monitored natural recovery. To be selected as a preferred alternative, the sediment cleanup action alternative must meet the minimum requirements listed in WAC 173-204-570(3)) and Section 12.4.2. Alternatives that do not comply with sediment cleanup standards and other applicable laws are considered interim actions. See Appendix H for case studies that show how this evaluation process can be done.

The results of this assessment should be presented in a matrix to compare the alternatives and identify the key tradeoffs among them. This evaluation serves as the basis for selecting a preferred cleanup action alternative in the FS report.

Based on the information presented in the FS report, Ecology may select one of the alternatives described or modify an alternative as necessary. Ecology's choice of preferred remedy will be documented in the cleanup action plan (CAP) with appropriate rationale.

The following is a description of the recommended process for identifying, screening and evaluating alternatives for cleaning up a site (see Appendix H for case studies):

***Step 1 - Identify Cleanup Action Goals***. Identify the goals expected to be achieved by the cleanup beyond compliance with the SMS. Example goals might be to improve public access to the shoreline or maintain the area for navigation.

***Step 2 - Identify Alternatives.*** Identify alternatives that address all areas of the site where cleanup levels have been exceeded. The alternatives must provide for protection of human health and the environment by eliminating, reducing, or otherwise controlling risks posed by all exposure pathways.

- Evaluate a reasonable number and type of alternatives. The range of alternatives for more complex sites is expected to be greater than for simple sites (see Appendix H for case studies). Take into account the characteristics and complexity of the site, including natural- and human-made constraints (from both current and future site use) that pose future risks to the remedy. ,For example, actively used in-water structures, potential impacts from climate change (e.g., sea level rise, flooding, wildfire, and landslide; For further detail on how to assess these impacts see Ecology 2017a), and potential seismic risks to the site.

- Include at least one permanent cleanup action alternative. Under MTCA, permanent cleanup actions are actions that result in attainment of cleanup standards without further action being required (such as institutional controls), other than the disposal of any treated residuals. This alternative will serve as the baseline against which other alternatives are evaluated to determine whether an alternative is permanent to the maximum extent practicable. At many sediment sites, a truly permanent cleanup action where contaminants are destroyed may not be practical. Where this is the case, include an alternative that is closest to a permanent cleanup action. An example might be complete removal and upland disposal of all contaminated sediment.

- Unless the most permanent alternative is chosen (i.e., full removal), sites (including Superfund sites) must include a *no action* alternative.

- Include alternatives that bracket a range of cleanup standards (from sediment cleanup objective to cleanup screening level), different restoration timeframes and, if necessary, different sediment recovery zones.

- Include alternatives that consist of different mixes of cleanup action components. For example:

    1. Identify one alternative that consists of dredging and upland disposal of the areas of highest sediment concentrations, coupled with capping for the remaining areas of contamination, then

    2. Identify a second alternative using the same technologies, but using a different concentration to determine where dredging ends and capping begins.

- Alternatives can also include remediation levels to define when particular cleanup action components will be used. For example, in the preceding example, the concentration determining which sediments are dredged versus which are capped would be considered a remediation level. The basis for this concentration, such as technology limits or human health risk, would need to be explained in the feasibility report. See WAC 173-340-355 for additional discussion of remediation levels.

***Step 3 - Initial Screening of alternatives.*** Where appropriate, screen alternatives to reduce the number of alternatives included in the detailed evaluation. Examples of cleanup action alternatives that could be eliminated during this initial screening process are:

- Alternatives that are inconsistent with the cleanup process expectations in WAC 173-204-500(4).

- Alternatives that clearly have a net adverse environmental impact on the aquatic environment.

- Alternatives that so clearly do not meet the minimum requirements specified in WAC 173-204-570(3) and 12.4.1 that a more detailed analysis is unnecessary.

- Alternatives for which costs are clearly disproportionate to benefits under WAC 173-340-360(4).

- Alternatives that are not technically possible to implement at the site.

***Step 4 - Detailed evaluation of alternatives.*** Next, conduct a detailed evaluation of each alternative not eliminated under Step 3. Use the criteria specified in WAC 173-204-570(3) and (4) and this procedure in the following order:

- Confirm that each alternative meets all of the minimum requirements in WAC 173-204-570(3), except the restoration timeframe and the permanent to the maximum extent practicable requirements (which are evaluated later). Eliminate alternatives that do not meet the minimum requirements.

- Estimate a restoration timeframe for each alternative and describe the basis for this estimate. Then evaluate the reasonableness of this timeframe using the criteria in WAC 173-204-570(5). When sufficient information exists, eliminate alternatives that do not provide for a reasonable restoration timeframe. In some cases it will not be possible to determine what a reasonable restoration timeframe is until the disproportionate-cost analysis has been completed. In these cases, the alternatives should be carried through the full evaluation process and the restoration timeframe and permanence evaluation conducted concurrently.

- Determine the costs and benefits of each alternative using the evaluation criteria in WAC 173-340-360(3).

- Conduct the disproportionate-cost analysis specified in WAC 173-340-360(3), Section 12.4.5. Rank the alternatives by the degree to which they are permanent to the maximum extent practicable using the criteria in WAC 173-204-570(3)(d), with specific attention to analysis of long-term effectiveness in WAC 173-204-570(4)(b).

***Step 5 - Select a Remedy.*** On the basis of the detailed evaluation in step 4, and in consideration of a) the goals established in Step 1; b) the expectations in WAC 173-204-500(4); and c) known public concerns, propose a preferred remedy.

## 12.4.5 Permanent solutions to the maximum extent practicable

WAC 173-204-570(3)(d) includes a requirement that cleanup action alternatives use permanent solutions to the maximum extent practicable. To assess the permanence of cleanup action alternatives, use the disproportionate cost analysis (DCA) process and criteria in WAC 173-340-360(3) and WAC 173-204-570(4). This analysis compares the relative benefits and costs of cleanup alternatives in selecting the alternative where the incremental costs are not disproportionate to the incremental benefits. This analysis is conducted to determine which cleanup alternative, that otherwise meets the minimum requirements, is permanent to the maximum extent practicable.

### 12.4.5.1 DCA evaluation criteria

The cleanup action alternatives that meet the minimum requirements in WAC 173-204-570(3) and subsection 12.4.2 should be further evaluated using the DCA to allow Ecology to select a preferred remedy. However, a DCA is not required if Ecology and the PLP(s) agree to

implement a permanent cleanup action regardless of cost. For simple sites, a limited DCA may be appropriate (see Appendix H Case Studies #4 and #5). This detailed evaluation relies on data collected during the RI and on the results of any field or lab-scale studies used to assess treatment technologies. These evaluation criteria should include:

- Protectiveness. The extent to which human health and the environment are protected and the degree to which overall risk at a site is reduced by eliminating, reducing, or otherwise controlling risks posed through each exposure pathway and migration route. This also includes evaluating the degree of improvement in overall environmental quality and potential risks to the integrity of the remedy from climate change impacts (For detail on how to address these impacts see Ecology 2017a).

- Permanence. The degree to which the alternative permanently reduces the toxicity, mobility, or volume of contaminants.

- Management of short-term risks, including protection of human health and the environment during construction and implementation of the alternative. Cleanup actions involving short-term risks, such as potential suspension of contaminants and water quality degradation during dredging, should include methods that minimize these risks.

- Long-term effectiveness. This includes a) the degree of certainty that the alternative will be successful; b) long-term reliability (including impacts from climate change; For detail on how to address these impacts see Ecology 2017a); c) the magnitude of residual risks to human health and aquatic life; d) effectiveness of source controls for ongoing discharges; e) management of residuals from treatment; and f) risks at a disposal site. The following hierarchy of technologies (listed in descending order), should be used *as a guide* to assess long-term effectiveness (WAC 173-204-570(4)(b)):

    1. Source control in combination with other cleanup technologies.

    2. Beneficial reuse of the sediments.

    3. Treatment to immobilize, destroy, or detoxify contaminants. This includes the reduction of risk to human health and aquatic life by making contaminants less bio-available.

    4. Dredging and disposal in an upland engineered facility that minimizes subsequent releases and exposures to contaminants.

    5. Dredging and disposal in a nearshore, in-water, confined aquatic disposal (CAD) facility.

    6. Containment of contaminated sediment in-place with an engineered cap (i.e., capping).

7. Dredging and disposal at an open water disposal site approved by Ecology.

8. Enhanced natural recovery.

9. Monitored natural recovery.

10. Institutional controls and monitoring.

This hierarchy reflects current technologies that have a long implementation history, proven applicability, and appropriateness for sediment cleanup. Depending on site-specific circumstances, Ecology will consider new technologies as they become available and determine how they should be placed in the above hierarchy.

This hierarchy is to be used as a guide only and may be modified depending on site-specific circumstances. For example, shoreline configurations, seismic stability, or land use restrictions might make a site unsuitable for dredging and contained disposal (i.e., upland engineered facility or CAD technologies #4 and #5, above). In this case, technologies #6 through #10 would rank above others in the hierarchy.

- Implementability. Ability to implement the remedy by measuring the relative difficulty and uncertainty of implementing the cleanup action. This includes: a) the potential for landowner cooperation; b) technical possibility; c) availability of disposal facilities; d) required services and materials; e) administrative and regulatory requirements such as permitting; f) schedule; g) monitoring requirements; h) access needs; i) operation and maintenance; and j) integration with existing facility operations and other current or potential cleanup actions. Engineering design considerations are often of primary importance for this criterion, which is refined during the development of the engineering design report (EDR). For example, complete removal next to a bulkhead may not be technically feasible due to the potential for bulkhead collapse, therefore partial removal along with temporary tiebacks and partial cap might be evaluated instead and engineered in the EDR.

- Consideration of Public Concerns. The degree to which community concerns are addressed.

- Cost. This includes consideration of all costs associated with implementing an alternative, including a) design; b) construction; c) present and future direct and indirect capital; d) long term operation, maintenance, and monitoring; and e) other foreseeable costs. Costs, along with benefits, are used to conduct the disproportionate cost analysis.

#### 12.4.5.2 Disproportionate-cost analysis

While costs can typically be quantified, the evaluation of benefits is both quantitative and qualitative. Costs are considered disproportionate to the benefits if the incremental costs of a

more permanent alternative substantially exceed the incremental degree of benefits achieved by a lower cost alternative, WAC 173-340-360(3)(e)(i).

The evaluation of benefits relative to cost may be quantitative, based on available data such as the estimated acreage or volume of contaminants removed or contained. However, Ecology's analysis of which alternative is permanent to the maximum extent practicable is largely qualitative. It is based on best professional judgment of the importance of each evaluation criterion listed above. Where two or more alternatives are equal in benefits, Ecology must select the less costly alternative WAC 173-340-360(3)(e)(ii)(C).

The DCA should be documented in the FS. When conducting the DCA for a site that has both an upland and sediment cleanup unit, the DCA should be performed separately for each. This is important because the upland unit may inappropriately influence the outcome of the sediment cleanup unit, resulting in a preferred remedy that is not permanent to the maximum extent practicable for the sediment cleanup unit. See Appendix H for case studies on how to conduct DCAs for simple and complex sites.

#### 12.4.5.3 Ranking alternatives

Alternatives should be ranked from most to least permanent, and compared to the cleanup alternative that provides the greatest degree of permanence (i.e., the baseline alternative), WAC 173-340-360(3)(e)(ii).

It is important to quantify as many elements of the alternatives as possible because it will help support the analysis and provide the basis for the assigned ranking. Examples of quantified elements might include:

- The mass of contaminants treated or removed, and the mass remaining after cleanup.
- The volume of contaminated material treated or removed, and the volume remaining on the site after cleanup.
- The maximum concentrations of contaminants treated or removed, and the maximum concentrations remaining after cleanup.
- The amount of reduction in risks to human and environmental health.
- The reduction of risks to human and environmental health in both the short and long-term.
- The acres of habitat restored.
- The acres of sediment restored to levels protective of aquatic life.

- The area of the site capped, including any enhancements (such as carbon amendments) used to sequester contaminants to limit their bioavailability.
- The area of the site designated for monitored natural recovery.

## 12.5 Reasonable Restoration Timeframe

The cleanup action decision must include the selection of a reasonable timeframe within which the cleanup action must be completed. Cleanup action alternatives must achieve sediment cleanup standards as quickly as feasible. Alternatives that achieve cleanup standards within 10 years of completion of construction of the active components of the cleanup are presumed to have a reasonable restoration timeframe. To further determine if a cleanup action alternative has a reasonable restoration time period, the following should be considered (WAC 173-204-570(5)) and should be documented in the feasibility study:

- The time required for the cleanup action to achieve cleanup standards, with a preference for alternatives that achieve cleanup standards sooner.
- Potential or actual risks posed by the site to human health or the environment.
- Practicability of achieving the cleanup standards in less than a 10-year period.
- Current and potential uses of the site, surrounding areas, and associated resources that are, or may be affected by, residual contamination at the site.
- The aquatic land use classification for state-owned aquatic lands.
- The likely effectiveness of source control measures to achieve cleanup standards and compliance timeframe for planned source control actions.
- The likely effectiveness and reliability of institutional controls.
- The degree of contamination at the site.
- The ability to control and monitor migration of contamination from the site.
- The degree that natural recovery processes will reduce contamination at the site.

Although a 10-year timeframe or less is preferred under the SMS, Ecology may authorize natural recovery timeframes that exceed 10 years if it is not practicable to accomplish cleanup actions within this amount of time. If this is the case, a sediment recovery zone is required.

## 12.6 Sediment Recovery Zones

The cleanup action alternatives may include establishing a sediment recovery zone (SRZ; see Chapter 14) if active cleanup actions require a restoration timeframe longer than 10 years after completion of construction of the cleanup action's active components. If an SRZ is part of a cleanup action alternative, the following additional criteria must be addressed as part of the FS:

- The time period during which an SRZ is estimated to be needed, based on an analysis of source loading and environmental recovery processes.
- The legal location and ownership of property proposed as a SRZ.
- Operational terms and conditions are required, such as chemical and/or biological monitoring for the discharge effluent, the receiving water column, and sediment (see Chapter 13 for monitoring requirements).
- Potential risks posed by the proposed SRZ to human health and the environment.
- The technical practicability of eliminating or reducing the size, degree of contamination, and/or degree of biological effects within the proposed SRZ.
- Current and potential uses of the SRZ, surrounding areas, and associated resources that may be affected by releases within or from the proposed SRZ.
- The need for institutional controls or site-use restrictions to reduce risks to human health from the proposed SRZ.

## 12.7 Cleanup Action Plan

After the RI/FS reports are completed, Ecology will use the reports and any other appropriate information, to prepare the cleanup action plan consistent with the requirements in WAC 173-340-380. The cleanup action plan will document Ecology's cleanup decisions for the site, which will be incorporated into the consent decree or other appropriate legal document under Chapter 70.105D. The process will involve:

- Development of a draft cleanup action plan that contains the following:
    - A general description of the proposed cleanup action alternative.
    - A summary of the rationale for selecting the proposed cleanup action alternative.
    - A brief summary of other cleanup action alternatives evaluated in the RI/FS reports.

  - Cleanup standards for each contaminant at the site and sediment cleanup unit.
  - The schedule for implementing the cleanup action plan including, if known, the restoration timeframe.
  - Institutional controls required as part of the proposed cleanup action alternative.
  - Applicable state and federal laws for the proposed cleanup action alternative.
  - A preliminary determination by Ecology that the proposed cleanup action will comply with WAC 173-340-360 and 173-204-575.
  - Where the cleanup action involves on-site containment, include a) a specification of the types, levels, and amounts of contaminants remaining on site; and b) the measures that will be used to prevent migration and contact with those substances.

- Public involvement consistent with the requirements in WAC 173-204-575(5) that includes a public review opportunity for the public to comment on the cleanup decision.
- Development of the final cleanup action plan, which will be published in the Site Register and will include consideration of all comments received during the public review period.

## 12.8 References for Alternative Technologies


- Beesley, L.; Moreno-Jimenez, E.; Gomez-Eyles, J. L. Effects of biochar and greenwaste compost amendments on mobility, bioavailability and toxicity of inorganic and organic contaminants in a multi-element polluted soil. *Environmental Pollution.* 2010, 158, 2282– 2287.

- Cho, Y.; Smithenry, D. W.; Ghosh, U.; Kennedy, A. J.; Millward, R. N.; Bridges, T. S.; Luthy, R. G. Field methods for amending marine sediment with activated carbon and assessing treatment effectiveness *Marine Environmental Research.* 2007, 64, 541– 549.

- Cho, Y.; Ghosh, U.; Kennedy, A. J.; Grossman, A.; Ray, G.; Tomaszewski, J. E.; Smithenry, D.; Bridges, T. S.; Luthy, R. G. Field application of activated carbon amendment for in-situ stabilization of polychlorinated biphenyls in marine sediment. *Environmental Science and Technology.* 2009, 43, 3815– 3823.

- Cornelissen, G.; Breedveld, G. D.; Christanis, K.; Kalaitzidis, S.; Kibsgaard, A.; Oen, A. M. P. Strong sorption of native PAHs to pyrogenic and unburned carbonaceous geosorbents in sediments. *Environmental Science and Technology.*2006, 40, 1197– 1203.

- Cornelissen, G.; Breedveld, G. D.; Oen, A. M. P.; Næs, K.; Ruus, A. Bioaccumulation of native PAHs from sediment by a polychaete and a gastropod: Freely dissolved concentrations and activated carbon amendment. *Environmental Toxicology and Chemistry*.2006, 25, 2349– 2355.

- Cornelissen, G.; Gustafsson, O.; Bucheli, T. D.; Jonker, M. T. O.; Koelmans, A. A.; van Noort, P. C. M. Extensive sorption of organic compounds to black carbon, coal, and kerogen in sediments and soils: Mechanisms and consequences for distribution, bioaccumulation, and biodegradation. Critical Review. *Environmental Science and Technology.* 2005, 39, 6881– 6895.

- Ehlers, L. J.; Luthy, R. G. Contaminant bioavailability in soil and sediment *Environmental Science and Technology.* 2003, 37, 295A– 302A.

- Fagervold, S. K.; Chai, Y.; Davis, J. W.; Wilken, M.; Ghosh, U. Bioaccumulation of polychlorinated dibenzo-p-dioxins/dibenzofurans in *E. fetida* from floodplain soils and the effect of activated carbon amendment. *Environmental Science and Technology.* 2010, 44, 5546– 5552.

- Fitzmorris, K. B.; Lima, I. M.; Marshall, W. E.; Reimers, R. S. Anion and cation leaching or desorption from activated carbons from municipal sludge and poultry manure as affected by pH. *Water Environ. Res.* 2006, 88, 2324– 2329.

- Ghosh, U. Rational selection of tailored amendment mixtures and composites for *In Situ* Remediation of Contaminated Sediments (SERDP Project # ER 1491), Final Report submitted to Strategic Environmental Research and Development Program, U.S. Department of Defense. 2008. Retrieved from: http://docs.serdp-estcp.org/index.cfm

- Ghosh, U.; Luthy, R. G.; Gillette, J. S.; Zare, R. N. Microscale location, characterization, and association of polycyclic aromatic hydrocarbons on harbor sediment particles. *Environmental Science and Technology.* 2000, 34, 1729– 1736.

- Janssen, E. M. L.; Croteau, M. N.; Luoma, S. N.; Luthy, R. G. Measurement and modeling of polychlorinated biphenyl bioaccumulation from sediment for *Neanthes arenaceodentata* and response to sorbent amendment. *Environmental Science and Technology.* 2010, 44, 2857– 2863.

- Jonker, M. T. O.; Suijkerbuijk, M. P. W.; Schmitt, H.; Sinnige, T. L. Ecotoxicological effects of activated carbon addition to sediments. *Environmental Science and Technology.* 2009, 43, 5959– 5966.

- Kim, E.; Seyfferth, A. L.; Fendorf, S.; Luthy, R. G. Immobilization of Hg(II) in water with polysulfide-rubber (PSR) polymer-coated activated carbon *Water Resources.* 2011, 45, 453– 460.

- Kwon, S.; Thomas, J. W.; Reed, B. E.; Levine, L.; Magar, V. S.; Ghosh, U. Evaluation of sorbent amendments for *in situ* remediation of metal contaminated sediments. *Environmental Toxicology and Chemistry*. 2010, 29, 1883– 1892.

- Lehmann, J. A handful of carbon. *Nature.* 2007, 447, 143– 144.

- Luthy, R. G.; Aiken, G. R.; Brusseau, M. L.; Cunningham, S. D.; Gschwend, P. M.; Pignatello, J. J.; Reinhard, M.; Traina, S. J.; Weber, W. J., Jr.; Westall, J. C. Sequestration of hydrophobic organic contaminants by geosorbents. *Environmental Science and Technology*. 1997, 31, 3341– 3347.

- Marris, E. Putting the carbon back: Black is the new green. *Nature.* 2006, 442, 624– 626.

- McLeod, P. B.; Luoma, S. N.; Luthy, R. G. Biodynamic modeling of PCB uptake by *Macoma balthica* and *Corbicula fluminea* from sediment amended with activated carbon. *Environmental Science and Technology.* 2008, 42, 484– 490.

- McLeod, P. B.; Van Den Heuvel-Greve, M. J.; Allen-King, R. M.; Luoma, S. N.; Luthy, R. G. Effects of particulate carbonaceous matter on the bioavailability of benzo[a]pyrene and 2,2′,5,5′-tetrachlorobiphenyl to the clam, *Macoma balthica*. *Environmental Science and Technology.* 2004, 38, 4549– 4556.

- McLeod, P. B.; van den Heuvel-Greve, M. J.; Luoma, S. N.; Luthy, R. G. Biological uptake of polychlorinated biphenyls by *Macoma balthica* from sediment amended with activated carbon. *Environmental Toxicology and Chemistry.* 2007, 26, 980– 987.

- Millward, R. N.; Bridges, T. S.; Ghosh, U; Luthy, R. G.; Zimmerman, J. R. Addition of activated carbon to sediments to reduce PCB bioaccumulation by the polychaete, *Neanthes arenaceodentata*, and the amphipod, *Leptocheirus plumulosus.* *Environmental Science and Technology*. 2005, 39, 2880– 2887.

- National Research Council. *Sediment Dredging at Superfund Megasites: Assessing the Effectiveness*. The National Academies Press: Washington, DC, 2007.

- National Research Council. *Bioavailability of Contaminants in Soils and Sediments*. National Academies Press: Washington, DC, 2003.

- Sun, X.; Ghosh, U. PCB bioavailability control in *Lumbriculus variegatus* through different modes of activated carbon addition to sediments. *Environmental Science and Technology*. 2007, 41, 4774– 4780.

- Sun, X.; Ghosh., U. The effect of activated carbon on partitioning, desorption, and biouptake of native PCBs in four freshwater sediments. *Environmental Toxicology and Chemistry*. 2008, 27, 2287– 2295.

- Sun, X.; Werner, D.; Ghosh, U. Modeling PCB mass transfer and bioaccumulation in a freshwater oligochaete before and after amendment of sediment with activated carbon. *Environmental Science and Technology*. 2009, 43, 1115– 1121.

- Tomaszewski, J. T.; Werner, D.; Luthy, R. G. Activated carbon amendment as a treatment for residual DDT in sediment from a superfund site in San Francisco Bay, Richmond, California, USA. *Environmental Toxicology and Chemistry*. 2007, 26, 2143–2150.

- USEPA. *EPA proposes comprehensive plan to clean up Hudson River PCBs*. USEPA, Dec 6, 2000.

- USEPA. *EPA's Contaminated Sediment Management Strategy*. EPA-823-R-98-001; Office of Water. April 1998.

- USEPA. Superfund and Green Remediation. Retrieved from: http://www.epa.gov/superfund/greenremediation/

- Werner, D.; Ghosh, U.; Luthy, R. G. Modeling polychlorinated biphenyl mass transfer after amendment of contaminated sediment with activated carbon. *Environmental Science and Technology*. 2006, 40, 4211– 4218.
- Werner, D; Hale, S. E.; Kwon, S.; Ghosh, U.; Luthy, R. G. Polychlorinated biphenyl sorption and availability in field-contaminated sediments. *Environmental Science and Technology*. 2010, 44, 2809– 2815.

- Zimmerman, J. R.; Werner, D; Ghosh, U.; Millward, R. N.; Bridges, T. S.; Luthy, R. G. The effects of dose and particle size on activated carbon treatment to sequester PCBs and PAHs in marine sediments. *Environmental Toxicology and Chemistry*. 2004, 24, 1594–1601.

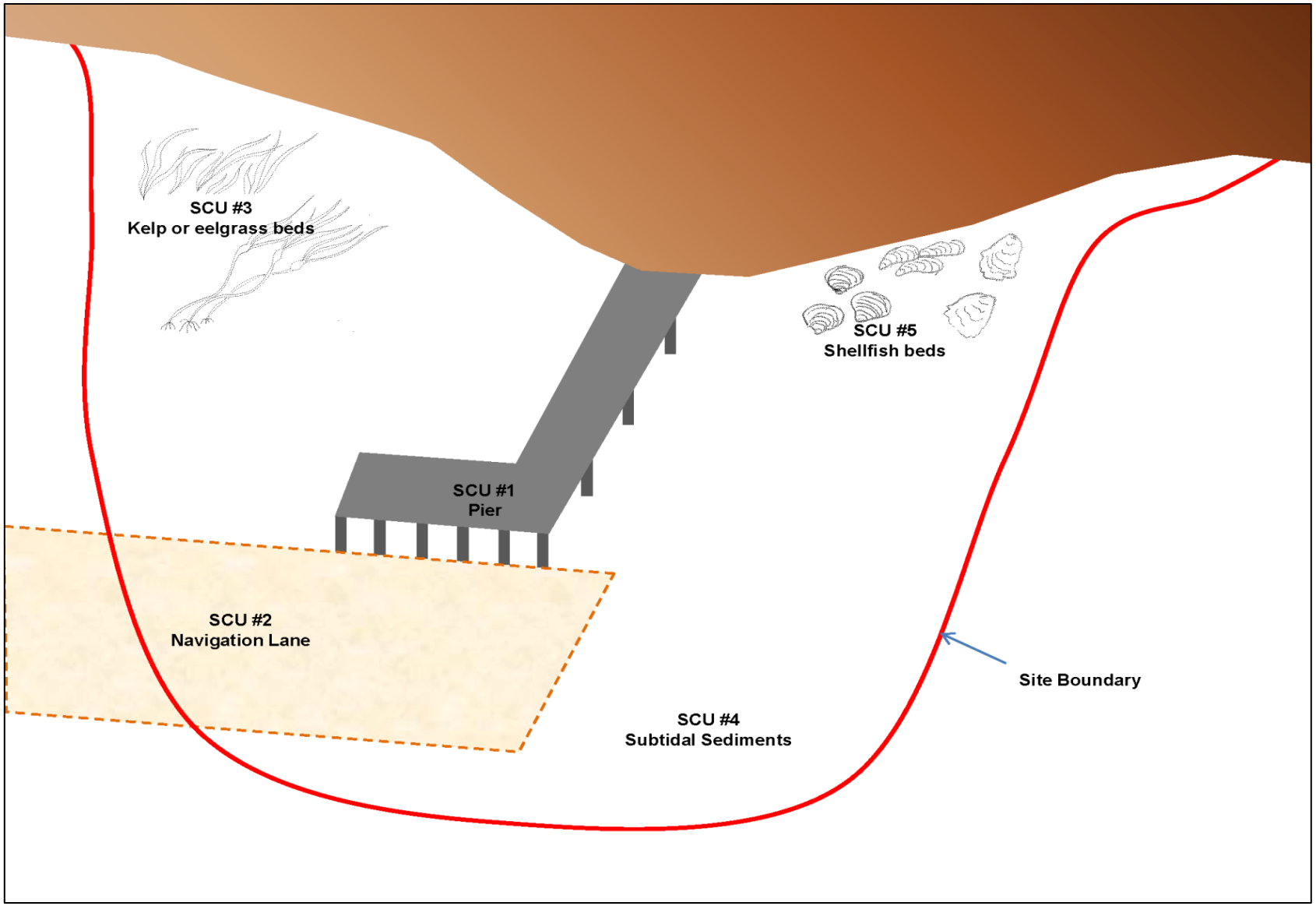



**Figure 12-1.** Example of sediment cleanup units or sediment management areas**.**

*This page left intentionally blank.*

# Chapter 13
# Monitoring and Compliance with Sediment Cleanup Standards
# WAC 173-204-560

## 13.0 Introduction

At this point in the process, site-specific cleanup standards have been established (Chapters 7-11) and remedies have been selected for the site and finalized in a CAP (Chapter 12). This chapter presents information about a) how to develop an appropriate monitoring program; b) the different types and typical elements of monitoring that depend on site-specific conditions; and c) the methods for determining compliance with the site-specific sediment cleanup standards in both the short- and long-term.

The monitoring plan should be tailored to the size and complexity of the site. It should include only the amount of monitoring necessary to achieve specified objectives, which should also include the process to determine compliance with cleanup standards. The objectives of various types of monitoring are described in Section 13.1. Not all of these types of monitoring will be needed at all sites. The RI/FS should be used to focus the monitoring plan on the areas and relevant CoCs for each phase of cleanup, and the plan can be adjusted over time as conditions warrant.

## 13.1 Monitoring Objectives

PLPs may need to conduct several types of monitoring during and after cleanup. Not all types of monitoring will be needed at every site, and they will depend on the nature of the site and the types of cleanup actions being conducted. Each element of monitoring should correspond to specific objectives, examples for which are described below.

All monitoring should be described in detail in a Monitoring Plan associated with the final Consent Decree or Administrative Order. The plan should include clear objectives and metrics for each monitoring element, and contingency actions if the monitoring shows the objectives are not met. If the restoration timeframe to attain the site-specific cleanup standards is expected to be more than 10 years, an SRZ should be issued along with the Consent Decree (see Chapter 14). Similarly, if the restoration timeframe was expected to be less than 10 years, but long-term monitoring shows that it might need more than 10 years, an SRZ may need to be issued at a later date. Regardless, compliance monitoring—immediately after construction and/or ongoing over

time—must be performed to verify that site-specific cleanup standards have been attained before a site can be delisted or a sediment cleanup unit can obtain closure.

The following list provides an overview of the compliance monitoring elements that may be needed, depending on the site and the alternatives selected. MTCA terminology is used where appropriate, but because the process of sediment cleanup is somewhat different than upland cleanup, the list includes additional terminology and concepts.

- Source control monitoring. Conducted before and potentially after sediment cleanup. This monitoring determines whether sources at or near a site or sediment cleanup unit are controlled, or whether they may adversely affect the success of active cleanup and/or natural recovery through recontamination. This can also be a part of confirmation monitoring.
- Protection monitoring (also referred to as construction monitoring). This is conducted during cleanup construction to confirm that human health and the environment are protected. This also includes real-time monitoring to confirm compliance with permit conditions or the substantive requirements of applicable laws during construction (e.g., water quality requirements in a 401 Certification; Chapter 15). Note to Ecology site managers: this phase of the cleanup would be documented in ISIS under "Cleanup – Construction".
- Performance monitoring. This is conducted immediately following construction and/or over the long-term to a) confirm that engineering specifications have been met, b) verify compliance with permit conditions or substantive requirements of applicable laws after construction, and c) confirm cleanup standards have been met either immediately following cleanup construction or in the long-term. A monitoring event may be conducted shortly after active cleanup to provide a baseline to compare to long-term monitoring results and should include all aspects that will be monitored over time. It should incorporate the combined effects of pre-existing conditions, impacts and improvements due to active cleanup, and outside influences on the area.
- Confirmation monitoring (also referred to as long-term monitoring). This is conducted to monitor the continued effectiveness and integrity of constructed remedies such as caps and confined disposal facilities, long-term stability of habitat, and/or that source control is effective and the area is not becoming recontaminated above cleanup standards.

The various types of monitoring and the potential uses of the data are described in greater detail below. Methods for designing and conducting field investigations, laboratory testing, QA/QC, and data analysis and reporting are described in detail in Chapters 4 and 5.

## 13.2 Source Control Monitoring

Source control monitoring is conducted to demonstrate that the PLP's sources have been controlled to allow other elements of the remedy to achieve the site-specific sediment cleanup standards. This objective should be evaluated specifically in the context of the cleanup to determine whether sources under the authority or responsibility of the PLP are present that will cause the site-specific cleanup standard to be exceeded. In this section, "sources" may refer to a wide variety of source types that could include municipal and industrial point source discharges; groundwater discharges; surface water overland flow; in-water sources such as creosoted pilings; operational spills and releases over water; erosion of contaminated bank soils, etc.

Ideally, source control evaluations would be conducted as part of the RI/FS, demonstrating that PLP sources are controlled prior to active cleanup. Source control evaluations should be limited to those sources identified by the CSM as likely to have contributed to sediment contamination and/or that are pathways for cross-media transport of sediment CoCs from upland areas to sediment. Not every potential source at a site requires a source control evaluation if—based on the RI—there is no reason to believe it will result in an exceedance of the site-specific cleanup standard.

If sources are not controlled, actions could be included as part of the CAP and/or Monitoring Plan depending on the scale and type of site or facility, and the PLPs involved. These actions could include:

- Working with the operator to identify and reduce upstream sources (e.g., discharges).
- Implementing additional treatments or BMPs to reduce contaminant loading.
- Complete removal of the source or rerouting of discharges to municipal or other systems.
- Additional upland cleanup.
- Removal of creosoted structures.
- Adjustment of the expected restoration timeframe to accommodate implementing PLP source control, existing municipal CSO or stormwater management plans, or upland cleanup timeframes (such as groundwater natural attenuation).
- Cleanup of sediment areas that pose a high-risk, even if low-level recontamination may occur due to stormwater or other discharges.

Watershed-based source control efforts that support sediment cleanup are generally only used at the largest of sites (e.g., Commencement Bay and Lower Duwamish Waterway). Due to the size and complexity of sites such as these, Ecology, EPA, and local municipalities have agreed to make watershed-based source control efforts a priority within their respective programs. These types of source control efforts are not expected to be needed at smaller or less complex sites due to the high level of resources and planning required.

The type of source control monitoring will vary depending on the type of source and the source control actions taken, if any. In some cases, it may be as straightforward as verifying the removal of a pipe, creosoted pilings, or an upland source. In other cases, monitoring may be based on simple or detailed modeling of groundwater or point source discharges.

Data on contaminant concentrations in stormwater and/or wastewater discharges may be used with simple screening tools to determine whether a current discharge is likely to result in an exceedance of site-specific cleanup standards. It can also be used to verify success of source control efforts as part of the cleanup. The data required include the concentrations of the site CoCs and other conventional parameters (total suspended solids, grain size, etc.). In-line sediment collection or sediment trap sampling may also be useful as a conservative estimate of the potential for recontamination of sediment above cleanup standards.

Collection of physical data for the wastewater discharge may be necessary if modeling is used to predict the effects of natural recovery or the success of active cleanup. Physical data could include the flow of the discharge (to estimate total loading to the receiving water), the density of the wastewater (generally calculated from the temperature of the wastewater), and total suspended solids. As indicated above, modeling can be run with varying degrees of site-specific data. In some cases, default values for many of the model input variables can be used. In other cases, detailed site-specific data are required. Discharge models can be paired with sediment transport models to evaluate larger-scale impacts at sites that are large enough to warrant such an evaluation.

In all of these cases, the focus of the evaluation should be on sources that are under the PLP's authority or responsibility. The benchmark is whether the PLP's sources, in the absence of any other diffuse or point source, would cause recontamination above the site-specific cleanup standards. The PLP will not be required to monitor or evaluate other sources, particularly when a sediment cleanup unit has been defined within a larger cleanup site. Recontamination by sources outside the PLP's authority or responsibility will be dealt with as a potentially new site with different PLPs. See Chapter 14 Section 14.2.4 for further detail on recontamination.

In cases where ongoing sources may affect the rate of natural recovery or may potentially cause recontamination, monitoring of these discharges and their effects on the sediment at the site should be included in the long-term monitoring plan. If the discharges are under the authority or responsibility of the PLPs conducting the cleanup, these PLPs would conduct the monitoring,

and the sediment cleanup standards would need to be met before site closure. Alternatively, if another entity is responsible for the discharge, they may be responsible for long-term monitoring of potential recontamination under a separate monitoring plan. Finally, Ecology or another agency could choose to take responsibility for long-term monitoring of regional sources such as stormwater using a fund provided by cleanup settlements for sites.

## 13.3 Protection Monitoring

*Protection monitoring*, also referred to as *construction monitoring*, is conducted during construction to comply with the conditions in the Health and Safety Plan (Chapter 3) and specific permit requirements (discussed in greater detail in Chapter 15). These requirements are focused on protecting human health and the environment from adverse effects that may occur during construction activities. Each set of permit requirements will be unique and depend on the site and specific actions being taken, which could include one or more of the following:

- Health and safety monitoring for workers involved in cleanup activities.

- Water quality monitoring designed to ensure that water quality standards are met outside of a specified dilution zone surrounding the in-water activities (e.g., a barge, clamshell dredge, or other in-water construction equipment). Typical requirements include monitoring of turbidity and dissolved oxygen, since these can be monitored in real time. Water or particulate chemical analyses could also be required if there are specific concerns at the site, although it may be difficult to obtain results in time to make modifications.

- Monitoring of best management practices designed to reduce impacts on aquatic life and avoid exceedances of water quality standards. These include ensuring proper dredge operation; barge water filtration or settling; avoiding losses during transfer and transportation of material; precision placement of capping materials, etc. See Appendix G: Table G-1 for a more comprehensive list of best management practices.

- Monitoring community impacts such as noise, lighting, interference with vessel traffic and fisheries, timing of operations, etc.

- Monitoring for archaeological or cultural artifacts or of vulnerable endangered species or habitats, if present or potentially present at the site.

Each aspect of construction monitoring should be included in a written plan that has clearly defined procedures, roles and responsibilities, reporting requirements, and contingency actions to be taken under specified circumstances.

## 13.4 Performance Monitoring

*Performance monitoring,* also referred to as *post-construction monitoring,* is conducted after cleanup construction and has generally three purposes: a) to verify that post-construction performance standards (e.g., engineering and design requirements, etc.) have been met; b) to verify compliance with any post-construction permit requirements and applicable laws; and c) to verify that sediment cleanup standards have been met . Performance monitoring may be a short or one-time event in areas where active cleanup was expected to achieve cleanup standards immediately after construction; or it may entail collecting baseline data, followed by long-term monitoring to evaluate whether cleanup standards are met in the long-term after natural recovery or enhanced natural recovery.

### 13.4.1 Performance standards

A Construction Completion Report should be prepared following cleanup construction, which should include the following elements when appropriate:

- Verification that constructed or dredged elements of the remedy have met design specifications. This may include high-accuracy bathymetry; cap placement and thickness, volumes of dredged material and wastes removed and the area of removal; volumes of cap or enhanced natural recovery material placed; documentation of pilings or other structures removed; as-built cross-sections; disposal manifests, sediment chemistry of exposed surfaces etc., as appropriate to the cleanup action.

- Information on evaluation of cap performance or stability of other built structures within the first few years.

- Field observations and results of monitoring.

- Any water quality exceedances, permit violations, or other unforeseen circumstances (mechanical problems, unexpected materials in sediment, adverse weather, etc.) that resulted in contingencies or modifications to operations or the remedial design. All post-construction monitoring requirements in the permits, including submission of any reports or results, should be included.

- If any element of the remedy was a novel, pilot, or experimental approach, discuss what lessons were learned, what went well, what modifications would be recommended in the future, etc.

## 13.4.2 Cleanup Standards Monitoring

Monitoring must be done to verify if cleanup standards have been achieved either immediately after cleanup construction or in the longer-term when active cleanup does not immediately achieve cleanup standards for the entire site or sediment cleanup unit. In the case of long-term monitoring for recovery, RI/FS work will have been conducted that estimates the restoration timeframe to achieve cleanup standards through processes such as natural recovery and ongoing source control efforts. The ultimate goal is to demonstrate compliance with the sediment cleanup standards and the monitoring plans should be specifically designed to meet the requirements of Section 13.6.

Sediment chemistry and (optional) bioassay data should be collected for areas that did not meet sediment cleanup standards immediately after active cleanup or that are at risk of recontamination. These may be SMAs where passive cleanup alternatives were selected to achieve cleanup standards over the long-term (e.g., monitored natural recovery), or where active cleanup alternatives were selected to immediately achieve cleanup standards in part of the site (e.g., enhanced natural recovery). This data might also be collected if there are concerns about recontamination in actively cleaned up areas. The boundaries of the remediated site and any sediment management areas (SMAs) within the site should be identified in the CAP.

If the restoration timeframe (when cleanup standards will be met) is expected to take longer than 10 years, or long-term monitoring indicates that cleanup standards will not be met within 10 years as originally planned, an SRZ will need to be issued (see Chapter 14). In either of these cases, the technical aspects for performance monitoring are the same. Monitoring should be designed with the restoration timeframe in mind: more frequent monitoring if more rapid recovery is expected, and less frequent monitoring if slow recovery is expected. If many years of monitoring are anticipated, it may be appropriate to have more comprehensive monitoring events periodically, with smaller events in between to confirm that the trends are as expected. Monitoring can be reduced in size, scale, and/or number of CoCs, if SMAs or CoCs have achieved the cleanup standards.

Until cleanup standards are achieved, performance monitoring provides information on trends in sediment chemistry, benthic community, porewater, and tissue chemistry depending on what is being monitored. This information helps evaluate whether conditions are improving over time and how rapidly, or whether recontamination, remedy failure, or other unforeseen circumstances may prevent the cleanup standards from being met without further action. The monitoring plan should include contingencies in case recovery does not proceed as planned. Contingency actions could include:

- Extending the anticipated restoration timeframe and associated monitoring (with issuance of an SRZ as necessary).

- Determining whether additional source control measures are necessary.
- Conducting additional active cleanup (upland or in-water).
- Repairing or armoring caps or other constructed containment facilities.
- Reconsidering the technical possibility of achieving the cleanup standard during the 5-year review and (potentially) adjusting it accordingly. See Chapter 14, Sections 14.2.3, 14.2.4, and 14.2.6 for more information on adjusting cleanup standards and recontamination.

Although cleanup standards under the SMS rule are based on bulk sediment, site tissue or porewater chemistry may be analyzed for bioaccumulative CoCs that pose risks to human health or higher trophic level species. In general, larger sites that are expected to have a regional impact on tissue concentrations may benefit from having tissue incorporated into monitoring plans. This tissue and/or porewater information may be used in an informational capacity to evaluate remedy effectiveness and progress toward reducing tissue and sediment concentrations to risk-based or background-based levels. Tissue and porewater chemistry can also be used as lines of evidence in determining compliance with the site-specific sediment cleanup standards (see Section 13.6.2). In these cases, porewater should be sampled from within the biologically active zone. Sampling below the biologically active zone and in areas where groundwater upwelling is occurring (groundwater seeps) is not appropriate for purposes of sediment compliance monitoring because this is not porewater, but rather groundwater.

#### 13.4.2.1 Baseline monitoring

Monitoring shortly after active cleanup to provide a baseline to compare with long-term monitoring results should include all aspects that will be monitored over time such as the combined effects of pre-existing conditions, impacts and improvements due to active cleanup, and outside influences on the area. The sampling design should be similar to that for confirmation or performance monitoring, except that biased or stratified sampling may be appropriate for areas with gradients in chemical concentrations or where ongoing sources are a concern. Incremental sampling should not be used for baseline or long-term monitoring of areas that have not received active cleanup or where ongoing sources may cause recontamination. In general, baseline monitoring should include all of the types of data in Section 13.6, with similar sampling designs to allow trend analysis and statistical comparisons of later results to the baseline.

It should not be assumed that RI/FS results can be substituted for baseline monitoring post-construction. Active cleanup such as dredging or capping disturbs sediment and can result in unavoidable sediment transport and changes in chemical concentrations in both sediment and

tissue. It is not unusual to see a short-term spike in chemical concentrations in tissues immediately following dredging, for example. On the other hand, improvements in sediment chemistry due to natural recovery, active cleanup of high concentration source areas, and transport of capping material have also been observed in areas that did not receive active remediation. Therefore, it is important to obtain an accurate post-construction baseline to be able to evaluate long-term monitoring data for sites where substantial active cleanup was conducted, or where several years may have passed since the previous data set.

#### 13.4.2.2 Bioaccumulatives monitoring

When monitoring for bioaccumulative chemicals, appropriate random sampling within the remediated site should be used to obtain an unbiased, representative estimate of conditions at the site. (An example of this might be random sampling using a grid, with one sample per grid to achieve fairly even spatial coverage). If there are SMAs within the site that require separate exposure estimates and/or compliance statistics, then one of two options will apply:

1. If each SMA will be managed independently, each SMA should be treated individually from a statistical standpoint. Conduct appropriate random sampling and an independent compliance evaluation for each SMA.

2. If separate estimates of exposure are needed for one or more SMAs, but it is also necessary to evaluate the overall site or sediment cleanup unit, use stratified random sampling and treat each exposure area as a separate stratum. An example scenario is when a separate estimate of exposure is needed for the intertidal zone, but the entire bay (represented by the subtidal and intertidal areas combined) must also be in compliance. In this case, combine the data from all strata within the remediated sediment cleanup unit or site, to estimate site-wide summary statistics for the compliance evaluation. Calculate the weighted mean using the individual strata means with the areas of the strata as weighting factors, using the stratified sampling methods described in Appendix F.

Incremental sampling methodology (also referred to as incremental sampling in ITRC 2012) is another method that can be used to obtain an area average for the entire site, sediment cleanup unit, or SMAs in order to separately compare to site-specific cleanup standards. As described in ITRC (2012), “decision units” (equivalent to sediment cleanup units or SMAs) should be identified for the site and incremental sampling should be conducted separately within each unit. Incremental sampling only provides an estimate of the area-wide mean. It provides no information about the variability of individual concentrations within the site. Therefore, it should only be used for areas that are expected to have relatively homogeneous concentrations (e.g., dredged or capped) and are expected to be below the cleanup standard. This method should not be used for areas that may exhibit concentration trends (e.g., certain natural recovery areas) that will be masked by subsampling and compositing. It is also recommended to archive

sediment during incremental sampling, to allow further analysis and evaluation of the data should the mean exceed the cleanup standard. If different sediment management areas need to be combined to evaluate site-wide compliance with cleanup standards, the means for individual sediment cleanup units could be area-weighted to determine the site-wide mean. For more information on incremental sampling, see Chapter 4, Section 4.4.3.

While Ecology recommends a random sampling design for monitoring to verify if cleanup standards have been met, there may be cases where a non-random or biased sampling design is more appropriate. In such cases, the data should be area-weighted before determining the average. Regardless of which sampling design is used, however, the data set must have a sufficient number of samples to be representative of the site and to minimize false positives and false negatives when comparing to the cleanup standards. Ecology recommends at least 15 – 20 values (Appendix L). For an alternative procedure for smaller or less complex sites, see Option B in Section 13.6.1.

Whether or not the data are area-weighted, a sufficient percentage of the data must be detected to calculate a mean. Nonparametric approaches (e.g., Kaplan-Meier) for calculating a mean when non-detects are present are best used with data sets that have at least 50% detected data (Appendix F). Data quality objectives should establish sufficiently low detection limits to maximize the probability of obtaining detected concentrations. When it is not possible to obtain sufficient detected data to determine the mean, a point-by-point compliance comparison may be used instead (Option A in Section 13.6.1). See Chapter 6 Section 6.3.4.2 for more information on averaging over exposure areas.

#### 13.4.2.3 Benthic monitoring

Benthic biological testing data (bioassay results and benthic community analyses) can be used to confirm the results of sediment chemistry or to directly assess the effectiveness of cleanup actions for sediment cleanup standards based on benthic toxicity. Whether sediment achieves or fails the site-specific cleanup standards based on chemical concentrations, they may be evaluated using biological criteria (Chapter 8). The results of these biological analyses override the results of the sediment chemistry analyses, so meeting the biological criteria means chemical criteria are met. Alternatively, biological testing is used when the site-specific cleanup standards are based on the numeric biological criteria (Chapter 8). Benthic community analysis or other biological monitoring may also be used to assess whether the biological community is becoming reestablished after active cleanup such as capping or dredging.

## 13.5 Confirmation Monitoring

*Confirmation monitoring*, also referred to as *long-term monitoring*, is conducted after performance monitoring. It is used to confirm the long-term effectiveness of the cleanup action once cleanup standards or other performance standards have been met. This information is used

for periodic reviews to confirm the cleanup is still protective. Confirmation monitoring can include:

- Periodic chemical monitoring of the sediment surface (e.g., top 2 cm) to evaluate the long-term effectiveness of source control, integrity of constructed remedies (e.g., caps), and natural recovery. Information from performance monitoring may serve as a baseline or a new baseline may be necessary.

- Chemical monitoring within caps to confirm chemicals are not migrating through.

- Bathymetric surveys, diver surveys, and visual evaluation of constructed remedies to ensure ongoing protectiveness and effectiveness of the remedy over the long-term. This type of monitoring may be particularly appropriate in areas subject to large vessel traffic, regular construction, sediment transport, or other forms of disturbance.

- Chemical or physical monitoring after natural events such as floods, severe storms, and earthquakes.

- If habitat restoration is conducted in conjunction with cleanup—either as a SEPA mitigation requirement or under NRDA—monitoring the success of restoration may also be included in the plan. This could include periodic monitoring of physical aspects of the constructed habitat (slopes, elevations, grain size); biological monitoring of plants and benthos; and use of the site by animals, birds, and aquatic life.

## 13.6 Determining Compliance with Sediment Cleanup Standards

The SMS rule requires cleanup standards to be established for sediment, which includes the sediment cleanup level (chemical concentration or level of biological effects) and the point of compliance (horizontal area and/or vertical depth in sediment where the sediment cleanup level must be met). Once established, all sediment cleanup standards are considered threshold or bright-line values and should be treated as such regardless of the basis for their development (e.g., background, PQL, or risk-based).

However, the very low concentrations that may be used to establish and measure compliance with bioaccumulation-based cleanup standards have significant analytical variability, as well as field variability. Due to this variability, the following guidelines should be used for compliance purposes:

- Both the cleanup standards and compliance monitoring data should be rounded to the appropriate number of significant figures prior to the comparison (see Chapter 6 for

rounding rules). For area exposures, rounding should be conducted after calculating the mean.

- Based on typical analytical relative percent differences (RPDs) and field variability, any individual or mean value within 20% of the cleanup standard is considered to be indistinguishable from the cleanup standard and in compliance.

Compliance monitoring can be conducted immediately after active cleanup is completed, or as part of a long-term monitoring program. A routine monitoring event may be used as part of a long-term monitoring program to demonstrate compliance, provided that data requirements in the following section are met.

### 13.6.1 Using sediment data to evaluate compliance

Compliance monitoring data from a site are evaluated using one of the following (Options A or B) to determine whether the sediment cleanup standards are met (Figure 13-1). Different options may be chosen for different chemicals based on the considerations described below each option:

***Option A: Point-by-Point Comparison***

- For sites, sediment cleanup units, or SMAs with cleanup standards based on benthic toxicity, compare the individual chemical and biological results from each sampling station to the cleanup standard. The point of compliance is typically within the top 15 – 10 centimeters, but can be deeper based on site-specific benthic communities. This approach is required for compliance with standards based on the benthic freshwater or marine chemical or biological criteria (Chapter 8, Table 8-1). As discussed in Chapter 8, sediment bioassay data overrides sediment chemistry data if both are available.

- For sites, sediment cleanup units, or SMAs with cleanup standards based on background, PQL, human health or upper trophic levels (bioaccumulative chemicals), point-by-point comparison (Option A) may be used in lieu of calculating the mean for area-based exposures (Option B). Specifically, it could be used in cases where the compliance data set is comprised of mostly (or all) non-detects and the PQL is below the cleanup standard. But due to the potential for false positives expected with Option A (see Appendix L), make every attempt to obtain a dataset with sufficient detected data to calculate a reliable mean so that Option B could be used.

  Ecology recognizes that a random sample from a population with a mean below the cleanup standard may contain a few concentrations in the upper tail of the distribution that exceed the cleanup standard, particularly in larger data sets. If this occurs and the exceedances are not obviously clustered together, a process similar to the site identification rules (see Chapter 2) should be used to evaluate the data:

1. If three stations for any chemical exceed the site-specific cleanup standard AND the cleanup standard is the CSL, the site or sediment cleanup unit is out of compliance and additional action may be warranted. This will depend on the magnitude and area of the exceedance; the expected timeframe for compliance for the selected cleanup alternative: and whether there is an upward or downward trend in concentrations.

2. If three stations for any chemical exceed the site-specific cleanup standard BUT the cleanup standard is below the CSL, further monitoring is required. However, further action may not be immediately necessary unless an upward trend over time shows a strong potential for the CSL to be exceeded.

3. If less than three stations exceed the site-specific cleanup standard, the site or sediment cleanup unit is considered in compliance.

   However, should stations above the site-specific cleanup standard appear to cluster in an area adjacent to a former source area or otherwise suggest that the remedy may be failing in a specific area, site managers may use their discretion to require additional confirmatory sampling. If a small area of exceedance is confirmed but the rest of the site is below the cleanup standards, future monitoring can focus on that remaining area of concern.

***Option B: Comparison Using the Mean or Area-Weighted Mean***

For cleanup standards based on area-wide exposures (e.g., human health or ecological risk-based, background-based, or PQL-based standards; Chapters 9-11), the site compliance data set may be evaluated by comparing the mean of the measured sediment concentrations to the cleanup standard. This approach reflects the fact that the route of exposure for bioaccumulative chemicals is largely through ingestion of fish and shellfish (for both human health and higher trophic levels), and that these receptors average their exposures over the entire area of concern. The Option B approach may also be appropriate for intertidal sediment where direct contact of humans or wildlife with sediment within a specific area may occur, such as during beach play or clam-digging.

For these cleanup standards, it is more likely that the compliance monitoring data set will have a mean relatively close to the cleanup standard. To minimize the number of false positives and false negatives in this situation (see Appendix L), a data set of at least 15 - 20 samples is recommended. A larger data set will significantly improve the chances of compliance if the site mean is below the cleanup standard. Alternatively, incremental sampling methodology can be used to obtain a mean with a low variance. The number of detected values should be sufficient to calculate a reliable mean.

For smaller sites where analysis of a large number of samples may be impractical, the following alternative procedure may be used at the site manager's discretion:

1. Collect 20 samples. Randomly analyze 10 and archive 10.

2. If the mean of the first 10 samples exceeds the cleanup standard for one or more chemicals, and the mean is less than 50% above the cleanup standard, Ecology recommends: a) analyzing all 10 archived samples for any chemicals that fail the site-specific cleanup standard; and b) recalculating the mean using all 20 samples. The analysis must be conducted within the holding time of the archived samples.

The area over which the data are averaged should be the same as the point of compliance for the cleanup standard, which may be established site-wide or for a specific SMA. For compliance monitoring, a random or grid sampling design is recommended (this includes stratified random sampling, systematic sampling with a random start, or incremental sampling methodology; Chapter 4). However, if the data are collected through a non-random biased sampling design (for example, specifically targeting particular areas of concern), area-weighted averaging is recommended for comparison to the cleanup standards.

If the compliance data are collected through a spatially balanced random sampling design or using incremental sampling methodology, the data may be averaged without manipulation or transformation. Each SMA should be evaluated separately to avoid masking potential areas with higher concentrations. If the exposure area or point of compliance warrants it, data sets from multiple SMAs can also be combined into one overall data set for further evaluation of the site-wide area-weighted mean. While incremental sampling will be allowed for compliance monitoring, it should only be used in areas where the concentrations are expected to be relatively homogeneous (e.g., capped areas). Archiving samples for later analysis is recommended during incremental sampling in case the mean exceeds the cleanup standard and to support further data analysis and decision-making.

When using Option B, all data must be included to calculate the mean, such as data that appear to be outliers or have higher concentrations. If the resulting mean exceeds the cleanup standard, contiguous areas with higher concentrations may be separated as SMAs for further investigation and/or action. The mean of the remaining areas should then be recalculated and evaluated for compliance if sufficient data remain for those areas. Additional data may need to be collected if there are not enough data in the remaining areas to meet compliance testing requirements.

On the other hand, if higher concentration stations that cause the mean to exceed the cleanup standard are scattered throughout the site, the site is not in compliance. Even if the mean falls below the cleanup standard, higher-concentration areas further investigation may be needed if there is reason to believe they may be associated with remaining sources, areas with higher

concentrations, or areas where the remedy is failing. Evaluating the trends in these locations will help determine whether these higher concentration areas are of concern.

Whether or not the data are area-weighted, a sufficient percentage of the data must be detected to calculate a mean. Nonparametric approaches (e.g., Kaplan-Meier) for calculating a mean when non-detects are present are best used with data sets that have at least 50% detected data (Appendix F). Data quality objectives should establish sufficiently low detection limits to maximize the probability of obtaining detected concentrations.

### 13.6.2 Using tissue or porewater chemistry data in a weight-of-evidence approach

Tissue chemistry may be used in a weight-of-evidence approach to evaluate compliance with the sediment cleanup standards (WAC 173-204-500(4)(e); 173-204-560(6)(b)). In addition, porewater chemistry may be considered by Ecology. Procedures for evaluating compliance using tissue or porewater concentrations must be approved by Ecology. Such an approach should be used with caution, because 1) tissue concentrations integrate exposures to sediment, water, and prey organisms, as well as chemicals that may have originated from land-based, aquatic, or airborne sources, 2) organisms may integrate exposures over wide areas that are larger than the site (i.e., chemical concentrations in tissues may not originate solely from the site), and 3) porewater concentrations do not represent risks from all exposure routes and what may be bioavailable to the benthic community. Any use in a compliance context should take into account the site fidelity of the organism, its contact with primarily sediment sources, exposure from sediment ingestion, and other monitoring information for sediment. Before using tissue or porewater data in this context, a clear goal and interpretive guidelines should be developed in advance and the approach should be designed specifically for the site.

An example using tissue concentrations in a weight-of-evidence approach: If sediment concentrations in a data set were slightly above cleanup standards, a laboratory bioaccumulation test could provide additional information on whether these concentrations were likely to exceed risk-based or background-based tissue concentrations. This could help determine if additional cleanup is needed versus continued monitoring or site closure. In this case, a laboratory test might be selected to avoid the influence of factors beyond those of site sediment. Another factor that should be considered is whether concentrations in sediment and/or tissue appeared to be increasing or decreasing. In this example, the type of evaluation is site-specific and should take into account all available data in a weight-of-evidence approach.

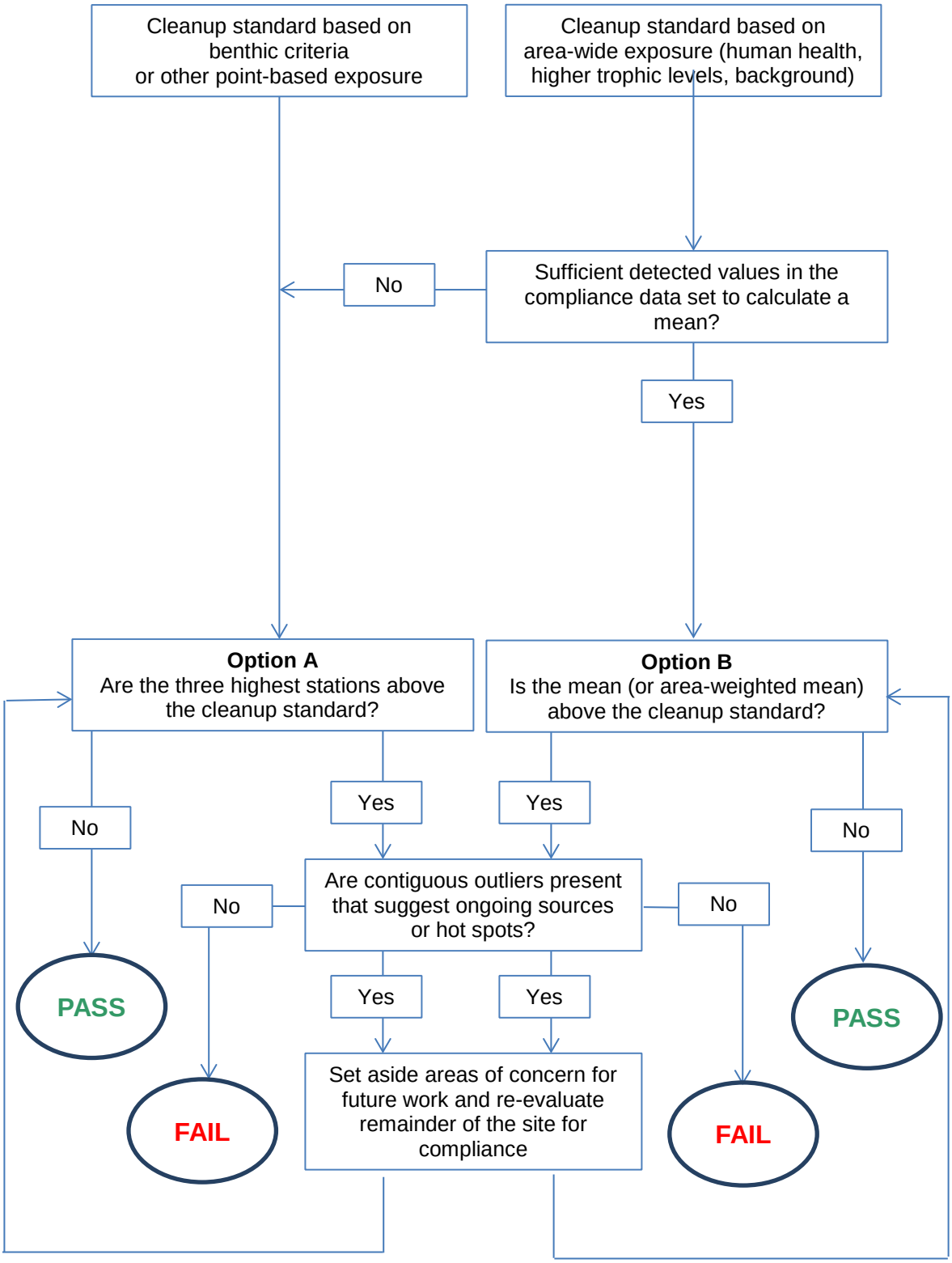



**Figure 13-1.** Evaluating compliance with a sediment cleanup standard.

# Chapter 14
# Sediment Recovery Zones
# WAC 173-204-590

## 14.1 Introduction

Sediment recovery zones (SRZs) are issued for areas of a site or sediment cleanup unit where a) sediments are left in place to be monitored for natural recovery; and b) it has been determined that the site-specific cleanup standard will not be met within the 10-year restoration timeframe. SRZs are not intended to be used in place of active cleanup where such cleanup is practicable (as outlined in WAC 173-204-570). SRZs may be part of the selected cleanup action alternative in the following instances:

1. When monitored natural recovery is determined to be the preferred alternative for cleanup for part of a site or sediment cleanup unit:
   a) Due to the presence of widespread, low-level contamination, and
   b) Based on a determination during the remedy selection process (Chapter 12; WAC 173-204-570) that active cleanup alternatives for the entire site are not practicable.

2. When greater environmental harm would result by cleaning up a portion of the site, rather than allowing that area to naturally recover (e.g., in areas with unique or sensitive resources, or areas where resources would re-colonize very slowly).

### 14.1.1 When a sediment recovery zone is required

Sediment recovery zones are required at sites and sediment cleanup units where:

1. Sediments are not expected to recover to the site-specific cleanup standards within a restoration timeframe of 10 years after completion of the active components of the cleanup action (WAC 173-204-590(1)(a)).

2. Performance monitoring or periodic review shows that the cleanup action has not achieved, or is not expected to achieve, the site-specific cleanup standards within 10 years after completion of the active components of the cleanup action (WAC 173-204-590(1)(b)).

### 14.1.2 Criteria Ecology considers for authorization

Ecology will consider the following criteria before authorizing a sediment recovery zone (WAC 173-204-590(3)). These criteria are also evaluated during the remedy selection process (Chapter 12):

- Modeling information, and the limitations inherent in the model, used to determine the areal extent and timeframe needed for the SRZ.
- The potential risks to human health and the environment within the area proposed for an SRZ.
- The technical practicability, as determined in WAC 173-204-570, of eliminating or reducing the chemical concentrations or risks to human health and the environment within the area proposed for an SRZ.
- Current and future uses of the land proposed for the SRZ.
- Impacts to any resources that may be affected by the SRZ.
- Any institutional controls or land use restrictions required while the SRZ is in place.

## 14.2 Requirements for a Sediment Recovery Zone

### 14.2.1 Minimum requirements

#### 14.2.1.1 Authorization document

An SRZ must be specifically authorized by Ecology as part of the cleanup action plan and consent decree. In addition, the approval and cleanup action decision must contain a legal description of the property proposed as an SRZ, the landowners of the property, and the time period over which the SRZ is authorized. Ecology must make a reasonable effort to notify the landowner(s) of the affected property and provide that information on the SRZ application, as described in WAC 173-204-590(7). Landowners are given the opportunity to comment on the proposed SRZ within 30 days.

#### 14.2.1.2 Areal extent and duration

SRZs may be authorized for only as large an area as necessary, and chemical concentrations within the SRZ must be as close to the site-specific sediment cleanup standard as practicable. These factors are considered during the remedy selection process (WAC 173-204-570). Additionally, it is expected that source control, best management practices for PLP sources, and active cleanup in adjacent areas of the site will also be included in the selected remedy. All of

these factors combined will help maintain concentrations in the SRZ as close to the cleanup standards as possible and allow the best opportunity for recovery.

SRZs are initially authorized for 10 years, and the goal is to achieve natural recovery to the site-specific cleanup standards within this timeframe. If the restoration timeframe is expected to be longer than 10 years, the goal would be to see the expected amount of natural recovery in the first 10 years. SRZs may be reauthorized for additional 10 year increments, if needed.

The estimated timeframe needed to achieve natural recovery to the site-specific cleanup standards should be determined using Ecology-approved models or other methods, and should be included in the Cleanup Action Plan.

#### 14.2.1.3 Public involvement

Ecology will make a reasonable effort to identify and notify all landowners that may be affected by the proposed SRZ. Notification can be in the form of a certified letter or personal notification (e.g. submission of the public notice to affected landowners). The notification should include:

- Name(s) of the affected landowner and the PLP(s).
- General description of the proposed SRZ including the CoCs and areal extent.
- Ecology's determination of whether the SRZ meets the requirements of WAC 173-204-590 and Ecology's intent to authorize the SRZ.
- Opportunity for public comment. A minimum of 30 days (from the date of receipt of the notification) must be allowed for comments.
- If the SRZ is part of the Consent Decree, the public comment period for the Consent Decree and the SRZ could be combined, but notice to landowners would be conducted separately.

### 14.2.2 Renewal, expansion, or reduction of an SRZ

Once the SRZ is established, any adjustments to the duration or boundary of the SRZ may only be done during the periodic review process or during renewal of the SRZ. Any renewal, extension, or other changes to the SRZ must be authorized in a consent decree, permit, or other appropriate legal document.

Expansion of an SRZ will not be used as a substitute for active cleanup when active cleanup actions are determined practicable under WAC 173-204-570.

If monitoring data shows that the SRZ (or portions of the SRZ) have met cleanup standards for certain CoCs, it would be appropriate to eliminate either those portions, or the CoCs that meet cleanup standards from the SRZ when it is renewed.

If a trend analysis shows *decreasing* concentrations at the site—either the whole site, or near any PLP sources, or from PLP sources—a review of the SRZ is warranted to determine appropriate actions. These actions could include:

- Reducing the size of the SRZ,
- Eliminating CoCs from the SRZ,
- Revising the requirements of the SRZ, and/or
- Closing the SRZ.

If a trend analysis shows *increasing* concentrations at the site, then additional investigation may be warranted to determine if the increase is due to remedy failure, inadequate control of PLP sources, or other sources not under the control or authority of the PLP. See Section 14.2.4 for more detail on recontamination.

### 14.2.3 Monitoring and compliance requirements

Biological and chemical monitoring of sediment, benthic infauna, tissue, receiving water column, and/or discharges may be required as part of the SRZ authorization to ensure compliance with the terms and conditions and to monitor the progress of natural recovery. Monitoring requirements may be modified during periodic reviews or renewal of the SRZ.

The approved cleanup monitoring plan may suffice to meet the SRZ monitoring requirements. For further details on establishing appropriate monitoring plans and requirements, see Chapter 13.

### 14.2.4 Recontamination

Ecology included policies and expectations in the SMS to address the issue of recontamination (WAC 173-204-500(4)(b)):

> *Recontamination may occur from ongoing discharges or other releases. It is the department's expectation that further cleanup of recontamination will not be required by the person(s) conducting the initial cleanup when the person(s) can demonstrate, upon department approval, that the recontamination is caused by ongoing discharges or other releases not under the authority or responsibility of the person(s) conducting the initial cleanup.*

To meet these expectations and when establishing an SRZ, Ecology will consider the potential for diffuse sources—those not under the authority or responsibility of the PLP—to recontaminate the site or sediment cleanup unit above the sediment cleanup standards.

It is expected that the PLP will conduct source identification and reasonable measures to address incoming contamination from sources that are under the authority or responsibility of the PLP. These measures will be established in the Consent Decree or other enforceable document. After these measures are implemented, if there is still ubiquitous contamination from diffuse sources not under the authority or responsibility of the PLP that is causing the site to exceed the cleanup standards, there are a number of options Ecology may consider, including but not limited to:

- Ecology will review the source(s) of the recontamination.
- If the PLP(s) has met all requirements in the Consent Decree or other enforceable document, but the site is recontaminated by sources not under the authority or responsibility of the PLP(s), Ecology does not expect to require further cleanup or investigations by that PLP(s).
- Ecology will look to the parties responsible for the source(s) to address the recontamination.
- If the recontamination is coming from a new release, it may be appropriate to identify the release/recontamination as a new site with different PLPs.
- If the source of the recontamination is under the authority or responsibility of an identifiable person(s), then it may be proper to name them as a PLP for the site and require cleanup actions to address the source and recontamination.
- Ecology will accept that PLP sources are controlled when the PLP can reasonably demonstrate that their source(s), in the absence of any other sources, will not result in contaminating sediment above the sediment cleanup level. When this demonstration is shown, Ecology does not expect the original PLP(s) to prove what sources or parties are responsible for recontamination or to join the responsible entities in long-term monitoring.
- If all other site-specific cleanup standards have been met, Ecology may consider closure of the SRZ for the original PLP(s).

### 14.2.5 Enforcement

Ecology will review all available information to evaluate compliance with the SRZ requirements and determine appropriate actions. If Ecology determines that the terms and conditions of the SRZ have not been met, Ecology has four options:

1. Require additional chemical or biological monitoring to better determine the extent of, or potential for, a violation.

2. Revise the terms of the SRZ authorization to reflect the needs of the site. This could include revising monitoring requirements, the size of the SRZ, or the need for a renewal.

3. Require additional cleanup of the site, increased source control, and/or maintenance.

4. Withdraw authorization of the SRZ.

### 14.2.6 Closure

If, at any time during the duration of the SRZ, monitoring data shows cleanup standards have been met and the PLP sources are controlled, the SRZ will be closed. Ecology will accept that PLP sources are controlled when the PLP can reasonably demonstrate that their source(s), in the absence of any other sources, will not result in contamination above the site-specific sediment cleanup standards. PLPs will not be responsible for controlling or monitoring sources that are not under the authority or responsibility of the PLPs.

If monitoring data shows cleanup standards cannot be met, the following options are available for Ecology to consider:

1. If noncompliance is due to PLP sources not being controlled, additional source control may be necessary.

2. If noncompliance is due to contribution from other sources that are not under the responsibility or authority of the PLP, closure of the SRZ may be appropriate or adjustment of the cleanup level may be appropriate. For example:

    a. Ecology may consider whether the cleanup level should be adjusted upwards according to the process detailed in Chapter 7, Section 7.2.3. An example of when this may be appropriate is where the cleanup level was established below regional background, but Ecology has since established or approved regional background for the geographic area where the site is located. In this case, Ecology may determine that regional background represents the concentration in sediment that is technically possible to maintain, due to ongoing sources that are not under the authority or responsibility of the PLP. Therefore, Ecology could

allow upwards adjustment of the sediment cleanup level to the CSL if regional background has been established as the CSL.

b. If the cleanup levels are based on background (regional or natural), Ecology will consider whether background concentrations have increased and the cleanup level should be adjusted upwards.

- Ecology may consider whether establishment of a PLP-funded mechanism for long-term monitoring would be appropriate, to allow SRZ closure.

*This page left intentionally blank.*

# Chapter 15
# Applicable Laws and Required Permits for Cleanup Actions

## 15.1 Applicable Laws

"Applicable laws" are defined in the SMS rule (WAC 173-204-505(2)) as all legally applicable requirements in MTCA (WAC 173-340-710(3)), and those requirements that the department determines are relevant and appropriate requirements in WAC 173-340-710(4).

The term "applicable laws" includes:

- Legally applicable requirements, where the law has jurisdiction over the cleanup action.

- Requirements that Ecology determines are relevant and appropriate, commonly referred to as ARARs, or "applicable or relevant and appropriate requirements." These are regulatory requirements that might not be legally applicable but make common sense to apply to a site and must be considered when selecting and implementing cleanup actions to meet the minimum requirements of WAC 173-204-570(3).

Cleanup standards must be at least as stringent as all applicable state and federal laws, and applicable laws may impose certain technical and procedural requirements for performing cleanup actions (WAC 173-340-710). It is the PLP's responsibility to comply with all applicable laws during all phases of cleanup.

### 15.1.1 Relevant and appropriate requirements

Relevant and appropriate requirements may include state, federal, local, or tribal laws that Ecology determines meet the criteria in WAC 173-340-710(4). Relevant and appropriate requirements are those cleanup standards that address problems or situations sufficiently similar to those encountered at a particular site, and are therefore well suited to use at that site. The determination of "relevant and appropriate" relies on Ecology's best professional judgment after consideration of environmental and technical factors at the site. Ecology expects that tribal laws may be determined to be relevant and appropriate in cases where releases of hazardous substances at a cleanup site are impacting tribal lands.

A cleanup action conducted under the authority of the MTCA law must include ARARs in the final agreed order or the consent decree and should be identified in the initial agreed order. As more information becomes available about the site and its chosen cleanup action, additional

ARARs may be identified in the FS, which should include a section on potential ARARs for the cleanup actions evaluated. The cleanup action chosen for the site must meet the requirements of the identified ARARs.

### 15.1.2 Applicable laws

Once a requirement is determined by Ecology to be relevant and appropriate, it must be complied with as an applicable law. The PLP must identify all applicable laws. Ecology will make the final determination whether those requirements have been correctly identified and are legally applicable or relevant and appropriate.

Below is a list of applicable laws that should be considered when conducting cleanup actions:

- **Federal Clean Water Act (CWA)**, the **State Water Pollution Control Act RCW 90.48**, and the **Water Quality Standards for Surface Waters of Washington Chapter 173-201A WAC**. These are the primary federal and state regulations for protecting water quality.
    - Section 404 of the CWA includes requirements for the discharge of dredged or fill material to waters of the United States including wetlands and is applicable to any in-water work. This may require issuance of a federal permit from the Army Corps of Engineers (Corps).
    - Section 401 of the CWA requires the state to certify that federal permits are consistent with RCW 90.48 and WAC 173-201A. This may include the issuance of a 401 Water Quality Certification.
    - Section 402 of the CWA also includes requirements for discharges under the National Pollutant Discharge Elimination System Discharge (NPDES) permit system.
        - The dewatering of sediment prior to upland disposal must meet all known, available, and reasonable technologies (also known as AKART) for treating the wastewater prior to discharge to state waters. This activity may require an NPDES permit.
        - Upland construction activities related to the in-water work disturbing one or more acres of land require an NPDES permit.

- **Section 10 Rivers and Harbors Act.**

- **Archaeological and Historical Preservation Act 16 USCA 496a-1 and Section 106.** This is applicable if any relevant materials are discovered during the RI/FS or cleanup construction.

- **Endangered Species Act 16 U.S.C. 1531 et seq., Title 77 or 79 RCW.** If the site includes existing or potential habitat for threatened and/or endangered species, the cleanup actions will be subject to Endangered Species Act review.

- **Washington Solid and Hazardous Waste Management Act RCW 70.105 and Dangerous Waste Regulations Chapter 173-303 WAC.** This applies if dangerous wastes are generated during the cleanup action. For example, if sampling results of dredged material for upland disposal exceeded dangerous waste characteristics or criteria.

- **National Environmental Policy Act (NEPA) and State Environmental Policy Act (SEPA) RCW 43.21C, WAC 197-11, and WAC 173-802.** Construction projects are subject to environmental impact review under SEPA and/or NEPAs. Prior to taking any cleanup actions, such as implementing the Cleanup Action Plan, the SEPA/NEPA procedures must be followed.

- **Shoreline Management Act RCW 90.58**. Requirements for substantial developments occurring within waters of the state or within 200 feet of the shoreline must be met. Local jurisdictions set forth requirements such as shoreline use and public access in the Shoreline Management Plans adopted under state law.

- **Washington Hydraulics Code RCW 77.55.** Includes regulations for the construction of any hydraulic project or the performance of any work that will use, divert, obstruct, or change the natural flow or bed in waters of the state. Hydraulic Project Approval (HPA) permits are required for any activities that could adversely affect fisheries and water resources. For example, timing restrictions and technical requirements under the hydraulics code may be applicable to dredging and placement of capping material.

- **Federal OSHA 29 CFR 1910, 1926 and the Washington Industrial Safety and Health Act RCW 49.17.** These include requirements to protect workers from exposure to contaminants and ensure that excavations are properly shored.

- **The Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA, P.L. 92-532).** Includes requirements for ocean disposal of materials and related research.

- **Washington Clean Air Act RCW 70.94.** Includes requirements for site work generating dust or affecting air quality.

## 15.2 Exemption from Procedural Requirements

For in-water sediment cleanup work, certain permits and approvals are required. For sediment cleanup actions conducted under a MTCA Order or Decree, the cleanup actions must comply with the substantive requirements, but are exempt from the procedural requirements of Chapters 70.94, 70.95, 77.55, 90.48 and 90.58 RCW and from any laws requiring or authorizing local government permits or approvals (RCW 70.105D.090; WAC 173-340-710).

It is the responsibility of the PLP to ensure the substantive requirements of those laws/permits/approvals are met. Ecology is required to consult with the state agencies and local governments regarding the substantive requirements, and is required to provide a public notice and/or comment period.

The procedural exemption does not apply if Ecology determines the exemption would result in loss of approval from a federal agency, since approval is necessary for the state to administer any federal law.

Ecology has determined that the procedural exemption does not apply to NPDES permits. If an NPDES permit is needed to conduct a cleanup action, it must be obtained and the public notice period requirements must be implemented.

Under the Order or Decree boilerplate documents, all known ARARs and exempt laws/permits/approvals must be identified. For example, a cleanup action that involves in-water construction has the HPA as an ARAR and the placement of capping material requires an HPA permit. However, the HPA may qualify as an exempt permit. In this case, Ecology would consult with the Washington Department of Fish and Wildlife (WDFW) to determine the substantive requirements. Those substantive requirements would be included in the Order or Decree.

### 15.2.1 Substantive requirements

Identification of the exempt laws/permits/approvals and substantive requirements for a cleanup action must be determined before starting the in-water work. It is the responsibility of Ecology and the PLPs to coordinate and consult with the state agencies and local governments to determine the substantive requirements for the exempt laws/permits/approvals. Below are permits/approvals and substantive requirements that will likely be required for in-water sediment work, and the agency that should be consulted:

- **HPA.** Projects involving in-water construction activities typically require an HPA. HPAs are issued by the WDFW, and define state requirements for construction activities in order to avoid unnecessary disturbance to fish, shellfish, and wildlife.

- **Shoreline Management Substantial Development Permit.** Projects within the city and county limits and within 200 feet of the ordinary high water mark of a waterbody typically must obtain a Shoreline Management Substantial Development Permit. Permits are issued by the local government, and include requirements to protect the ecological function of shorelines. The WDFW and the local government should be consulted as part of cleanup design and permitting to identify applicable substantive requirements, and to ensure these requirements are addressed.

- **Coastal Zone Management Consistency.** The Coastal Zone Management Act (CZM) requires the state to review all federal permits for consistency with the CZM. Ecology is the agency responsible for CZM review in Washington's 15 coastal counties: Clallam, Grays Harbor, Island, Jefferson, King, Kitsap, Mason, Pacific, Pierce, San Juan, Skagit, Snohomish, Thurston, Wahkiakum, and Whatcom. Ecology reviews proposed projects to determine if the project activities are consistent with Washington's CZM Program's Enforceable Policies. A CZM Certification of Consistency Form may need to be submitted for certain projects.

## 15.3 Required Permits, Approvals, and Reviews

Cleanup actions at a sediment site may require a permit, an approval, or a consultation with the applicable agency. See Appendix G for a list of recommended best management practices that may be applicable when conducting sediment cleanup. The following list of permits or approvals may apply to sediment cleanup actions:

- **Federal 404 Nationwide 38 Permit (NWP 38).** Permit for discharge of dredged, excavated, or fill material to waters of the United States pursuant to Section 404 of the CWA. This permit is required if the cleanup will be performed under the authority of MTCA using a NWP 38 permit issued by the Corps. The federal permitting process includes review of issues relating to wetlands; tribal treaty rights; threatened and endangered species; habitat impacts; historical/archeological resources; dredged material management; environmental impacts in accordance with NEPA; and other factors. A Joint Aquatic Resources Permit Application (JARPA) must be submitted to the Corps. The following describes several of the federal permitting requirements:

    - **CWA Section 401 Water Quality Certification**. The general requirements under section 401 of the Clean Water Act must be met and detailed in the Consent Decree or other enforcement mechanism under MTCA. This will ensure that the cleanup actions will comply with state water quality standards and other aquatic resource protection requirements under Ecology's authority. Consultation with the Shorelands and Environmental Assistance Program 401 permit writers is

required. An individual 401 review is required for cleanup actions that affect more than half an acre of wetlands or are not authorized under MTCA.

- **Pre-construction notification to the Corps district engineer prior to beginning in-water construction**. This is required under General Condition 31 (U.S. Corps, 2012) and Section 10 of the Rivers and Harbors Act and Section 404 of the Clean Water Act.

- **Endangered Species Act**. The Corps will be responsible for issuing approval of the NWP 38 following consultation with the federal agencies.

- **Federal 404 Individual Permit**. Permit for discharge of dredged, excavated, or fill material to waters of the United States pursuant to Section 404 of the Clean Water Act. This is required if the Corps determines the cleanup does not meet the requirements of an NWP 38. The federal permitting process includes review of issues relating to wetlands; tribal treaty rights; threatened and endangered species; habitat impacts; historical/archeological resources; dredged material management; and environmental impacts in accordance with NEPA. The time required to complete 404 permitting and associated regulatory reviews can vary from one to several years. A JARPA must be submitted to the Corps. The following describes several of the federal permitting issues:

  - **Endangered Species Act Review**. If the site area is current or potential habitat for threatened and/or endangered species, the cleanup actions will be subject to Endangered Species Act review. The National Marine Fisheries Service (NMFS) and the United States Fish and Wildlife Service (USFWS) will perform the review as part of the Section 404 Individual permit process.

  - **Historical/Archaeological Review**. As part of the Section 404 permit process, the Corps will review the cleanup actions to determine whether they will disturb historical or archaeological resources. If such resources are likely to be present, certain provisions and response actions during implementation of the cleanup may be required, consistent with Section 106 requirements of the National Historic Preservation Act (NHPA). The regulations also place major emphasis on consultation with tribes and consultation must respect tribal sovereignty and the government-to-government relationship between the federal and tribal governments.

  - **Puget Sound Dredged Material Management Program**. In Puget Sound and freshwater, except port projects on the lower Columbia River, the open water disposal of sediment is managed by the Dredged Material Management Program (DMMP). This program is administered jointly by the Corps (Seattle District), the US Environmental Protection Agency, the Washington State Department of

Natural Resources (WDNR), and Ecology. The DMMP has developed the Puget Sound Dredged Disposal Analysis protocols which include testing requirements to determine whether dredged sediments are appropriate for open-water disposal. The protocols also evaluate whether the surface exposed by dredging meets state anti-degradation requirements. Additionally, the DMMP designates disposal sites throughout Puget Sound. As part of the Section 404 permit process, the Corps will ensure that dredged material is managed in accordance with the requirements of the DMMP.

- **Portland Sediment Evaluation Team.** For port projects on the lower Columbia River, the open water disposal of sediment is managed by the Portland Sediment Evaluation Team (PSET). This program is administered jointly by the Portland Corps, the EPA, USFWS, NMFS, Oregon State Department of Environmental Quality, the WDNR, and Ecology. PSET uses the Sediment Evaluation Framework protocols (RSET 2009) that include testing requirements to determine whether dredged sediments are appropriate for open-water disposal, and evaluating whether the surface exposed by dredging meets state anti-degradation requirements. PSET also designates disposal sites throughout the lower Columbia River. As part of the Section 404 permit process, the Corps will ensure dredged material is managed in accordance with the requirements of PSET.

- **NEPA Review**. Construction projects are subject to environmental impact review under SEPA and/or NEPA regulations. The SEPA review for the site cleanup will be completed by Ecology. NEPA review will be completed by the Corps through the Federal 404 permit process.

- **CWA Section 401 Water Quality Certification**. This will be issued by Ecology's SEA Program pursuant to Section 401 of the CWA unless the project is permitted under an NWP 38. As part of the 404 Individual permitting process, a section 401 water quality certification must be obtained from Ecology. Certification ensures that the 404 permitted actions will comply with state water quality standards and other aquatic resource protection requirements under Ecology's authority. If a project is permitted under an NWP 38, an individual 401 Certification will not be issued.

- **NPDES Permit**. This is for discharge of pollutants to waters of the United States pursuant to CWA Section 402. The cleanup of the site may generate wastewater that will be either discharged to the local sanitary sewer system or to surface water. In addition, upland areas may be used for staging, treatment or processing of water during cleanup. Discharge of pollutants to surface water requires a permit under CWA Section 402 to ensure compliance with state water quality standards. NPDES permits are obtained from Ecology.

- **Washington State Scientific Collection Permit**. This is for the collection of food fish, shellfish, or wildlife, or their nests and/or eggs for the purpose of research or display pursuant to WAC 220-20-045 and WAC 232-12-276. Post-cleanup monitoring of the site may require the collection of fish or shellfish tissue to ensure that concentrations remain below applicable standards. The WDFW issues this permit as part of their management and protection of the resource.

# Chapter 16
# Removal of Creosote-Treated Pilings and In-Water Structures

## 16.1 Introduction

Chapter 16 provides guidance on how to remove creosote-treated pilings and structures (such as docks, in-water structures, and bulkheads) that are located in or near cleanup sites, and why their removal may be necessary. Ecology also encourages using this guidance when removing creosote-treated pilings and structures that are not associated with cleanup actions (e.g., habitat restoration or mitigation projects).

Information found in this chapter is important for managing source control and minimizing impacts to human health and the environment, such as benthic organisms, fish, and critical habitat. It also helps meet remedial action requirements.

Previous Washington state and federal guidance for removing creosote-treated pilings and structures had been limited to instructions for meeting minimum requirements for a) development projects, b) maintaining existing structures, and c) restoring habitat. This section differs because it provides specific technical and policy recommendations for all piling removal projects, with an emphasis on those associated with remedial actions.

Ecology developed this chapter to help people navigate the unique problems caused by the presence and improper removal of creosote-treated pilings and structures in the aquatic environment, because the situations:

- Contribute to contamination and impairment of aquatic life in nearshore environments where a) the benthic community thrives, b) forage fish spawn, c) juvenile salmon migrate, and d) both humans and aquatic life harvest resources such as shellfish.
- Impact the quality of critical nearshore habitat.
- Be a recontamination risk for cleanup sites.
- Physically interfere with the implementation and effectiveness of a selected remedy.
- Pose a risk to humans, as creosote can cause chemical burns on bare skin that comes into direct contact with treated pilings and structures.

- Pose physical hazards to vessels and water-based activities due to structural degradation.

Section 16.4 later in this chapter describes the history of creosote-treated pilings in Washington.

## 16.2 Policy for Removal of Creosote-Treated Pilings

Scientific studies show that creosote-treated pilings and structures have harmful effects on cornerstone aquatic animals in the nearshore that impact the health of higher trophic-level species. For example, harmful effects that result in contaminated fish and shellfish, high forage fish mortality, and reduced embryo survival will impact salmon and Orca whales. (For more detail about the science, see Table 16-1 and Appendix G.) Since 2004, Ecology and the Department of Natural Resources (DNR) have removed roughly 25,000 creosote-treated pilings in Puget Sound through restoration and cleanup programs. Even with these significant removal efforts, King County estimates that more than 63,000 creosote-treated pilings remain in the Duwamish Estuary, Elliott Bay, Lake Union, and the Ship Canal.

Given this sobering information, Ecology generally recommends completely removing creosote-treated pilings and creosote-treated derelict structures, and fully replacing them (when necessary) with suitable material such as steel or cured concrete. The target goal is 100% removal, which means completely removing all pilings (not cutting them, for example). If necessary, Ecology may adjust this target during design or construction based on site-specific conditions (see Section 16.2.1). Recent data from construction completion reports shows that many of the piling removal efforts in Puget Sound have achieved a 97% or greater removal rate (see case studies in Section 16.5). The long-term benefits of full removal will usually outweigh any short-term impacts. Benefits include reducing a) the potential for recontamination of cleanup sites, b) sources of contaminants into the aquatic environment, and c) further degradation of critical nearshore habitat.

Incomplete or partial removal of creosote-treated pilings can happen for a number of reasons: selecting an unqualified contractor; false reporting by selected contractors; poor or limited oversight during construction; limited knowledge of negative effects of PAHs from treated pilings and their incomplete removal; shallow water and constrained site conditions; deteriorated condition of pilings; limited funding, etc.

It is crucial to try and prevent these possibilities, as illustrated by project examples:

- **Quilcene Bay piling removal project (Hood Canal).** Due to the improper and incomplete removal of creosote-treated pilings, PAH concentrations in herring eggs were elevated above the pre-removal concentrations. In addition, there were concerns about the additive and bioaccumulative effects of contaminant mixtures released to sediment and the water column.

- **Wyckoff Superfund site (Eagle Harbor; Figure 16-1).** Cut or broken creosote-treated piling stubs became exposed due to wind and wave action. These have remained for decades as unsightly stubs that continue to pose sources of contamination and nearshore hazards.

For complete removal, Ecology recommends in order of preference:

1. Vibratory hammer method
2. Direct pull method
3. Clamshell bucket method

For full replacement, Ecology recommends in order of preference:

1. Steel with a coating proven not to cause adverse impacts to aquatic life
2. Concrete that has been properly cured.

Ecology may choose alternate options such as wrapping or sleeving (Figure 16-2) if: a) complete removal and/or full replacement with a suitable material is not feasible due to technical limitations, and b) the pilings are in active use and structurally competent. Alternative options such as these will reduce leaching to sediment and the water column (CCC, 2012). The wrap or sleeve material should be polyvinyl chloride or fiberglass-reinforced plastic and extend above and below the portion of the piling in contact with the water. For more information on coatings and curing, see References in Section 16.5.

### 16.2.1 Removing creosote-treated piling within a cleanup site footprint

Ecology recommends completely removing creosote-treated pilings from the cleanup footprint and fully replacing (if necessary) with a suitable material under the following circumstances:

- **To implement source control actions, especially when:**
  - Retaining the pilings is likely to recontaminate the cleanup site.
  - The pilings are derelict, no longer in use, or causing ongoing chemical and physical degradation of aquatic life and habitat.
  - Leaving them is inconsistent with post-construction habitat restoration goals.

- **To implement an effective and protective remedy, especially when:**
    - Pilings physically interfere with movement and staging of dredging or construction equipment.
    - Contaminated sediment near the pilings must be remediated but the pilings interfere with implementing an active remedy (e.g., dredging, capping, *in situ* treatment).
    - Leaving them is inconsistent with post-construction habitat restoration goals

In unusual cases, 100% removal of pilings may contribute to slope instability. In these cases, efforts should be made to reduce slope instability, which could include decreasing the number of pilings to be removed, using additional Best Management Practices, or implementing slope stabilization measures after removal. Analysis should be conducted to identify any hydraulic connections to upland contamination, and piling removal should be conditioned to prevent sediment contamination.

As appropriate, Ecology will work with land owners, PLPs, and regulatory agencies to ensure that piling removal does not preclude the ability to rebuild a necessary structure.

### 16.2.2 Removing creosote-treated piling <u>outside</u> a cleanup site footprint

If derelict or active-use pilings are located near a cleanup site but outside the site footprint, Ecology may not require their removal when:

- It can be reasonably determined that the recontamination potential is low, and
- The pilings will not interfere with effectively implementing the remedy.

### 16.2.3 Removing creosote-treated piling near other in-water actions

When a MTCA piling removal project is in the vicinity of a planned in-water action (such as a CERCLA site, development, or habitat restoration), Ecology or PLPs should initiate early coordination and communication with appropriate parties (e.g., EPA, DNR, Ports) regarding piling removal and other source control efforts. Ecology recommends integrating piling removal with other cleanup, habitat restoration, and development activities, such as dredging, excavation, capping, and structure removal or replacement.

This guidance should also be shared with project partners, stakeholders, and agencies conducting similar piling removal work, to convey Ecology's expectations for MTCA cleanup sites and their

vicinity. Such work could include Washington DNR lease close-outs; habitat restoration, enhancement, and mitigation projects; and natural resource damage settlement projects.

Clearly communicating expectations and consistently implementing guidance and regulatory requirements for in-water projects in similar geographic locations will improve cleanup outcomes.

### 16.2.4 State-funded in-water actions

The complete and effective removal of creosote-treated pilings will be a high priority when a cleanup project is entirely or partially funded by the state (e.g., through Ecology's Remedial Action Grant program, a legislative proviso, or a natural resource damage settlement).

## 16.3 Methods and Best Management Practices for Removing Pilings

This section includes methods and BMPs for the most effective piling removal process. Ecology expects these or more stringent practices to be implemented when removing creosote-treated pilings and structures associated with cleanup actions. Refer to the flowchart (Figure 16-3) for when and how to employ each method and BMP.

The following methods and BMPs include and build on the minimum requirements found in:

- EPA (EPA 2016)
- WDFW [(WAC 220-660-380(10)(F)(i) through 220-660-380(10)(F)(v) and WAC 220-660-400(6) through 220-660-400(7)]
- DNR (DNR 2017)

These minimum requirements provide greater specificity with respect to equipment, qualified contractors, sequencing, goals and expectations, intertidal and subtidal environments, handling, containment, and disposal as related to cleanup actions.

An important consideration for any piling removal effort is potential changes to hydraulic and shoreline dynamics. Often, the presence of pilings attenuates wave and current energy, resulting in deposition of materials that would otherwise be carried along in the drift cell. When pilings and structures are removed, the increased erosion and transport of previously deposited material can result in significant changes to the beach profile, shoreline conditions, and an existing remedy. Piling stubs can be exposed if pilings are cut. Dynamics such as these should be considered when developing a piling removal plan.

Consideration should also be given to protective and restorative actions that address or compensate for changes to wetlands, eelgrass beds, and other important habitats that may result from wave, current, light, and other dynamics. Project managers should discuss these possible changes with PLPs, consultants, tribal resource managers, and natural resource agency staff throughout the cleanup process, especially during the Feasibility Study, Cleanup Action Plan, and Engineering Design phases.

### 16.3.1 Piling removal methods

There are three basic methods for removing pilings: vibratory hammer, direct pull, and clamshell bucket. Each method should use proper equipment, along with general and site-specific BMPs, to reduce resuspension of sediments, control turbidity, and manage wood pilings and fragments in the containment basin and within the boomed area.

Ecology expects these methods to be used in this order of preference:

1. Vibratory hammer. This method uses a land-based or barge-mounted excavator or crane-mounted platform (Figure 16-4). This method should be used first, since it typically results in complete removal of the piling and least disturbance to the bottom substrate. (If the piling is too decayed or too short to efficiently use a vibratory hammer, Ecology may allow the alternate methods of direct pull or clamshell bucket—see Figure 16-3.) The piling should first be "woken up" by vibrating it to break the sediment bond, thereby reducing the volume of sediment and potential for breakage. Vibratory hammers create a vertical vibration from rotating eccentric weights powered by hydraulic or electric motors. This in turn liquefies the sediment, causing the substrate particles to lose their frictional grip on the piling so the surrounding sediment does not have to be moved.

2. Direct pull. This method wraps a chain or choker around the piling and pulls it directly from sediment using a crane or excavator. It is typically used with vibratory extraction to lift and place the freed piling in a containment and processing area. Careful excavation of sediment around the piling base may be necessary to provide enough surface area to apply the chain or choker.

3. Clamshell bucket. This method uses a land-based or barge-mounted excavator or crane-mounted clamshell bucket to grasp then pull up the piling. This method may be appropriate when a vibratory hammer or direct pull method fails to remove a) broken or damaged pilings, or b) pilings cut at or below the mudline where there is little or no stub above the mudline (Figure 16-1).

## 16.3.2 Piling removal BMPs

The following BMPs should be used to implement the methods described in Section 16.3.1:

- Site assessment. Conduct a survey to estimate the number, condition, depth, and distribution of pilings (i.e., whether they are intertidal, subtidal, individual or groupings of pilings):
    - For pilings above the mudline, a visual survey may be adequate.
    - For derelict structures or areas that have undergone reconstruction or filling, there may be broken or discarded pilings below the mudline (Figures 16-1, 16-5, 16-6). In these cases, it will be necessary to use a diver, a high-resolution or side scan sonar, or a remote-operated vehicle to take photos or videos.
- Equipment. The project engineer or contractor should evaluate the condition of the pilings to determine the most effective land- or water-based equipment necessary to reach the target removal goal of 100%. Land-based equipment may be appropriate for intertidal areas. Water-based equipment (e.g., integrated tug and spud or jack-up barge systems) will be necessary in deeper water. A spud consists of a heavy-duty steel pipe driven into the sediment to stabilize heavy equipment and prevent barge movement. Appropriate containment is necessary if removed pilings will be temporarily stored on the barge.
- Sensitive aquatic habitat (e.g., eelgrass, wetlands, and kelp beds; Figure 16-6). The following should be implemented when pilings are located in sensitive habitat:
    - Map the locations of sensitive aquatic habitat and provide the information to the construction contractor before starting the work.
    - Avoid or minimize working above or adjacent to sensitive habitat. Implement at least a ten-foot buffer around the area.
    - To prevent barges and tugboats from becoming grounded and disturbing underlying sediment, keep them at adequate tidal elevations. Do not allow the construction barge spuds to damage sensitive habitat.
    - Between the window of March 21 through September 21, barge operations should not shade eelgrass beds longer than four consecutive days. If eelgrass beds are shaded for four consecutive days, allow the shaded portion three consecutive days of uninterrupted natural light.

- Tidal conditions. To reduce turbidity, increase visibility, and reduce risks of breakage, removal should occur during low tide conditions and in the dry when possible. If water-based removal is being performed, tidal conditions should be tracked to maintain booms and containment devices, and to avoid grounding barges (Figure 16-7).

- Piling damage. To reduce leaching of creosote, every attempt should be made to minimize damage to pilings, i.e., twisting, bending, shearing, or snapping them. To grasp any stubs adequately, it may be necessary to carefully excavate around the piling by using either an excavator or a diver (Figure 16-5).

- Resuspension and turbidity. To reduce turbidity, resuspension of sediment, and the release of creosote, pilings should be extracted slowly and proper equipment should be used (e.g., the correct size of both bucket and barge, booms, and silt curtains).

- Hydraulic jetting. These devices must not be used to remove pilings or sediment around the base of pilings because they can significantly increase turbidity and resuspend contamination. If sediment must be excavated from around the piling, hand excavation by divers is more appropriate.

- Divers. During or after the removal process, divers may be needed to remove sediment around pilings in order to gain access to competent portions of a piling, or to verify post-removal conditions. Divers and/or underwater video are good methods for confirming that all pilings and debris have been removed.

- Multiple attempts. Cutting a piling should be the last resort. Multiple attempts should first be made to fully remove the piling through vibratory extraction, direct pull, or clamshell bucket methods.

- Containment Booms and Devices**.** Containment booms (Figures 16-7 and 16-8), absorbent booms, and/or silt curtains should be used to confine resuspended sediment and debris, reduce turbidity, and manage surface water sheens Deploy them as follows:

    - Extend booms and/or silt curtain around the entirety of the work area including barges and transfer equipment. This will prevent debris and contaminants from migrating off-site.

    - Anchor booms to the substrate or surrounding overwater structures when strong winds or currents are present.

- Deploy sorption pads to absorb sheens created during the removal process.

- Tides, river flows, wind, and waves can entangled or shift booms or other containment devices resulting in off-site migration of debris or contaminants. Monitor booms on a daily basis to ensure they are functioning properly, and conduct maintenance as soon as problems arise.

- Before booms are removed, all sheens and debris must be removed from the water surface. If pilings or fragments are transferred to a containment basin using the clamshell bucket or similar equipment, the bucket should not leave the boomed area during that transfer. .

- Vessel traffic. When working in areas that are subject to a high degree of vessel traffic and boat wakes (e.g., port or ferry terminals, marinas) and recreational activity (e.g., fishing, kayaking), additional coordination with other authorities may be required to ensure all BMPs are functioning properly.

- Qualified contractors. All contractors conducting piling removal should be qualified and experienced to work in environments typically found at cleanup sites in Washington state. One such example is being certified in Hazardous Waste Operations and Emergency Response. Ecology may request documentation related to a contractor's past work performance. The selected contractor should submit a detailed Work Plan to the Ecology project manager that describes all BMPs to be used—such as equipment, sequencing, methods, and procedures for containment and disposal. The project manager should meet with the contractor before construction to review and discuss BMPs and expectations.

#### 16.3.2.1 Incomplete removal by cutting

Cutting pilings should be the last option for removal (Figure 16-3). If Ecology determines it is necessary—due to breakage at or near the existing substrate, or if removal was not possible by vibratory hammer, direct pull, or clamshell bucket—the following should be done:

1. **In intertidal habitat,** cut the piling at least 3 feet below the existing mudline or final grade. Cut it even lower if the area is subject to beach profile changes.

2. **In subtidal habitat**, cut the piling at least 2 feet below the existing mudline.

3. To allow access for cutting, hand excavate around the base of the piling to the cut depth. If an excavator must be used, take care to avoid damaging the piling, e.g., shearing, scraping, or breaking it.

4. Make a single cut using a chainsaw, hydraulic chainsaw (for underwater removal), hydraulic shear, or other appropriate equipment.

5. Load the piling into a container and bring it to the surface for verification and disposal. Avoid placing the cut piling on the existing substrate.

6. Following removal, cap the pile stub using an organoclay and sand mixture or bonnet—or add mounded substrate into the cut piling hole to contain any leaching.

7. Tarp the area next to the piling and attach a bag to the saw to minimize sawdust and debris loss.

8. In intertidal areas, cut during the lowest tide possible to reduce turbidity and protect water quality.

9. Document the location of the cut piling, typically by GPS. Provide the coordinates of cut pilings to project managers at Ecology, the U.S. Army Corps of Engineers, and DNR (if the site is located on state-owned aquatic land). To report cut or broken pilings, follow agency and site-specific permitting requirements provided by the project manager.

#### 16.3.2.2 Removing pilings in highly contaminated sediment

The above BMPs apply when removing pilings within the cleanup site footprint. However, there may be pilings located in an area that is <u>known</u> to be highly contaminated that will require special attention:

1. Minimize disturbance of contaminated sediment by identifying the optimal tidal conditions and piling removal method during the planning phase. For example, consider if a clamshell bucket may more effectively remove buried or broken pile stubs than a vibratory hammer or direct pull.

2. Determine if it is most effective to work:

    a. In the dry at low tide, which may be more protective of water quality, or

    b. At high tide, which may allow greater access of in-water equipment, or

    c. During a slack or incoming tide, which may be more protective of water quality.

3. To minimize water quality exceedances such as turbidity and to keep BMPs effective, consider the timing of tidal height and direction of water flow, and factor in the changing tidal conditions throughout the day.

4. Complete removal is preferred. If Ecology determines that cutting below the mudline is necessary, the cut depth should minimize resuspension of contaminated sediment.

5. To control resuspension of contaminated sediment, clean sand may be placed within the piling removal area prior to extraction on a case-by-case basis.

6. If no further remedial action is being taken in the area, place a cover of 6 inches of clean sand in a 5-foot perimeter over the piling removal area. The type of sand—such as grain size—must be appropriate for using in a benthic habitat and for controlling any residuals that may be exposed.

#### 16.3.2.3 Sequencing with cleanup actions

Ensure the Cleanup Action Plan and Engineering Design Report outline how to sequence piling removal and cleanup construction to avoid recontamination, and how to implement in-water activities effectively. Such details could include identifying:

- The different construction activities such as piling and structure removal, land- or water based excavation, dredging, capping, and construction of structures (bulkheads, piers, or breakwaters, for example).

- The specific location(s) of each construction activity.

- The number of construction seasons and work periods, for example, summer low tides, fall and winter high tides, and forage fish spawning seasons.

- The direction, volume, and velocity of water flow, tidal cycles and drift cells.

---

**EXAMPLE:** The Port Gamble Bay sediment cleanup documented descriptions such as these in the Cleanup Action Plan and Engineering Design Report, including:

- Defining three cleanup footprints: North Mill (6 acres), South Mill (19 acres), and Central Bay (77 acres).

- Avoiding disturbing eelgrass habitat to the extent possible and mitigating for any impacted habitat as a result of cleanup.

- Extensive piling, overwater structure, and bulkhead removal.
- Intertidal excavation and engineered cap construction.
- Subtidal dredging and capping (engineered and enhanced monitored natural recovery).
- A large drift cell transported sediment from south to north and factored into sequencing of the cleanup over two consecutive seasons:
    - Season 1 (September to January). First, the intertidal pilings and overwater structures in the South Mill were removed. This was followed by excavating intertidal sediment during nighttime low tides and backfilling segments before the incoming tide inundated the work area. Piling removal in the subtidal was done parallel to the intertidal sediment excavation. This was followed by subtidal dredging and capping which included creating an eelgrass mitigation bench at appropriate elevations to support eelgrass transplants. All in-water work was done moving south to north to match the dominant sediment transport pathway and reduce the potential for recontamination of the excavated, dredged, and capped areas.
    - Season 2 (July to January). A small area of the South Mill was completed because there was a delayed start during Season 1 and construction in the North Mill and Central Bay were completed.
- Eelgrass beds located immediately adjacent to the cleanup footprint were buffered by a minimum of 10 feet to minimize impacts to this habitat. Creosote-treated piling stubs were present within an area of eelgrass and required careful management during removal (Figure 16-6). Removal of these pilings was performed during high tides with diver assistance. Stubs that extended above the mudline were removed using a vibratory hammer attached to each pile. For stubs at or below the mudline, divers hand excavated sediment from around the base of each piling to provide access to the piling. Following removal, hand-excavated sediment was placed in the divots left by the removed pilings.

---

#### 16.3.2.4 Handling, containment, storage, and disposal

Once the piling is removed, it should not be shaken or hosed off to remove any sediment still attached. Instead the piling should be immediately moved to a containment area (e.g., barge deck, adjacent pier, or designated upland location) for processing and disposal.

Containment areas prevent the release of sediment, untreated or unfiltered water, debris, and materials from the processing area (Figure 16-9). The containment basin should be constructed of durable plastic sheeting or a similar material. It should have continuous sidewalls that are supported by hay bales, ecology blocks, and other non-contaminated materials, and lined with an oil-absorbent boom to collect leachate or runoff.

Processing pilings in the containment area typically means a) cutting them into at least 4-foot sections to prevent their reuse , and b) containing sawdust, splintered wood, and other debris using materials such as a walled canopy, geotextile or plastic sheeting, absorbent pads, or bedding material (Figure 16-9).

Within six months, all material in the containment area should be removed and disposed of in compliance with applicable local, state, and federal regulations. The treated wood must be disposed according to WAC 173-303-07(3)(g) within six months of becoming waste. Burning for energy recovery may pose a risk of generating dioxins and is not recommended.

#### 16.3.2.5 Post removal

Holes left by the removed piling may need to be filled with clean sand or gravel when:

- The holes will not naturally fill within 24 hours.
- Removing the piling will result in a significant modification of the sediment grade—in areas where pilings are dense, for example.
- There is contamination at-depth that may be released to the environment.

Because pilings and supported structures can provide habitat for birds and wildlife, Ecology recommends coordinating with WDFW to discuss constructing new habitat features in areas where suitable—for example, building non-toxic nesting platforms or poles for nesting boxes.

## 16.4 History of the Environmental Effects and Use of Pilings in Washington State

For hundreds of years, wood pilings have supported industrial, commercial, and residential in-water uses: log rafting, wood product manufacturing, cargo transport, and vessel operations, and served as protective structures such as breakwaters, docks, and piers. Most pilings were treated with pentachlorophenol, creosote, or metal-based chemicals to preserve the pilings from damage by wood-boring animals, microorganisms, and the erosive effects of marine and freshwater environments. However, the WDFW now prohibits oil-based preservatives such as creosote or

pentachlorophenol to treat wood in marine and freshwater environments, due to adverse impacts on aquatic resources (WAC 220-660-120(6)(f)). Treated wood may also be a source of dioxins/furans, a by-product from the manufacture of pentachlorophenol.

Creosote is a derivative of coal tar produced by high temperature carbonization of bituminous coal, and is impregnated into a wooden piling using pressurized and vacuum treatment processes (WDFW/WDOE/WDOT, 2001). Creosote mixtures vary and their composition includes different percentages of low molecular weight PAHs (i.e., 2-3 ring structures such as naphthalene, fluorene, and anthracene) and high molecular weight PAHs (i.e., 4-6 ring structures such as pyrene, chrysene, benzo[a]pyrene).

Weathering, wood treatment processes, PAH solubility, and diffusion rates from treated wood influence the composition of PAHs in treated wood products (WDFW/WDOE/WDOT, 2001). In general, low molecular weight soluble PAHs diffuse into the water column faster than the higher molecular weight less soluble PAHs—which tend to adsorb to organic matter and settle in sediment.

Given Washington state's reliance on commercial and recreational aquatic activities, existing creosote-treated pilings that support aquatic structures will continue to be in demand. Therefore, it is important to understand the expanding body of scientific literature that discusses toxicity and effects of PAHs from creosote-treated pilings on: Pacific herring (*Clupea pallasii*), English sole (*Pleuronectes vetulus*), zebrafish (*Danio rerio*), pink salmon (*Onchorhynchus gorbuscha*), and invertebrates. PAHs are pervasive in aquatic environments, particularly urban areas that receive stormwater and are near individual pilings or dense clusters of pilings that support mooring structures (such as dolphins).

Because PAHs are typically metabolized or processed by marine and freshwater vertebrates such (e.g. fish), they do not bioaccumulate but they are capable of causing a variety of other toxic effects (Johnson et al., 2002). Some invertebrates (e.g., shellfish) can bioaccumulate PAHs and pose risks to humans and higher trophic levels (e.g., birds) through consumption of contaminated shellfish. For further information on these environmental effects, see Table 15-5, which summarizes environmental effects of PAHs from creosote-treated structures on aquatic life.

# 16.5 Literature Resources for BMPs and PAH Effects

## 16.5.1 Piling removal BMPs

California Coastal Commission. (2012). *Pilings – Treated wood and alternatives.* California Coastal Nonpoint Source Program Water Quality Fact Sheet. Spring 2012.

EPA Region 10. *Best Management Practices for piling removal and placement in Washington state.* February 18, 2016.

Fisheries and Oceans Canada. *Standards and best practices for instream works.* Version 1.0.

U.S. Army Corps of Engineers. (2017). *Programmatic Endangered Species Act Consultation Piling Replacement List of Requirements*. Version: May 3, 2017.

Washington Department of Natural Resources. (2017). *Derelict Creosote Piling Removal Best Management Practices For Pile Removal & Disposal.* Updated 1/25/2017.

Western Wood Preservers Institute. *Specifiers guide Best Management Practices for the use of preserved wood in aquatic and sensitive environments.* Developed for the U.S. and Canada by: Western Wood Preservers Institute, Southern Pressure Treaters' Association, Southern Forest Products Association, Wood Preservation Canada, Creosote Council.

Wood Preservation Canada. 2011. *Best Management Practices for the use of treated wood in aquatic and wetland environments.* Revised November 1, 2011.

## 16.5.2 Case Studies

Anchor QEA, LLC. (2018). *Final cleanup action report – season 2. Port Gamble bay and mill site cleanup project.* Prepared for Pope Resources, LP/OPG Properties, LLC. February 2018.

Anchor QEA, LLC. (2016). *Final cleanup action report – Season 1. Port Gamble Bay cleanup project.* Prepared for Pope Resources, LP/OPG Properties, LLC. December 2016.

Anchor QEA, LLC. (2012). *MJB north area as-built construction completion report. Former Scott Paper Mill site, Anacortes, Washington*. Ecology Consent Decree No. 09-2-01247-7. Prepared for Washington State Department of Ecology. February 2012.

GeoEngineers. (2012). *Volume 1 – Port uplands and marine area as-built construction completion report. Former Scott Paper Mill site, Anacortes, Washington*. Ecology Consent Decree No. 09-2-01247 for Washington State Department of Ecology on Behalf of Port of Anacortes. September 19, 2012.

Lanksbury, J.A. and West, J.E. (2015). *Toxic contaminants in bay mussels (Mytilus trossulus) transplanted to Port Gamble Bay, Washington before cleanup and restoration (2015-2017).* Prepared for Washington Department of Ecology, WDFW-Ecology Interagency Agreement #C1500080. June, 2015.

Parametrix. (2011). *Creosote release from cut/broken piles, Asarco Smelter Site.* Prepared for Department of Natural Resources. Revised April 2013.

West, J.E., Carey, A.J., Lanksbury, J.A., Niewolny, L.A., and O'Neill, S.M. (2015). *Effectiveness monitoring for a creosote-piling removal project: Embryos of Pacific Herring (Clupea pallasii) as sentinels for the presence of polycyclic aromatic hydrocarbons (PAHs).* Washington Department of Fish and Wildlife.

West, J.E., Carey, A.J., Lanksbury, J.A., Niewolny, L.A., and O'Neill, S.M. (2015). *Toxic contaminants in embryonic and adult Pacific herring (Clupea pallasii) from Port Gamble Bay, Washington: Extent and magnitude of contamination by polycyclic aromatic hydrocarbons (PAHs) and other toxic contaminants.* Washington Department of Fish and Wildlife.

Weston Solutions. (2006). *Jimmycomelately piling removal monitoring project final report.* Prepared for: Jamestown S'Klallam Tribe. March 2006.

## 16.5.3 Rules and Regulations

Washington State Department of Ecology (Ecology). 2013. Sediment Management Standards. Chapter 173-204 WAC. Publication no. 13-09-055.

Washington State Department of Fish and Wildlife. (WDFW) WAC 220-660-380(10)(f)(i) – (f)(v) and WAC 220-660-400(7)

## 16.5.4 Scientific Literature

Arfsten, D. P., Schaeffer, D. J., & Mulveny, D. C. (1996). The effects of near ultraviolet radiation on the toxic effects of polycyclic aromatic hydrocarbons in animals and plants: a review. *Ecotoxicology and Environmental Safety, 33,* 1-24.

Arkoosh, M.R., Clemons, E., Huffman, P., Kagley, A.N., Casillas, E., Adams, N., Sanborn, H.R., Collier, T.K., and Stein, J.E. (2001). Increased susceptibility of juvenile Chinook salmon to vibriosis after exposure to chlorinated and aromatic compounds found in contaminated urban estuaries. *Journal of Aquatic Animal Health*, 13:3, 257-268.

Arkoosh, M.R., Casillas, E., Clemons, E., McCain, B., and Varanasi, U. (1991). Suppression of immunological memory in juvenile Chinook salmon (*Onchorhynchus tshawytscha*) from an urban estuary. *Fish and Shellfish Immunology*, 1, 261-277.

Becker, L, Matuschek, G., Lenoir, D., and Kettrup, A. (2001). Leaching behavior of wood treated with creosote. *Chemosphere*, 42, 301-308.

Betowski, L.D., Enlow, M., and Riddick, L.A. (2001). *The phototoxicity of polycyclic aromatic hydrocarbons.* Presented at The ACS meeting, San Diego, CA. April 1-5, 2001.

Bjorn, L.O. and Huovinen. P. (2015). *Phototoxicity.* In: Bjorn L. (eds) Photobiology The science of light and life. Springer, New York, NY.

Carls, M.G., Rice, S.D., and Hose, J.E. (1999). Sensitivity of fish embryos to weathered crude oil: Part I. Low-level exposure during incubation causes malformations, genetic damage, and mortality in larval Pacific herring (*Clupea pallasi*). *Environmental Toxicology and Chemistry*, 18:481-493.

Carls, M.G., Holland, L., Larsen, M., Lum, J.L., Mortensen, D.G.., Wang, S.Y., and Wertheimer, A.C. (1996). *Growth, feeding, and survival of pink salmon fry exposed to food contaminated with crude oil.* American Fisheries Society Symposium, 18:608-618.

Coles, J.A., Farley, S.R., and Pipe. R.K. (1994). Effects of fluoranthene on the immunocompetence of the common marine mussel, *Mytilus edulis*. *Aquatic Toxicology*, Volume 30:367-379.

Collier, T.K., Anulacion, B.F., Arkoosh, M.R., Dietrich, J.P. Incardona, L.L., Johnson, G.M. Ylitalo, and Myers, M.S. (2013). Effects on fish of polycyclic aromatic hydrocarbons (PAHs) and naphthenic acid exposures. *Organic Chemical Toxicology of Fishes*, Volume 33. DOI:http://dx.doi.org/10.01016/B978-0-12-398254-4.00004-2.

Dawoon, J., Matson, C.W., Collins, L.B., Laban, G., Stapleton, H.M., Bickham, J.W., Swenberg, J.A., and Di Giulio, R.T. (2011). Genotoxicity in Atlantic killifish (*Fundulus heteroclitus*) from a PAH-contaminated Superfund site on the Elizabeth River, Virginia. *Ecotoxicology*, November; 20(8): 1890-1899. doi:10.1007/s10646-011-0727-9.

Department of Health. (2015). *Final public health assessment, evaluation of chemical exposures from shellfish and sediments, Port Gamble Bay, Kitsap County, Washington*. Prepared by

The Washington State Department of Health Under Cooperative Agreement with the Agency for Toxic Substance and Disease Registry. DOH 334-368.

Duncan, D.L., Carls, M.G., Rice, S.D., and Stekoll, M.S. (2017). The toxicity of creosote-treated wood to Pacific herring embryos and characterization of polycyclic aromatic hydrocarbons near creosoted pilings in Juneau, Alaska. *Environmental Toxicology and Chemistry*, 336, No. 5, pp. 1261-1\1269.

Eertman, R.M.H., Groenink, C.L.F.M.G., Sandee, B., Hummel, H., and Smaal, A.C. (1994). Response of the blue mussel *Mytilus edulis* following exposure to PAHs or contaminated sediment. *Marine Environmental Research*, 39:169-173.

Heintz, R. A. (2007). *Chronic exposure to polynuclear aromatic hydrocarbons in natal habitats leads to decreased equilibrium size, growth, and stability of Pink salmon populations.* Publications, Agencies and Staff of the U.S. Department of Commerce. 280. http://digitalcommons.unl.edu/usdeptcommercepub/280

Heintz, R.A., Rice, S.D., Wetheimer, A.C., Bradshaw, R.F., Thrower, F.P., Joyce, J.E., and Short, J.W. (2000). Delayed effects on growth and marine survival of pink salmon *Onchorhynchus gorbuscha* after exposure to crude oil during embryonic development. *Marine Ecological Progress Series*, 208:205-216.

Heintz, R.A., Short, J.W., and Rice, S.D. (1999). Sensitivity of fish embryos to weathered crude oil: Part II. Increased mortality of pink salmon (*Onchorhynchus gorbuscha*) embryos incubating downstream from weather Exxon Valdez crude oil. *Environmental Toxicology and Chemistry*, 18:494-503.

Hese, J.E., Puffer, H.W., Oshida, P.S., and Bay, S.M. (1983). Developmental and cytogenetic abnormalities induced in purple sea urchin by environmental levels of benzo[a]pyrene. *Archives of Environmental Contamination and Toxicology*, *12*:3-19-325.

Incardona, J.P., Day, H.L., Collier, T.K., and Schulz, N.L. (2006). Developmental toxicity of 4-ring polycyclic aromatic hydrocarbons in zebrafish is differentially depending on AH receptor isoforms and hepatic cytochrome P4501A metabolism. *Toxicology and Applied Pharmacology*, *217*:308-321.

Incardona, J.P., Collier, T.K., and Schulz, N.L. (2004). Defects in cardiac function precede morphological abnormalities in fish embryos exposed to polycyclic aromatic hydrocarbons. *Toxicology and Applied Pharmacology*, *196*:191-205.

James, M.O., Schell, J.D., Boyle, S.M., Altman, A.H., and Cromer, E.A. (1991). Southern flounder hepatic and intestinal metabolism and DNR binding of benzo[a]pyrene (BaP) metabolites following dietary administration of low doses of BaP, BaP-7,8-dihydrodiol or a BaP metabolite mixture. *Chemical-Biological Interactions, 79*:305-321.

Jeong, W.G. and Cho, S.M. (2007). Long-term effect of polycyclic aromatic hydrocarbon on physiological metabolisms of the Pacific oyster, *Crassostrea gigas*. *Aquaculture, 265*:343-350.

Jeong, W.G. and Cho, S.M. (2005). The effects of polycyclic aromatic hydrocarbon exposure on the fertilization and larval development of the Pacific oyster, *Crassostrea gigas*. *Journal of Shellfish Research, 24*:209-213.

Johnson, L.L., Collier, T.K., and Stein, J.E. (2002). An analysis in support of sediment quality thresholds for polycyclic aromatic hydrocarbons (PAHs) to protect estuarine fish. *Aquatic Conservation: Marine and Freshwater Ecosystems, 12:*517-538.

Johnson, L.L., Landahl, J.T., Kubin, L.A., Horness, B.H., Myers, M.S., Collier, T.K., and Stein, J.E. (1998). Assessing the effects of anthropogenic stressors on Puget Sound flatfish populations. *Netherlands Journal of Sea Research, 39:*125-137.

Johnson, L.L., Stein, J.E., Collier, T.K., Casillas, E., McCain, B., and Varanasi, U. (1992). *Bioindicators of contaminant exposure, liver pathology, and reproductive development in prespawning female winter flounder (Pseudopheuronectes americanus) from urban and nonurban estuaries on the Northeast Atlantic coast.* NOAA Technical Memorandum NMFS-NWFSC-1. August 1992.

Lyons, B.P., Pascoe, C.K., and McFadzen, C.K. (2002). Phototoxicity of pyrene and benzo[a]pyrene to embryo-larval stages of the Pacific oyster *Crassostrea gigas*. *Marine Environmental Research, 54*:627-631.

Mastrangelo, G., Fadda, E., and Marzia, V. (1996). Polycyclic aromatic hydrocarbons and cancers in man. *Environmental Health Perspectives, 104*:1166-1170.

McElroy, A.E., Cahall, J.M., Sisson, J.D., and Kleinow, K.M. (1991). Relative bioavailability and DNR adduct formation of benzo[a]pyrene and metabolites in the diet of the winter flounder. *Biochemistry and Physiology, 100C*:29-32.

Meador, J.P, Stein, J.E., Reichert, W.L., and Varanasi, U. (1995). Bioaccumulation of polycyclic aromatic hydrocarbons in marine organisms. *Reviews of Environmental Contamination and Toxicology, 143*:79-165.

Myers, M.S., Johnson, L.L., Hom, T., Collier, T.K., Stein, J.E., and Varanasi, U. (1998). Toxicopathic hepatic lesions in subadult English sole (*Pleuronectes vetulus*), from Puget Sound Washington, U.S.A.: Relationships with other biomarkers of contaminant exposure. *Marine Environmental Research*. *45*:47-67.

NOAA Fisheries – Southwest Region. (2009). *The use of treated wood products in aquatic environments: Guidelines to West Coast NOAA fisheries staff for Endangered Species Act and essential fish habitat consultations in Alaska, Northwest and Southwest Regions.* October 12, 2009, 58 pp.

Perkins, Robert A. (2009). *Creosote treated timber in the Alaskan Marine Environmental. Final Report.* Institute of Northern Engineering. Report No. INE09.XX.

Sabin, L.D., Maruya, K.A. Lao, W., Diehl, D., Tsukada, D., Stolzenbach, K.D., et al. (2010). Exchange of polycyclic aromatic hydrocarbons among the atmosphere, water, and sediment in coastal embayments of southern California, U.S.A. *Environmental Toxicology and Chemistry, 29*:265-74.

Sheldon, B.C., and Verhulst, S. (1996). Ecological Immunology: Costly parasite defenses and trade-offs in evolutionary ecology. *Trends in Ecology and Evolution, 11*:317-321.

Stern, R.S., Zierler, S., and Parrish, J.A. (1980). Skin carcinoma in patients with psoriasis treated with topical tar and artificial ultraviolet radiation. *Lancet, 2*:732-733. PubMed: 6106838

Stratus Consulting, Inc. (2006). *Creosote-treated wood in aquatic environments: Technical review and use recommendations.* Prepared for Joe Dillon, NOAA Fisheries, Southwest Division, Habitat Conservation Division. December 31, 2006.

Varanasi, U., Stein, J.E., Nishimoto, M, Reichert, W.L., and Collier, T.K. (1987. Chemical carcinogenesis in feral fish – uptake, activation and detoxification of organic xenobiotics. *Environmental Health Perspectives, 71:*155-170.

Vines, C.A., Robbins, T., Griffin, F.J., and Cherr, G.N. (2000). The effects of diffusible creosote-derived compounds on development in Pacific herring (*Clupea pallasi*). *Aquatic Toxicology, 51*:225-239.

Vogelbein, W.K. and Unger, M.A. (2006). Liver carcinogenesis in a non-migratory fish: The association with polycyclic aromatic hydrocarbon exposure. *Bulletin of European Association of Fish Pathologist, 26:*11-20.

Weitkamp, D.E. (2011). *Creosote in estuarine habitats literature review*. Prepared for Washington Department of Natural Resources. May 2011.

Werme, C., Hunt, J., Beller, E., Cayce, K., Klatt, M., Melwani, A., Polson, E., and Grossinger, R. (2010). *Removal of creosote-treated pilings and structures from San Francisco Bay. Prepared for California State Coastal Conservancy.* Contribution No. 605. San Francisco Estuary Institute, Oakland, California.

WDFW/WDOE/WDOT. (2001). *Treated wood issues associated with overwater structure in marine and freshwater environments.* White paper submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology, Washington Department of Transportation. April 2001.

Wessel, N., S. Rousseau, X. Caisey, F. Quiniou, and F. Akcha. 2007. Investigating the relationship between embryotoxic and geotoxic effects of benzo[a]pyrene, 17α-ethinylestradiol, and endosulfan on *Crassostrea gigas* embryos. Aquatic Toxicology Vol. 85, pp. 133-142.

West, J.E., O'Neill, S.M., Ylitalo, G.M., Incardona, J.P., Doty, D.C., and Dutch, M.E. (2014). An evaluation of background levels and sources of polycyclic aromatic hydrocarbons in naturally spawned embryos of Pacific herring (*Clupea pallasii*), from Puget Sound, Washington, USA. *Science of the Total Environment, 499:*114-124.

Wolotira, R.J. (2002). *Appendix D: Defining injuries to natural resources in Hylebos Waterway.* Prepared for the Commencement Bay Natural Resource Co-Trustees. March 28, 2002.

*This page intentionally left blank*

**Table 16-1: Environmental effects on aquatic life of PAHs from creosote-treated structures.**

| Organism | Observed Effect | Chemical and Concentration | Detail of effects | Reference |
|---|---|---|---|---|
| Pacific Herring eggs[a] *(Clupea pallasii)* | • Embryo mortality<br>• Reduced hatching rate | Weathered creosote-treated pilings | • 100% mortality of embryos directly attached to pilings<br>• 90% reduction in hatching rate of exposed eggs directly attached to pilings compared to control<br>• 100% of hatched larvae exhibited morphological deformity (e.g., scoliosis, pericardial edema, ascites) | Vines 2000 |
| | $LC_{50}$ | PAHs 50 µg/L | Lethal concentration for 50% of embryos for hatching success | Vines 2000 |
| | Contaminant exposure | PAHs | Sediment exposure to embryos spawned on substrate on or near underlying sediment may serve as a source to surface water | Sabin 2010 |
| | Survival and growth | 22–108 ng/g ww | Manually spawned herring eggs exposed to PAHs in bays with >100-year old creosote-treated pilings | West 2014 |
| | Elevated tissue concentrations | PAHs | Embryos sampled from urban bays within Puget Sound had PAH concentrations similar to San Francisco Bay after the Cosco Busan oil spill. | West 2014 |
| | Elevated tissue concentrations | PAHs | Embryos sampled from Port Gamble in Puget Sound prior to sediment cleanup had PAH concentrations that exceeded the observed effects concentrations established by Carls et al. 1999. Lethal and sublethal risks to herring eggs were greater than in areas where creosote-treated pilings were absent or in lower quantities | West 2015 |
| | Elevated tissue concentrations | PAHs increased 2.1 ng/g ww to 51 ng/g ww | Quilcene Bay weathered creosote-treated piling removal study done in three phases in 2013, 2014, and 2015 to observe conditions before and after piling removal. Pilings were not completely removed, resulting in release of PAHs and elevated tissue concentrations ~17x pre-removal concentrations. Study shows that weathering does not appear to reduce or eliminate risk to embryos. | West 2015 |
| | Larval malformations | PAHs <0.7 ug/L | Weathered crude oil studies show herring sensitive to PAHs in early life stage. | Carls 1999 |
| | $EC_{50}$ failure to hatch (spinal deformation) | PAHs 18 µg/L | Toxicity of creosote-treated wood studied in Juneau, Alaska during spring, summer, and fall. Concentrations increased during summer (~290 µg/g) and decreased in fall. | Duncan 2017 |
| | Swimming impairment | PAHs 22 µg/L | | |
| | $EC_{10}$ (safe exposure level) | 4.6 µg/L | | |

| Organism | Observed Effect | Chemical and Concentration | Detail of effects | Reference |
|---|---|---|---|---|
| Pacific Herring *(Clupea pallasii)* | • Pericardial and yolk sac edema<br>• Jaw reductions<br>• Skeletal defects (lordosis and scoliosis)<br>• Bradycardia<br>• Cardiac arrhythmia<br>• Decreased size<br>• Inhibited swimming<br>• Mortality | Weathered PAHs | Increased weathering changed PAHs from two-ring (naphthalene) to three-ring (phenanthrene) which increased toxicity to fish. | • Incardona 2004<br>• Heintz 1999<br>• Carls 1999 |
| | Toxicity | PAHs | Fish may be susceptible to PAHs because some can metabolize PAHs to toxics and mutagenic intermediates.<br><br>Fish may be susceptible to dietary PAHs due to ingestion of contaminated prey (e.g., invertebrates). | • Meador 1995<br>• Varanasi 1987<br>• James 1991<br>• McElroy 1991 |
| English Sole[b] (*Pleuronectes vetulus*) | • Liver cancer<br>• Lesions<br>• Reproduction | PAHs<br><br>1 ppm dry wt. | Studies have demonstrated a link between cancer and related lesions. A cause and effect relationship between PAHs and toxicopathic liver lesions in English sole is supported by induction of lesions and reproductive impairment. | Johnson 2002, 1998<br>Myers 1998<br>Wolotira 2002 |
| | • Female infertility (3X increase)<br><br>• Lesions and reproductive impairment | PAHs<br>• 5 ppm dry wt.<br><br>• 10 and 100 ppm dry wt. | Increase in lesion prevalence and three-fold increase of lesions with sediment concentrations at 5 ppm dry wt. 40 – 70% studied have one or more lesions and 25 – 75% of adult females are infertile, have inhibited gonadal growth, or do not spawn. | Wolotira 2002 |
| Zebrafish[b] *(Danio rerio)* | • Developmental toxicity<br>• Genotoxicity | | Studies show fish exposed to PAHs have activation of receptors involved in PAH metabolism (e.g., cytochrome P4501A) and DNA damage | Incardona 2006<br>Dawoon 2011 |
| Mummichog *(Fundulus heteroclitus)* | Tumor growth | | Fish in Elizabeth River and Delaware estuary show a link between PAHs in sediment and formation of neoplasms and neoplasia related lesions. | • Vogelbein and Unger 2006<br>• Collier 2013 |

| Organism | Observed Effect | Chemical and Concentration | Detail of effects | Reference |
|---|---|---|---|---|
| Pink Salmon[b] *(Onchorhynchus gorbuscha)* | Reduced survival during incubation | PAHs 1.0 nL/L | Aqueous concentrations of 1.0 nL/L result in reduced survival during incubation. Of those surviving incubation, exposures of 5.4 nL/L had reduced survival in marine water than control. Populations diminished as PAH contamination in natal habitat increased therefore increasing risks of extinction. | Heintz 1999, 2000, 2007 |
| | Lower survival | PAHs 5.4 nL/L | | |
| | Reduced growth | Dietary PAHs | Growth was significantly reduced when exposed to dietary PAHs. | Carls 1996 |
| Invertebrates[c] | Bioaccumulation Toxicity | PAHs | • Study on the effects of PAHs on prey resources (invertebrates and English sole). Sediment concentrations of 7.9 – 8.1 ppm dry wt. had effects on Echinoderm and Neanthes.<br>• Sediment concentrations of 17 ppm dry wt. had effects on oyster larvae.<br>• Sediment concentrations of 69 ppm dry wt. had effects on all invertebrates studied. | • Johnson 2002<br>• PSEP 1988<br>• Ecology 1996 |
| | Impairment | • Benzo(a)pyrene 1 – 50 ng/ml<br>• PAHs | • Purple sea urchin *(Strongylocentrotus purpuratus)* exhibited development abnormalities exposed to PAHs in water.<br>• Pacific oysters *(Crassostrea gigas)* exhibited embryotoxicity, decreased growth, altered fertilization and larval development.<br>• Blue mussels *(Mytilus edulis, Mytilus trossulus)* have exhibited immune response changes, increases in disease susceptibility, reduced feeding rates, and decreased reproduction. | • Hese 1983<br>• Wessel 2007<br>• Jeong 2007<br>• Jeong 2005<br>• Coles 1994<br>• Grundy 1996<br>• Ertman 1995 |
| | Photoxicity | • PAHs 5ug/L | • Phototoxicity of PAHs inhibited shell development in Pacific oyster embryos | Lyons 2002 |
| Juvenile salmondis | Immunosuppression Reduced growth and reproduction | PAHs | Studies show that juvenile salmonids from urban estuaries were immunosuppressed and more susceptible to mortality compared to salmonids from non-urban estuaries. The ability of juvenile salmon to produce a protective immune response poses risks to growth, reproduction, and survival. | • Arkoosh 1991<br>• Sheldon and Verhalst 1996 |

a, Herring are opportunistic spawners in deep intertidal and subtidal habitat. They use substrates such as seagrasses, algae, rocks, and structures such as creosote-treated piling which tend to be located in herring spawning elevation ranges (0 to 20-feet MLLW in Puget Sound).

b, Bioaccumulation of PAHs in fish or other marine and freshwater vertebrates is generally not an issue since they tend to metabolize or process PAHs in some manner. However, PAHs can cause a variety of impairments and toxic effects unrelated to bioaccumulation (Johnson 2002).

c, Shellfish tend to bioaccumulate PAHs which tend to be consumed by humans, birds, and other wildlife that could result in biomagnification and further toxicity (Johnson 2002). Some invertebrates such as echinoderms, bivalves (e.g., clams, mussels, oysters), and amphipods can metabolize PAHs.

*This page intentionally left blank*

**Figure 16-1.** Cut piling stubs exposed on the intertidal beach at the Wyckoff Superfund Site on Bainbridge Island, WA. Pilings were cut at the mudline and wind and wave action exposed them over time.

**Figure 16-2.** Wrapped piling at the Squamish Terminal in Squamish, British Columbia. Wrapped pilings protected spawned herring eggs attached to the pilings, which allowed the eggs to hatch.

*This page intentionally left blank*

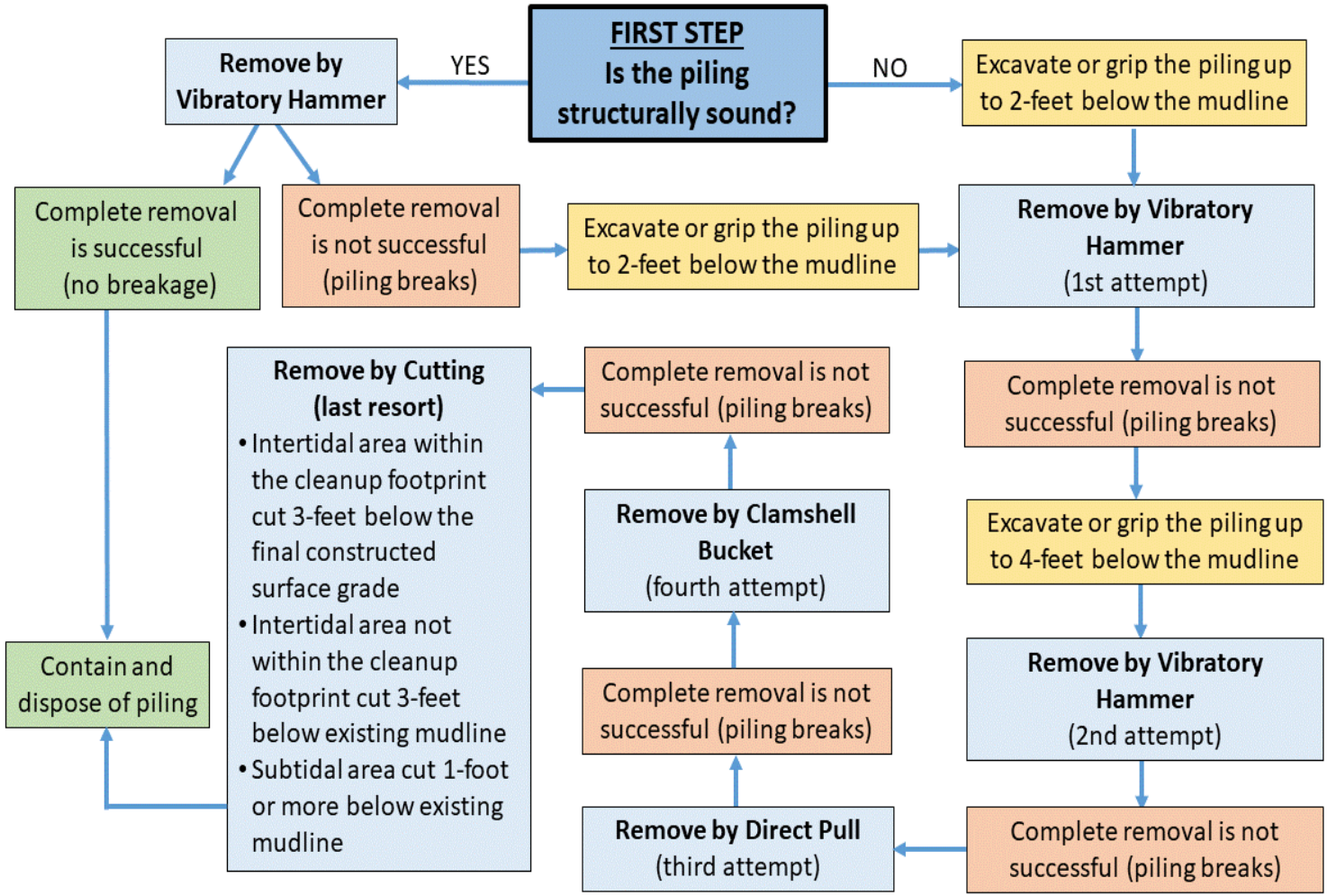



**Figure16-3.** Process of piling removal that includes sequencing using different methods.

*This page intentionally left blank*

**Figure 16-4**. Piling removal using the vibratory hammer method. The equipment is parked on a concrete bulkhead at the former Custom Plywood mill site in Anacortes, WA. Some pilings took nearly 30 minutes to extract and produced smoke during extraction.

**Figure 16-5**. Partially excavated piling stub on intertidal beach at the former Port Gamble sawmill in Port Gamble, WA. A vibratory hammer later facilitated full extraction of this stub. Visible sheen on water's surface is creosote leaching into the surrounding environment.

**Figure 16-6.** Decayed piling stubs in eelgrass at the former Port Gamble sawmill in Port Gamble, WA. Additional care was taken to hand excavate around individual pilings so they could be removed, which minimized disturbance to the eelgrass bed.

**Figure 16-7.** Removing pilings at the former mill site in Port Gamble Bay, WA. The boom around the piling removal area helps contain contaminants when the contractor is working the site during low tide.

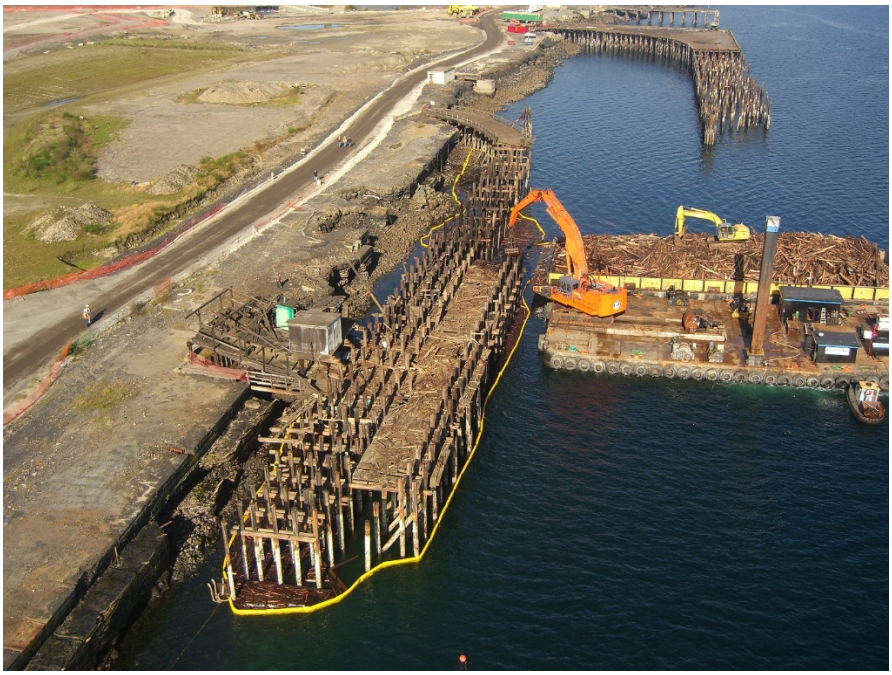


**Figure 16-8.** Removing pilings at the former Asarco Tacoma Smelter in Tacoma, WA. Boom is in place around the piling removal area and connected to a containment barge adjacent to the work platform.

**Figure 16-9.** Piling removal containment area at the former mill site in Port Gamble Bay, WA. The containment area is constructed of ecology blocks, a synthetic liner, and wood mulch that prevent the release of sawdust, debris, splintered wood, and unfiltered water.

*This page intentionally left blank*

# Chapter 17
# References

Adams, W.J., K.V. Brix, M. Edwards, L.M. Tear, D.K. DeForest, and A. Fairbrother. (2003). Analysis of field and laboratory data to derive selenium toxicity thresholds for birds. *Environmental Toxicology and Chemistry*, *22*, 2020-2029.

Ahrens, M. J. & Hickey, C. W. (2002). UV-photoactivation of polycyclic aromatic hydrocarbons and the sensitivity of sediment-dwelling estuarine organisms. In: *UV radiation and its effects: An update 2002. Proceedings of a workshop held in Christchurch, NZ.* Royal Society of New Zealand Miscellaneous Series No.60, 63-65.

Annan, S. Y., Liu, P., & Zhang, Y. (2009, December). *Comparison of the Kaplan-Meier, maximum likelihood, and ROS estimators for left-censored data using simulation studies*. Retrieved from http://www.divms.uiowa.edu/~kcowles/s166_2009/Annan.pdf

APHA. (1989). *Standard methods for the examination of water and wastewater* (17th ed.). (L. S. Clesceri, A. E. Greenberg, & R. R. Trussel, Eds.). Washington, DC: American Public Health Association.

Arfsten, D. P., Schaeffer, D. J., & Mulveny, D. C. (1996). The effects of near ultraviolet radiation on the toxic effects of polycyclic aromatic hydrocarbons in animals and plants: a review. *Ecotoxicology and Environmental Safety*, *33*, 1-24.

ASTM Standard E896-92. (1997). *Standard methods for conducting aqueous direct photolysis tests.* West Conshohocken, PA: American Society for Testing and Materials International, www.astm.org.

ASTM Standard E2122-02. (2001). *Standard guide for conducting in situ field bioassays with caged bivalves.* West Conshohocken, PA: American Society for Testing and Materials International, www.astm.org.

ASTM Standard. E1391-02. (2002). *Standard guide for collection, storage, characterization, and manipulation of sediments for toxicological testing*. West Conshohocken, PA: American Society for Testing and Materials International, www.astm.org.

ASTM Standard. E1706-05. (2010). *Standard test method for measuring the toxicity of sediment-associated contaminants with freshwater invertebrates.* West Conshohocken, PA: American Society for Testing and Materials International, www.astm.org.

ASTM Standard. E1688-10. (2010b). *Standard guide for determination of the bioaccumulation of sediment-associated contaminants by benthic invertebrates.* West Conshohocken, PA: American Society for Testing and Materials International, www.astm.org.

AXYS. (2005). *Analysis of polychlorinated dioxins and furans by Method 1613B.* MSU-018 (Rev. 5) 07-Jun-2005. Vancouver, BC, Canada: AXYS Analytical Services LTD.

Barrick, R. C., Becker, D. S., Brown, L. B., Beller, H. and Pastorok, R. (1988). *Sediment quality values refinement: 1988 update and evaluation of Puget Sound AET, Volume I, Final Report*. Prepared for Tetra Tech, Inc., Bellevue, WA, and the U.S. Environmental Protection Agency, Seattle, WA. Bellevue, WA: PTI Environmental Services.

Barron, M. G., Podrabsky, T., Ogle, S., and Ricker, R. W. (1999). Do aromatic hydrocarbons determine petroleum toxicity to aquatic organisms? *Aquatic Toxicology, 46,* 253-268.

Barron, M. G., Little, E. E., Calfee, R. D., and Diamond, S. (2000). Quantifying solar spectral irradiance in aquatic habitats for the assessment of photoenhanced toxicity. *Environmental Toxicology and Chemistry, 19,* 920-925.

Barron, M. G., M. G. Carls, J. W. Short, and S. D. Rice. (2003). Photoenhanced toxicity of aqueous phase and chemically dispersed weathered Alaska North Slope crude oil to Pacific herring eggs and larvae. *Environmental Toxicology and Chemistry, 22(3),* 650-660.

Barron, M. G. and Ka'aihue, L. (2001). Potential for photoenhanced toxicity of spilled oil in Prince William Sound and Gulf of Alaska waters. *Marine Pollution Bulletin, 43*: 86-92.

Baudo, R. (1990). Sediment sampling, mapping and data analysis. In: *Sediments: Chemistry and toxicity of in-place pollutants*. Baudo, R., J. Giesy, and H. Muntau (eds). Ann Arbor, MI: Lewis Publishers, 15–60.

Bligh, E. G. & Dyer, W. J. (1959). A rapid method for total lipid extraction and purification. *Canadian Journal of Physiology, 37,* 911-917.

Boese, B. L., Lamberson, J. O., Swartz, R. C., and Ozretich, R. J. (1997). Photoinduced toxicity of fluoranthene to seven marine benthic crustaceans. *Archives of Environmental Contamination and Toxicology, 32,* 389-393.

Bragdon-Cook, K. (1995). Review of new scientific information for SMS rule triennial review: Sediment Management Standards detection limits (memorandum May 1995). Olympia, WA: Washington State Department of Ecology.

Braune, B.M. and Norstrom, R.J. (1989). Dynamics of organochlorine compounds in herring gulls. Tissue distribution and bioaccumulation in Lake Ontario gulls. *Environmental Toxicology and Chemistry, 8,* 957-968.

Bridges T., Ells S., Hayes, D., Mount, D., Nadeau, S., Palermo, M., Patmont, C., and Schroeder, P. (2008). *The Four Rs of environmental dredging: Resuspension, release, residual, and risk.* Vicksburg, MS: USACE Engineer Research and Development Center, ERDC/EL TR-08-4. January 2008.

Bridges, T. S., Gustavson, K. E., Schroeder, P., Ells, S.J., Hayes, D., Nadeau, S.C., Palermo, M.R., and Patmont, C. (2010). Dredging processes and remedy effectiveness: Relationship to the 4 Rs of environmental dredging. *Integrated Environmental Assessment and Management, 6(4),* 619–630.

Bridges, T.S. and Lutz, C.H. (1999). Interpreting bioaccumulation data with the environmental residue-effects database. Vicksburg, MS: US Army Corps of Engineers, Waterways Experiment Station Environmental Laboratory. Dredging Research Technical Note EEDP-04-30.

Bridges T. S., Moore D. W., McFarland V., Wright T. D., Wilson J. R., Engler R. M. (1996). *Environmental effects of dredging technical notes: Proposed new guidance for interpreting the consequences of bioaccumulation from dredged material*. Vicksburg, MS: U.S. Army Corps of Engineers Waterways Experiment Station. EEDP-01-41.

Burkhard, L. (2009). *Estimation of biota sediment accumulation factor (BSAF) from paired observations of chemical concentrations in biota and sediment*. Final Report. Cincinnati, OH: U.S. Environmental Protection Agency, Ecology Risk Assessment Support Center. EPA/600/R-06/047, 2009.

Burton, G. A. Jr. (1992). *Sediment toxicity assessment*. Boca Raton, FL: Lewis Publishers.

Cal-EPA, (2005). Air *toxics hot spots program risk assessment guidelines, part II technical support document for describing available cancer potency factors*. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. May 2005.

Cochran, W. G. (1963). *Sampling techniques* (2nd ed). New York: John Wiley and Sons.

DMMP. (2009). *OSV Bold summer 2008 survey. Data Report, Final*. Prepared by the Washington State Dredged Material Management Program, with assistance from Science Applications International, Avocet Consulting, TerraStat Consulting Group. Olympia WA: Washington State Department of Ecology, Toxics Cleanup Program. Publication No. 09-09-226.

Ebert, E. S., Price, P., and Keenan, R. E. (1994). Selection of fish consumption estimates for use in the regulatory process. *Journal of Exposure Analysis and Environmental Epidemiology, 4*:373-393.

Ecology. (1995). *Guidance on sampling and data analysis methods*. Olympia WA: Washington State Department of Ecology, Toxics Cleanup Program. Publication No. 94-49.

Ecology. (1997). *Analytical methods for petroleum hydrocarbons*. Olympia WA: Washington State Department of Ecology, Toxics Cleanup Program. Publication No. ECY 97-602.

Ecology. (1999). *Analysis and selection of fish consumption rates for Washington state risk assessments and risk-based standards* [Draft]. Prepared by Leslie Kiell and Lon Kissinger for Ecology. Olympia WA: Washington State Department of Ecology, Toxics Cleanup Program. Publication No. 99-200.

Ecology, (2011a). *Fish consumption rates technical support document: A review of data and information about fish consumption in Washington, Version 1.0*. Olympia WA: Washington State Department of Ecology, Toxics Cleanup Program. Publication No. 11-09-050.

Ecology. (2011b). *Development of benthic freshwater standards for Washington, Oregon, and Idaho.* Prepared by Teresa Michelsen, Avocet Consulting for Ecology. Olympia WA: Washington State Department of Ecology, Toxics Cleanup Program. Publication No. 11-09-054.

Ecology, (2013a). *Wood waste cleanup: Identifying, assessing, and remediating wood waste in marine and freshwater environments: Guidance for implementing the Sediment Management Standards, Chapter 173-204-WAC*. Olympia WA: Washington State Department of Ecology, Toxics Cleanup Program. Publication No. 09-09-044.

Ecology. (2013b). *Fish consumption rates technical support document: A review of data and information about fish consumption in Washington, Version 2.0*. Olympia WA: Washington Department of Ecology, Toxics Cleanup Program. Publication No. 12-09-058. Retrieved from: http://www.ecy.wa.gov/programs/tcp/regs/fish/2012/FCR-doc.html.

Ecology. (2014). *Port Gardner bay regional background: Data evaluation and summary report.* Olympia WA: Washington State Department of Ecology, Toxics Cleanup Program. Publication No. 14-09-339. Retrieved from: https://fortress.wa.gov/ecy/publications/SummaryPages/1409339.html .

Ecology. (2015). *North Olympic peninsula regional background sediment characterization: Data and evaluation report.* Olympia WA: Washington State Department of Ecology, Toxics Cleanup Program. Publication No. 16-09-142. Retrieved from: https://fortress.wa.gov/ecy/publications/SummaryPages/1609142.html .

Ecology. (2016). *Bellingham bay regional background: Data evaluation and summary report.* Olympia WA: Washington State Department of Ecology, Toxics Cleanup Program. Publication No. 15-09-044. Retrieved from: https://fortress.wa.gov/ecy/publications/SummaryPages/1509044.html.

Ecology. (2017a). *Adaptation strategies for resilient cleanup remedies: A guide for cleanup project managers to increase the resilience of toxic cleanup sites to the impacts from climate change.* Olympia WA: Washington State Department of Ecology, Toxics Cleanup Program. Publication No. 17-09-052. Retrieved from: https://fortress.wa.gov/ecy/publications/SummaryPages/1709052.html

Ecology. (2017b). *Lake Washington area regional background: Data evaluation and summary report.* Olympia WA: Washington State Department of Ecology, Toxics Cleanup Program. Publication No. 16-09-064. Retrieved from: https://fortress.wa.gov/ecy/publications/SummaryPages/1609064.html.

Ecology. (2018). *South Puget Sound regional background: Final data evaluation and summary report.* Olympia WA: Washington State Department of Ecology, Toxics Cleanup Program. Publication No. 18-09-117. Retrieved from: https://fortress.wa.gov/ecy/publications/SummaryPages/1809117.html.

Fairbrother, A., Brix, K. V., Toll, J. E., McKay, S. and Adams, W. J. (1999). Egg selenium concentrations as predictors of avian toxicity. *Human and Ecological Risk Assessment, 5(6)*, 1229-1253.

Fox, D. R. (2008). NECS, NOECS and the ECX. *Australasian Journal of Ecotoxicology, 14*, 7-9.

Geller, J. B., Carlton, J.T., and Powers, D.A. (1993). Interspecific and intrapopulation variation in mitochondrial ribosomal DNA sequences of *Mytilus* spp. (Bivalvia: Mollusca). *Molecular Marine Biology and Technology, 2*, 44–50.

Gilbert, R. O. (1987). *Statistical methods for environmental pollution monitoring*. Van Nostrand Reinhold, New York. 320 pp.

Gobas, F. A. (1993). A model for predicting the bioaccumulation of hydrophobic organic chemicals in aquatic food-webs: application to Lake Ontario. *Ecological Modeling, 69*, 1–17.

Gobas, F. A. (2008). Food-web bioaccumulation models. In: *Encyclopedia of Ecology, Volume 2: Environmental Toxicology*. Elsevier, Oxford, pp. 1643–1652.

Hazardous Waste Cleanup—Model Toxics Control Act. WASH. REV. CODE § Chapter 70.105D RCW. (2013). Retrieved from: http://apps.leg.wa.gov/RCW/default.aspx?cite=70.105D

HDOH. (2011). Technical guidance manual notes: Decision unit and multi-increment sampling investigations. Memorandum prepared by R. Brewer and J. Peard, Hawai'i Department of Health, Hazard Evaluation and Emergency Response, March 2011.

Helsel, D. R. (2005). *Nondetects and data analysis: Statistics for censored environmental data.* Wiley-Interscience, John Wiley & Sons, New Jersey. 250 pp.

Helsel, D. R. (2010). Summing nondetects: incorporating low-level contaminants in risk assessment. *Integrated Environmental Assessment and Management, 6(3)*, 361–366.

Helsel, D. R. (2012). *Statistics for censored environmental data using Minitab and R.* 2nd ed. Wiley-Interscience, John Wiley & Sons, New Jersey. 324 pp.

Henny, C.J., Kaiser, J.L., Grove, R.A., Bentley, V.R., and Elliott, J.E. (2003). Biomagnification factors (fish to osprey eggs from Willamette River, Oregon, U.S.A.) for PCDDs, PCDFs, PCBs and OC pesticides. *Environmental Monitoring and Assessment, 84*, 275-315.

Hewett, P. and Ganser, G.H. (2007). A comparison of several methods for analyzing censored data. *Annals of Occupational Hygiene, 51(7)*, 611–632.

Huston, C. and Juarez-Colunga, E. (2009). *Guidelines for computing summary statistics for datasets containing non-detects.* Prepared for the Bulkley Valley Research Centre with assistance from the B.C. Ministry of Environment. January 19, 2009. Web Location: http://bvcentre.ca/files/research_reports/08-03GuidanceDocument.pdf.

ITRC. 2012. *Incremental Sampling Methodology*. The Interstate Technology & Regulatory Council, Washington DC. http://www.itrcweb.org/ism-1/pdfs/ISM-1_021512_Final.pdf.

Johnson et. al. (2007). Persistent organic pollutants in out-migrant juvenile Chinook salmon from the Lower Columbia Estuary, USA. *Science of the Total Environment, 374,* pages 342-366.

Jarvinen, A.W., and Ankley, G.T. (1999). Linkage of effects to tissue residues: Development of a comprehensive database for aquatic organisms exposed to inorganic and organic chemicals. SETAC Press, pp. 1-358.

Johnson, F. S., Mo, T., and Green, A.E. (1976). Average latitudinal ultraviolet radiation at the earth's surface. *Photochemistry and Photobiology, 23,* 179-188.

Judd N., Tear L., Toll J. (2013). From sediment to tissue and tissue to sediment: An evaluation of statistical bioaccumulation models. *Integrated Environmental Assessment and Management, 10(1),* 102-113.

Kirk, J. T. O. (1994a). *Light and photosynthesis in aquatic ecosystems.* Cambridge University Press, Cambridge.

Kirk, J. T. O. (1994b). Optics of UV-B radiation in natural waters. *Archiv für Hydrobiologie–Beiheft Ergebnisse der Limnologie, 43,* 1-16.

Klein, J.P. and Moeschberger. M.L. (2003). *Survival analysis: Techniques for censored and truncated data*, 2nd edition. Springer, New York, 536 pp.

Kosian, P. A., Makynen, E.A., Monson, P.D., Mount, D.R., Spacie, A., Mekenyan, O.G., and Ankley, G.T. (1998). Application of toxicity-based fractionation techniques and structure-activity relationship models for the identification of phototoxic polycyclic aromatic hydrocarbons in sediment porewater. *Environmental Toxicology and Chemistry,* 17, 1021-1033.

Krone, C. A., Brown, D.W., Burrows, D.G., Bogar, R.G., Chan, S.L., and Varanasi, U. (1989). A method for analysis of butyltin species and measurement of butyltins in sediment and English sole livers from Puget Sound. *Marine Environmental Research, 27,* 1–18.

Landis, W.G., Chapman, P.M. (2011). Well past time to stop using NOELs and LOELs. *IEAM, 7*(4): vi-viii.

Lee, H. II, Boese, B. L., Pelletier, J., Winsor, M., Specht, D. T., and Randall, R. C. (1989). *Guidance manual: Bedded sediment tests*. EPA-600/x-89-302, U.S. Environmental Protection Agency, Pacific Ecosystems Branch, Bioaccumulation Team, Newport, OR.

Lee, L. 2013. NADA: Nondetects and data analysis for environmental data. R package version 1.5-6. Web Location: http://CRAN.R-project.org/package=NADA.

Little, E. E., Cleveland, L., Hurtubise, R., and Barron, M.G. (2000). Assessment of the photoenhanced toxicity of weathered petroleum to the tidewater silverside. *Environmental Toxicology and Chemistry, 19,* 926-932.

Magar, V. S., Chadwick, D. B., Bridges, T. S., Fuchsman, P. C., Conder, J. M., Dekker, T. J., Steevens, J. A., Gustavson, K. E., and Mills, M. A.. (2009). *Monitored natural recovery at contaminated sediment sites*. Technical Guide ESTCP Project ER-0622. May 2009.

Maruya, K. A. (2010). An in situ sediment porewater sampler for organic micropollutants based on solid phase microextraction (SPME) technology. Submitted to the NOAA/UNH Cooperative Institute for Coastal and Estuarine Environmental Technology. March 31, 2010.

McDonald, J. H. and Koehn, R. K. (1988). The mussels *Mytilus galloprovincialis* and *M. trossulus* on the Pacific coast of North America. *Marine Biology, 99,* 111–118.

McDonald, J. H., Seed, R., and Koehn, R. K. (1991). Allozymes and morphometric characters of three species of *Mytilus* in the Northern and Southern Hemispheres. *Marine Biology, 111,* 323–333.

Mekenyan, O. G., Ankley, G. T., Veith, G.D, and Call, D. J. (1994). QSARs for photoinduced toxicity: I. Acute lethality of polycyclic aromatic hydrocarbons to *Daphnia magna*. *Chemosphere, 28,* 567-582.

MFA. (2013). Bank and sediment remedy operations, maintenance, and monitoring plan, Zidell Waterfront Property, Portland, OR. Prepared by Maul, Foster, & Alongi for ZRZ Realty Company.

Michelsen, T. C. (1992). *Organic carbon normalization of sediment data.* Technical Information Memorandum. Washington Department of Ecology, Olympia, WA.

Microbics Corporation. (1992). *Microtox® manual, volume 2: Detailed protocols*. 1992 ed. Microbics Corporation, Carlsbad, CA.

Missildine et. al. (2005). Polychlorinated biphenyl concentrations in adult Chinook salmon (*Oncorhynchus tshawytscha*) returning to coastal and Puget Sound hatcheries of Washington state. *Environmental Science & Technology, 39(18),* 6944 to 6951.

Model Toxics Control Act—Cleanup Regulation. WASH. ADMIN CODE § Chapter 173-340 WAC. (2013). Retrieved from: http://apps.leg.wa.gov/wac/default.aspx?cite=173-340

Moore, D.R.J., Caux, P.Y. Estimating low toxic effects. *Environmental Toxicology and Chemistry, 16(4),*794-801.

Mudroch, A. and MacKnight, S. D. (1991). *Handbook of techniques for aquatic sediments sampling*. CRC Press, Boca Raton, FL.

Nagpal, N. K. (1993). Ambient water quality criteria for polycyclic aromatic hydrocarbons (PAHs). Ministry of Environment, Lands and Parks, Province of British Columbia, Water Quality Branch, Water Management Division, Vancouver, BC.

Nebeker, A. V., Cairns, M. A., Gakstatter, J. H., Malveg, K.W., Schuytema, G. S., and Krawczyk, D.F. (1984). Biological methods for determining toxicity of contaminated freshwater sediments to invertebrates. *Environmental Toxicology and Chemistry, 3,* 617–630.

ODEQ. (2012). Columbia slough sediment study, Whitaker Slough between river mile 0 and 3.2. January 2012.

OEPA. (2007). *Multi-incremental sampling for soils and sediments. Standard operating procedure 2.6.1.* Ohio EPA, Division of Emergency and Remedial Response. January 2007.

OEPA. (2009). *Difference between incremental or multi-increment (MI) sampling and composite sampling.* Ohio EPA. March 2009.

O'Neill, S.M., West, J.E. (2009a). Marine distribution, life history traits the accumulation of polychlorinated biphenyls (PCBs) in Chinook salmon (*Oncorhynchus tshwaytscha*) in Puget Sound Washington. In Review.

O'Neill, S.M., and J.E. West. (2009b). Marine distribution, life history traits, and the accumulation of polychlorinated biphenyls in Chinook salmon from Puget Sound,

Washington. Trans. Am. Fish. Soc. *Transactions of the American Fisheries Society. 138 (3),* 616-632.

Palermo, M. R., Maynord, S., Miller, J., and Reible, D. (1998a). *Assessment and remediation of contaminated sediments (ARCS) program guidance for in situ subaqueous capping of contaminated sediment.* EPA 905-B96-004, Great Lakes National Program Office, Chicago, IL.

Palermo, M. R., Randall, R. E., Fredette, R., Clausner, J., Myers, T., Rollings, M., and Williams, G. (1998b). *Technical guidance for subaqueous dredged material capping.* United States Army Corps of Engineers. Waterways Experiment Station, Vicksburg, MS.

Palermo, M. R., Schroeder, P. R., Estes, T. J., and Fracingues, N. R. (2008). *Technical guidelines for environmental dredging of contaminated sediment.* U.S. Army Corps of Engineers, Engineer Research and Development Center. ERDC/EL TR-08-29. September 2008.

Patmont C. R. and Palermo, M. R. (2007). Case studies of environmental dredging residuals and management implications. In: *Proceedings of Remediation of Contaminated Sediments 2007*. Savannah, Georgia. Columbus (OH): Battelle Press.

Pelletier M. C., Burgess, R. M., Ho, K. T., Kuhn, A., McKinney, R. A., and Ryba, S.A. (1997). Phototoxicity of individual polycyclic aromatic hydrocarbons and petroleum to marine invertebrate larvae and juveniles. *Environmental Toxicology and Chemistry, 16,* 2190-2199.

Pinza, M., Word, J., Schuh, T., Watts, S. (2009). Tier 2 biological testing of sediment for March Point (Whitmarsh) Landfill, Anacortes, Washington. Newfields, Port Gamble, Washington.

Plumb, R. H. Jr. (1981). *Procedure for handling and chemical analysis of sediment and water samples.* Technical Report EPA/CE-81-1. U.S. Environmental Protection Agency and U.S. Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Polissar, N., Neradilek, M., Aravkin, A., Danaher, P., Kalat, J. (2013). *(Draft) Statistical analysis of national and Washington state fish consumption data.* The Mountain-Whisper-Light-Statistics. September 2013.

PSEP. (1986). *Recommended protocols for measuring conventional sediment variables in Puget Sound.* Final Report. Prepared for U.S. Environmental Protection Agency, Seattle, WA.

PSEP. (1987). *Recommended protocols for sampling and analyzing subtidal benthic macroinvertebrate assemblages in Puget Sound*. Final Report. Prepared for U.S. Environmental Protection Agency, Seattle, WA.

PSEP. (1991). *Reference area performance standards for Puget Sound*. Ecology Publication No. 06-09-096. EPA 910/9-91-041. Puget Sound Estuary Program, Prepared for the Washington Department of Ecology and U.S. Environmental Protection Agency, Region 10, Seattle, WA.

PSEP. (1995). *Recommended guidelines for conducting laboratory bioassays on Puget Sound sediments.* Interim Final Report. Puget Sound Estuary Program, U.S. Environmental Protection Agency Region 10, Seattle, WA.

PSEP. (1997a). *Recommended protocols for measuring metals in Puget Sound marine water, sediment, and tissue samples*. Final Report. Prepared for U.S. Environmental Protection Agency, Seattle, WA.

PSEP. (1997b). *Recommended guidelines for measuring organic chemicals in Puget Sound waters and tissue samples*. Final Report. Prepared for U.S. Environmental Protection Agency, Seattle, WA.

PSEP. (1997c). *Recommended guidelines for sampling marine sediment, water column, and tissue in Puget Sound*. Final Report. Prepared for U.S. Environmental Protection Agency, Seattle, WA.

PTI. (1989a). *Puget Sound dredged disposal analysis guidance manual: Data quality evaluation for proposed dredged material disposal projec*ts. Prepared for the Washington Department of Ecology, Olympia, WA. PTI Environmental Services, Bellevue, WA.

PTI. (1989b). *Data validation guidance manual for selected sediment variables*. Prepared for the Washington Department of Ecology, Olympia, WA. PTI Environmental Services, Bellevue, WA.

R Development Core Team. (2014). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.
Retrieved from: http://www.R-project.org/

Rantala, R. T. T. and Loring, D. H. (1975). Multi-element analysis of silicate rocks and marine sediments by atomic absorption spectrophotometry. *Atomic Absorption Newsletter, 14(5)*, 117–120.

RSET. (2016). *Sediment evaluation framework for the Pacific Northwest.* Regional Sediment Evaluation Team, Portland District Corps of Engineers, Portland, OR.

Salazar, M. H. and Salazar, S. M. (1998). Using caged bivalves as part of an exposure-dose-response triad to support an integrated risk assessment strategy. In: *Proceedings: Ecological Risk Assessment: A Meeting of Policy and Science.* de Peyster, A. and K. Day (eds). SETAC Press, Pensacola, FL, pp 167–192.

Sediment Management Standards. WASH. ADMIN CODE § Chapter 173-204 WAC. (2013). Retrieved from: http://apps.leg.wa.gov/WAC/default.aspx?cite=173-204

Sloan, J. and Blakley, N. (2009). *Baseline characterization of nine proposed freshwater sediment reference sites, 2008*. Washington State Department of Ecology, Olympia, WA. Publication No. 09-03-032. Retrieved from: www.ecy.wa.gov/biblio/0903032.html

Suter, G.W. II. (1996). Abuse of hypothesis testing in ecological risk assessment. *Human and Ecological Risk Assessment, 2,* 331-347.

True, C. J. and Heywood, A. A. (1989). Relationships between Microtox test results, extraction methods, and physical and chemical compositions of marine sediment samples. *Environmental Toxicology, 5,* 29-45.

UNEP. (1998). *Environmental effects of ozone depletion: 1998 assessment*. United Nations Environment Programme, 205 pp. ISBN 92-807-1724-3.

USEPA. (1983). *Methods for chemical analysis of water and wastes*. EPA 600/4-79-020. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, OH.

USEPA. (1986). *Method 9060: Total organic carbon, procedures for solid waste. 3rd ed. SW-846.* U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC.

USEPA. (1989a). *Generalized methodology for conducting industrial toxicity reduction evaluations (TREs)*. EPA-600-2-88-070. Office of Research and Development, Cincinnati, OH.

USEPA. (1989b). *Risk assessment guidance for superfund (RAGS): Volume 1: Human health evaluation manual (HHEM), Part A, interim final.* Office of Emergency and Remedial Response. Washington, DS. EPA/540/1-89/002. NTIS PB90-155581/CCE.

USEPA. (1991). Method 1624C: Volatile organic compounds by isotope dilution GC/MS. Method 1625C: Semivolatile organic compounds by isotope dilution GC/MS. U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Industrial Technology Division, Washington, DC.

USEPA/USACE. (1991). *Evaluation of dredged material for ocean disposal testing manual.* EPA 503/8-91/001.

USEPA. (1992a). *Guidance for data usability in risk assessment (Part A), Appendix III*. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington DC. Publication 9285.7-09A.

USEPA. (1992b). *Guidelines for exposure assessment*. Washington, DC: Office of Research and Development, Office of Health and Environmental Assessment. EPA/600/Z-92/001.

USEPA. (1993). *Wildlife exposure factors handbook*. U.S. Environmental Protection Agency, Washington, D.C. EPA/600/R-93/187.

USEPA. (1994). *Methods for measuring the toxicity and bioaccumulation of sediment-associated contaminants with freshwater invertebrates*. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC. EPA 600/R-94/024.

USEPA. (1994a). *Method 1613: Tetra- through octa-chlorinated dioxins and furans by isotope dilution HRGC/HRMS*. U.S. Environmental Protection Agency, Office of Water Engineering and Analysis Division, Washington, DC. EPA 821/B-94/005.

USEPA. (1994b). *Method 7471A: Mercury in solid or semisolid waste (manual cold-vapor technique).* U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC.

USEPA. (1996). *Method 8270C: Semivolatile organic compounds by gas chromatography/mass spectrometry (GC/MS).* U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC.

USEPA/USACE. (1998a). *Evaluation of dredged material proposed ford in Waters of the U.S.—Testing manual (Inland Testing Manual).* EPA-823-B-98-004.

USEPA. (1998b). *Guidance for conducting fish and wildlife consumption surveys.* U.S. Environmental Protection Agency. EPA-823-B-98-007.

USEPA. (2000). *Methods for measuring the toxicity and bioaccumulation of sediment associated contaminants with freshwater invertebrates*, Second Edition. U.S. Environmental Protection Agency. Washington, D.C. EPA-600-R-99-064.

USEPA. (2001). *Methods for collection, storage, and manipulation of sediments for chemical and toxicological analysis: Technical manual.* U.S. Environmental Protection Agency. EPA-823-B-01-002.

USEPA. (2003a). *Literature review and report surface sediment sampler database*. Prepared for USEPA, by Tetra Tech EM Inc. July 24, 2003. Project No. G1058.3.1.03.104.02

USEPA. (2003b). *Human health toxicity values in superfund risk assessment.* (Publication 9285.7-53). Office of Solid Waste and Emergency Response, Washington DC. Retrieved from: http://rais.ornl.gov/homepage/hhmemo.pdf.

USEPA. (2004a). *Guidelines for exposure assessment.* U.S. Environmental Protection Agency. Federal Register Vol. 57, No. 104, pages 22888-22938.

USEPA. (2004b). *An examination of EPA risk assessment principles and practice*s. U.S. Environmental Protection Agency. EPA/100/B-04/0001.

USEPA (2004c). *Risk assessment guidance for superfund (RAGS), volume I: Human health evaluation manual (Part E, supplemental guidance for dermal risk assessment).* U.S. Environmental Protection Agency. Office of Superfund Remediation and Technology Innovation, Washington DC. EPA/540/R/99/005.

USEPA. (2005). *Contaminated sediment remediation guidance for hazardous waste sites*. EPA-540-R-05-012. December 2005.

USEPA. (2007a). *Test methods for evaluating solid waste, physical/chemical methods*. EPA-SW-846, 3500C series. Retrieved from: http://www.epa.gov/solidwaste/hazard/testmethods/sw846/online/index.htm.

USEPA. (2007b). *Framework for selecting and using tribal fish and shellfish consumption rates for risk-based decision making at CERCLA and RCRA cleanup sites in Puget Sound and the Strait of Georgia*. Working Document. August 2007.

USEPA. (2009a). *Exposure factors handbook: 2009 Update*. EPA/600/R-09/052A.

USEPA. (2009b). *Estimation of biota sediment accumulation factor (BSAF) from paired observations of chemical concentrations in biota and sediment*. EPA/600/R-06/047/ERASL-013F.

USEPA. (2011). *Exposure factors handbook: 2011 Edition.* National Center for Environmental Assessment. Office of Research and Development. EPA/600/R-090/052F.

USEPA. (2013). *ProUCL 5.0.00. Statistical software for environmental applications for data sets with and without nondetect observations*. U.S. Environmental Protection Agency, Office of Research and Development, Washington D.C. Retrieved from: http://www.epa.gov/osp/hstl/tsc/software.htm

USEPA. (2014). *Human health evaluation manual, supplemental guidance: Update of standard default exposure factors*. Office of Solid Waste and Emergency Response, Washington, D.C. OSWER Directive 9200.1-120. Retrieved from: http://www.epa.gov/oswer/riskassessment/pdf/superfund-hh-exposure/OSWER-Directive-9200-1-120-ExposureFactors.pdf

USEPA. (2017). Laboratory, field, and analytical procedures for using passive sampling in the evaluation of contaminated sediments: User's manual. Final web version 1.0. Publication No. EPA/600?R-16/357.

USFWS. (1999). Changes in productivity and environmental contaminants in bald eagles nesting along the Lower Columbia River. Final Report. Portland, OR: U.S. Fish and Wildlife Service, Oregon State Office. 56 p.

USFWS. (2004). Environmental contaminants in aquatic resources from the Columbia River. Final Report. Portland, OR: U.S. Fish and Wildlife Service, Oregon Fish and Wildlife Office. 112 p.

Van den Berg et al. (2006). The 2005 World Health Organization re-evaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicological Sciences, 93(2),* 223-241; doi:10.1093/toxsci/kfl055.

Weinstein, J. E. (2001). Characterization of the acute toxicity of photoactivated fluoranthene to glochidia of the freshwater mussel, *Utterbackia imbecillis*. *Environmental Toxicology and Chemistry, 20,* 412-419.

Young, Derek S. (2010). Tolerance: An R package for estimating tolerance intervals. *Journal of Statistical Software, 36(5),* 1-39. Retrieved from: http://www.jstatsoft.org/v36/i05/

Zhong, M. and Hess, K.R. (2009). Mean survival time from right censored data. COBRA Preprint Series, Paper 66. Retrieved from: http://biostats.bepress.com/cobra/ps/art66/

*This page left intentionally blank.*

# Appendix A
# Sampling Guidance for NPDES Permits under the Sediment Management Standards

## A.1 Sediment Management Standards for Permitted Discharges

### A.1.1 Introduction

Part IV (Sediment Source Control) of the Sediment Management Standards (SMS) includes a process for addressing the release of hazardous substances from discharges permitted under the National Pollution Discharge Elimination System (NPDES) that have the potential to contaminate sediment. The focus of sediment sampling for NPDES permits is on surface sediment within the biologically active zone, because surface sediments are the most likely to show impacts from recent discharges of contaminants.

The SMS standards that apply to NPDES permits in WAC 173-204-320 through -340 and WAC 173-204-420 are as follows.

- **For marine sediment**, there is a two-tiered framework that includes different numeric chemical and biological benthic criteria as follows (Appendix A: Table A-1 through Table A-3):
    - Sediment quality standards (SQS) criteria (WAC 173-204-320, Part III of the SMS rule). This is the lower tier of chemical and biological criteria and the sediment quality goal for marine sediment in the state.
    - Sediment impact zone (SIZmax) criteria (WAC 173-204-420, Part IV of the SMS rule). This is the upper tier of chemical and biological criteria. This represents the maximum chemical concentration or level of biological effects allowed in a sediment impact zone (SIZ) for marine sediment. Part IV allows the sediment quality within the immediate vicinity of a permitted discharge to temporarily exceed the SQS up to the SIZmax, if a sediment impact zone (SIZ) is approved by Ecology. A SIZ is somewhat analogous to a mixing zone within the water column, which represents a volume of water where water quality standards may be temporarily exceeded.

- A narrative human health standard. There are no adopted numeric criteria for the protection of human health in Parts I – IV of the SMS rule. This will be addressed on a case-by-case basis.

- **For freshwater sediment,** there is:

  - A narrative benthic standard for freshwater sediment (WAC 173-204-340). There are no adopted SQS or SIZmax numeric chemical or biological criteria for freshwater sediment. Ecology will address freshwater sediment on a case-by-case basis using best professional judgment. The Ecology-approved benthic bioassays in Appendix A: Table A-4 may be used as a guide to assess sediment quality on a site-specific basis.

  - A narrative human health standard. There are no adopted numeric criteria for the protection of human health in Parts I – IV of the SMS rule. This will be addressed on a case-by-case basis.

- **For marine and freshwater sediment**, there is a narrative standard for "other toxic, radioactive, biological, or deleterious substances." This standard can be met using Ecology-approved benthic bioassays (Appendix A: Table A-2 through Table A-4).

- **For marine and freshwater sediment**, there is a narrative standard for sediment affected by non-anthropogenic sources.

## A.1.2 Benthic criteria and selection of study-specific parameters

### A.1.2.1 Marine Chemical Criteria and Study Parameters

Appendix A: Table A-1 identifies the marine benthic chemical criteria (SQS and SIZmax) that apply to NPDES permitted discharges.

An analysis of all chemicals listed in Table A-1 should be conducted. In addition, if contaminants or chemicals not listed in Table A-1 are suspected in the discharge, analysis of additional chemicals or bioassays may be required. See Chapter 4, Table 4-1 for a list of additional chemicals and their potential sources.

### A.1.2.2 Marine Biological Criteria and Tests

Appendix A: Table A-2 identifies the marine biological criteria (SQS and SIZmax). Biological tests can include sediment toxicity tests (bioassays) or benthic community analysis tests. Ecology may determine it necessary to conduct biological testing when:

- An exceedance(s) of the chemical benthic criteria for any one station occurs (Appendix A: Table A-1).
- There is reason to believe the site contains chemicals that are not listed in Table A-1 that may be contributing to toxicity (e.g., pesticides; see Chapter 4, Table 4-1).
- There are physical factors contributing to toxicity (e.g., wood waste).
- There is a need to confirm or override chemistry results, or to preclude the need for a second round of sampling or chemical testing.

When conducting bioassay testing, each sampling station must be evaluated using at least three bioassays (Appendix A: Table A-3) that include:

- At least two acute effects tests; and
- At least one chronic effects test.

Table A-3 identifies the list of marine biological tests in the SMS rule. For further information on these and how to choose among them, refer to Chapter 4, Section 4.2.3.1.

### A.1.2.3 Freshwater Biological Criteria and Tests

Table 8-4 in Chapter 8 identifies the freshwater biological criteria which are considered best available science and may be used as a guide on a site-specific bases to determine if sediment impacts have occurred from an NPDES permitted discharge. These criteria in Part V of the SMS rule were adopted under MTCA authority and are not approved water quality standards.

Each sampling station must be evaluated using bioassays that include:

- Three toxicity test endpoints using at least two species,
- Both acute and chronic tests, and
- At least one sublethal endpoint (e.g., growth).

Appendix A: Table A-4 identifies the list of freshwater bioassays that may be used. For further information on these bioassays and how to choose among them, refer to Chapter 4, Section 4.2.3.2.

Biological tests can include sediment toxicity tests (bioassays) or benthic community analysis tests. It may be necessary to conduct biological testing when:

- Chemical criteria do not exist.
- There are physical factors contributing to toxicity (e.g., wood waste).
- There is a need to confirm or override chemistry results or to preclude the need for a second round of sampling or testing.

## A.2 Types of Monitoring and Objectives

There are five general types of sediment monitoring that may be conducted for NPDES permits. These are the responsibility of the permittee:

- Baseline monitoring. This is conducted to evaluate current conditions, the potential for an NPDES permitted discharge to cause sediment impacts, or to determine if a SIZ may be necessary. This can apply to new discharges or existing discharges without Ecology-approved sediment monitoring data.

- Maintenance monitoring. This is conducted to evaluate any continuing impacts from an NPDES permitted discharge or the effectiveness of best management practices that may be required to protect sediment.

- Closure monitoring. This is conducted following the closure of an NPDES permitted discharge to determine sediment quality at the time of closure.

- SIZ application monitoring. This is conducted to collect baseline information to support an application for a SIZ.

- SIZ maintenance monitoring. This is conducted during the term of a permit with an authorized SIZ. This information is used to determine whether the SIZ should be renewed, reduced, or eliminated, whether areas of special importance have been adversely impacted by the discharge, and to establish conditions for SIZ reauthorization.

- SIZ closure monitoring. This is conducted following closure of a SIZ to determine if the SQS has been met.

The monitoring objectives and design vary with the type of discharge characteristics. Most NPDES permit monitoring represents baseline and maintenance monitoring, which is the focus of this section (Appendix A: Figure A-1).

The primary objective of baseline monitoring is to:

- Establish baseline sediment conditions for a new discharge or existing discharge without previous sampling, and
- Determine whether a current discharge is contaminating sediment above the SQS, in which case an SIZ may be necessary.

Such data may be used:

- As a simple screening tool (e.g., obtain information on the nature of the wastewater discharged, based either on knowledge of the type of facility or on actual chemical analyses of the wastewater).
- To determine baseline sediment conditions in the vicinity of the discharge to:
    - Identify other potential contaminant sources in the area.
    - Relieve the discharger from liability for sediment contamination contributed by other permitted or unpermitted (and possibly historical) discharges.

Most sediment investigations for source control are typically baseline or maintenance monitoring. In the following sections, the selection of appropriate sampling station locations in the vicinity of existing permitted wastewater discharges is discussed in the context of whether it is baseline, maintenance, or SIZ maintenance monitoring.

## A.3 Sampling Station Locations

### A.3.1 NPDES permit baseline or maintenance monitoring

The intent of baseline monitoring is to determine whether there are current SQS exceedances in depositional areas of a discharge and if they may be caused by the discharge. Baseline monitoring is generally not intended to accurately characterize sediment or definitively link exceedances to the discharge. The purpose is to:

- Establish the impact of ongoing discharges to determine a) if concentrations are increasing or decreasing; and b) the effectiveness of any required best management practices.

- Establish baseline sediment conditions for a new discharge.

The selection of the appropriate number and array of sampling station locations for both types of monitoring can be site-specific, but Ecology recommends an array between 6 to 18 stations (Appendix A: Figure A-1) as follows:

- For discharges with relatively small volumes of wastewater and low concentrations of contaminants (minor discharges), an array of 6 stations may suffice.
    - The stations should be located along a transect extending from the point of discharge to a point downstream (or in the direction of predominant current flow) beyond direct effects of the discharge (Figure A-1).
    - If the current is unidirectional (e.g., a river), it may suffice to have one station upstream from the discharge.
    - If the current is bidirectional (e.g., where tidal currents predominate), the 6 stations might be arrayed along a transect in the direction of the predominant current. In general, these stations will be at a similar depth because currents typically flow along contours of equal depth.
- For discharges with relatively large volumes of wastewater and high concentrations of contaminants (major discharges), or for discharges to complex receiving environments, it may be necessary to have 2 to 3 transects—each with up to 6 stations extending out from the point of discharge (Figure A-1).
- The appropriate spacing of stations along transects will vary with both the volume of the discharge and velocity of currents as follows:
    - For minor discharges and relatively weak currents, the transect may be 20 to 40 meters in length.
    - As the volume of the discharge or the velocity of receiving water currents increases, the length of the transect should increase.
    - For major discharges of approximately 100 million gallons per day and strong currents, an appropriate transect could be 200 to 300 meters in length.
    - If the current in the immediate vicinity of the discharge is so strong that sediments are unlikely to accumulate, stations may need to be located in the nearest depositional area. In rivers and certain estuarine environments with strong currents, such depositional areas may be far removed from the point of discharge.

These recommendations may be modified based on site-specific conditions. For example, a permittee with multiple points of discharge within the same general vicinity may require a larger number and different array of stations. The stations should be arrayed along transects extending away from the single point discharge in the direction of other known or suspected contaminant sources. This array may help evaluate whether any exceedances of criteria are attributable to a given discharge. Appendix A: Figure A-2 provides several examples of how stations might be positioned for a major discharge with a single or multiple points of discharge.

## A.3.2 SIZ maintenance monitoring

The purpose of SIZ maintenance monitoring for NPDES permitted discharges is to demonstrate that sediment within an authorized SIZ do not exceed the SIZmax criteria, and sediment outside the authorized SIZ do not exceed the SQS criteria. It is equally important to sample both within and outside the authorized SIZ. Following are possible scenarios for the appropriate number and locations of sampling stations:

- For minor discharges in an area with minimal contaminant sources, approximately 6 sampling stations are recommended. Four should be within the SIZ and the remaining two on opposite sides of the discharge outside the SIZ along the axis of predominant current flow (Appendix A: Figure A-3).

- For major discharges in an area with minimal contaminant sources, as many as 18 sampling stations may be appropriate. Six to nine should be within the discharge and at least two on opposite sides of the discharge outside the SIZ.

- For major discharges in an area with multiple contaminant sources, as many as 18 sampling stations may be appropriate (Figure A-3).

    - Six to nine sampling stations should be within the SIZ for discharges far removed from other contaminant sources. The remaining stations should be arrayed along transects extending just beyond the SIZ toward other contaminant sources to investigate possible gradients in contaminant concentrations.

    - Depending on the number of other nearby contaminant sources, fewer sampling stations may be needed within the SIZ and more outside the SIZ.

    - The higher density of sampling stations is warranted for major discharges to establish patterns of sediment contamination, investigate potential impacts from other contaminant sources, and collect representative samples.

## A.4 Sampling and Analysis Plan Requirements

A sampling and analysis plan (SAP) should be drafted and submitted to Ecology for review and approval before field work begins.

The contents of a SAP should include the following:

1. **Introduction and Background Information**

- Site history
- Regulatory framework
- Summary of previous sediment investigations with EIM Study ID provided
- Location and characteristics of current and/or historical wastewater or stormwater discharge(s) in the local area
- Information about on-site waste disposal practices or chemical spills in the local area
- Site location map showing the surrounding area
- Site map showing site features

2. **Objectives and Design of the Sediment Investigation**

- Objectives of the sediment investigation
- Overall design of the sediment investigation
- Chemical analytes, including a description of their relevance to the objectives and the SMS (Section A.2)
- Biological tests, including a description of their relevance to the objectives and the SMS (Section A.2)
- Sampling station locations (Section A.3)
- Rationale for station locations
- Site map(s) showing sampling stations and other pertinent features, such as: bathymetry, predominant current direction, outfall(s)/diffuser(s), waste disposal sites, spills, or other activities that may have affected the sediments (e.g., sandblasting, boat repair, historical dredging activities)
- Proposed reference stations
- Water depth at each sampling station
- Sediment sampling depth at each sampling station

**3. Field Sampling Methods (see Chapter 4, Section 4.5)**

- ☐ Station positioning methods
- ☐ Sampling equipment
- ☐ Decontamination procedures
- ☐ Sample containers and labels
- ☐ Field documentation procedures
- ☐ Procedures for disposal of contaminated sediment

**4. Sample Handling Procedures (see Chapter 4, Section 4.6)**

- ☐ Sample storage requirements (e.g., conditions, maximum holding times)
- ☐ Chain-of-custody procedures
- ☐ Delivery of samples to analytical laboratories

**5. Laboratory Analytical Methods (see Chapter 5)**

- ☐ Chemical analyses and target detection limits, which must be below the SQS
- ☐ Biological analyses and testing
- ☐ Corrective actions

**6. Quality Assurance and Quality Control Requirements (see Chapter 5)**

- ☐ QA/QC for chemical analyses
- ☐ QA/QC for biological testing
- ☐ Data quality assurance review procedures

**7. Data Analysis, Record Keeping, and Reporting (see Chapter 6 and Section A.7)**

- ☐ Analysis of sediment chemistry data
- ☐ Analysis of biological test data
- ☐ Data interpretation
- ☐ Record keeping and reporting procedures

**8. Health and Safety Plan (see Chapter 3)**

- ☐ Description of tasks
- ☐ Key personnel and responsibilities
- ☐ Chemical and physical hazards
- ☐ Safety and health risk analysis for each task
- ☐ Air monitoring plan
- ☐ Personal protective equipment
- ☐ Work zones
- ☐ Decontamination procedures
- ☐ Disposal procedures for contaminated media and equipment
- ☐ Safe work procedures
- ☐ Standard operating procedures
- ☐ Contingency plan
- ☐ Personnel training requirements
- ☐ Medical surveillance program
- ☐ Reporting and record keeping procedures

**9. Schedule (see Chapter 4, Section 4.3.4)**

- ☐ Table or figure showing key project milestones

**10. Project Personnel and Responsibilities**

- ☐ Table identifying the project team members and their responsibilities

**11. References**

- ☐ List of references

## A.5 Field Sampling Methods

Refer to Chapter 4 for information and requirements related to:

- Frequency, timing, and phasing of sampling (Section 4.3.1 through 4.3.3)
- Water depth (Section 4.4.4)
- Sampling depth interval (Section 4.4.5)
- Field sampling methods (Section 4.5)
- Sample handling procedures (Section 4.6)

## A.6 Chemistry and Biological Analytical Methods

Refer to Chapters 4 and 5 for information and requirements related to chemistry analytical methods, biological testing methods, and quality assurance and quality control requirements.

## A.7 Data Report

The results of sediment sampling and analyses should be provided to Ecology in a data report (in both hard copy and electronic format), which should include:

- A brief statement of the purpose of sampling.
- A brief summary of the field sampling and laboratory analytical procedures. Reference can be made to the SAP but any deviations from the SAP should be noted.
- A general vicinity map showing the location of the site, sampling stations, outfall/storm drain location(s), and predominant current direction.
- Coordinate values (i.e., latitude and longitude) and their datum should be reported in an accompanying table for all stations, including background or reference stations and the outfall diffuser beginning and end points. An electronic GIS shape file with projection details is recommended.
- Tables summarizing the data results, as well as pertinent QA/QC data, including:
    - Station numbers
    - Sample numbers (corresponding to laboratory data sheets)
    - Sampling station water column depth
    - Sample collection date

  - Sampling interval (upper and lower sediment sampling depth in centimeters)
  - Sample replicates
  - Chemistry results converted to the same units as the criteria (e.g., mg/kg dry weight for metals, mg/kg TOC for nonionizable organics; ppm)
  - Chemistry data for organic compounds should also be reported as dry weight concentrations (ug/kg dry weight; ppb)
  - Practical quantitation limits with appropriate qualifiers, which must be below the SQS

- A discussion of the interpretation of the results including any exceedances of the benthic criteria.
- A map indicating area(s) exceeding the SQS and SIZmax.
- Copies of complete laboratory data packages as an appendix.
- Quality assurance report as an appendix.
- Copies of field logs as an appendix.
- Copies of signed chain-of-custody forms as an appendix.
- See Section 6.3.1 for EIM data submittal requirements.

All appropriate data should be submitted to Ecology's EIM database. Data reports will be reviewed and approved only after data has been submitted to EIM and confirmed to be accurate using MyEIM analytical tools. Any differences between the MyEIM results and the data report should be identified and explained in the data report. Send a report (electronic and hard copy) for all NPDES permit required monitoring to:

1. The facility NPDES permit manager, and

2. The Sediment Source Control Specialist care of:
   Toxics Cleanup Program - HQ
   Aquatic Lands Cleanup Unit
   Washington State Department of Ecology
   P.O. Box 47600
   Olympia, WA 98504-7600

**Appendix A: Table A-1.** Marine benthic chemical criteria.

| | SMS Marine Sediment[a] | | Marine Sediment AETs[b] | |
|---|---|---|---|---|
| **Analyte** | **SQS** | **SIZmax** | **SQS** | **SIZmax** |
| **Conventional Pollutants** | | | | |
| Ammonia | | | | |
| Total sulfides | | | | |
| Total organic carbon | | | | |
| Sediment grain size | | | | |
| Total volatile solids | | | | |
| Total solids | | | | |
| **Metals** | **mg/kg dw** | | **mg/kg dw** | |
| Arsenic | 57 | 93 | 57 | 93 |
| Cadmium | 5.1 | 6.7 | 5.1 | 6.7 |
| Chromium | 260 | 270 | 260 | 270 |
| Copper | 390 | 390 | 390 | 390 |
| Lead | 450 | 530 | 450 | 530 |
| Mercury | 0.41 | 0.59 | 0.41 | 0.59 |
| Silver | 6.1 | 6.1 | 6.1 | 6.1 |
| Zinc | 410 | 960 | 410 | 960 |
| **Organic Chemicals** | **µg/kg dw (except *)** | | **µg/kg dw** | |
| 2,4-Dimethylphenol | 29 | 29 | 29 | 29 |
| 2-Methylphenol | 63 | 63 | 63 | 63 |
| 4-Methylphenol | 670 | 670 | 670 | 670 |
| Benzoic acid | 650 | 650 | 650 | 650 |
| Benzyl alcohol | 57 | 73 | 57 | 73 |
| Dibenzofuran | 15* | 58* | 540 | 540 |
| Phenol | 420 | 1200 | 420 | 1200 |
| N-nitrosodiphenylamine | 11* | 11* | 28 | 40 |
| **Phthalates** | **mg/kg OC** | | **µg/kg dw** | |
| Bis(2-Ethylhexyl)phthalate | 47 | 78 | 1300 | 1900 |
| Butylbenzyl phthalate | 4.9 | 64 | 63 | 900 |
| Diethyl phthalate | 61 | 110 | 200 | *> 1200* |
| Dimethyl phthalate | 53 | 53 | 71 | 160 |
| Di-n-butyl phthalate | 220 | 1700 | 1400 | 1400 |
| Di-n-octyl phthalate | 58 | 4500 | 6200 | 6200 |
| **Polychlorinated Biphenyls** | **mg/kg OC** | | **µg/kg dw** | |
| Total Aroclors | 12 | 65 | 130 | 1000 |
| **Polycyclic Aromatic Hydrocarbons** | **mg/kg OC** | | **µg/kg dw** | |
| Total LPAH | 370 | 780 | 5200 | 5200 |
| Naphthalene | 99 | 170 | 2100 | 2100 |
| Acenaphthylene | 66 | 66 | 1300 | 1300 |
| Acenaphthene | 16 | 57 | 500 | 500 |

**Appendix A: Table A-1** (continued). Marine benthic chemical criteria.

| | SMS Marine Sediment[a] | | Marine Sediment AETs[b] | |
|---|---|---|---|---|
| **Analyte** | **SQS** | **SIZmax** | **SQS** | **SIZmax** |
| **Polycyclic Aromatic Hydrocarbons** | **mg/kg OC** | | **µg/kg dw** | |
| Fluorene | 23 | 79 | 540 | 540 |
| Phenanthrene | 100 | 480 | 1500 | 1500 |
| Anthracene | 220 | 1200 | 960 | 960 |
| 2-Methylnaphthalene | 38 | 64 | 670 | 670 |
| Total HPAH | 960 | 5300 | 12000 | 17000 |
| Fluoranthene | 160 | 1200 | 1700 | 2500 |
| Pyrene | 1000 | 1400 | 2600 | 3300 |
| Benz[a]anthracene | 110 | 270 | 1300 | 1600 |
| Chrysene | 110 | 460 | 1400 | 2800 |
| Total benzofluoranthenes | 230 | 450 | 3200 | 3600 |
| Benzo[a]pyrene | 99 | 210 | 1600 | 1600 |
| Indeno[1,2,3-c,d]pyrene | 34 | 88 | 600 | 690 |
| Dibenzo[a,h]anthracene | 12 | 33 | 230 | 230 |
| Benzo[g,h,i]perylene | 31 | 78 | 670 | 720 |
| **Chlorinated Organics** | **mg/kg OC** | | **µg/kg dw** | |
| 1,2,4-Trichlorobenzene | 0.81 | 1.8 | 31 | 51 |
| 1,2-Dichlorobenzene | 2.3 | 2.3 | 35 | 50 |
| 1,4-Dichlorobenzene | 3.1 | 9 | 110 | 110 |
| Hexachlorobenzene | 0.38 | 2.3 | 22 | 70 |
| Hexachlorobutadiene | 3.9 | 6.2 | 11 | 120 |
| Pentachlorophenol | 360[c] | 690[c] | 360 | 690 |

a, Marine values are dry weight normalized for metals and polar organics and normalized to total organic carbon for nonpolar organics.

b, TOC normalized values and dry weight normalized AETs should be considered when total organic carbon is outside the recommended range of 0.5 – 3.5% for organic carbon normalization.

c, µg/kg dry weight

> *italicized* "greater than" value indicates that the toxic level is unknown, but above the concentration shown.

*mg/kg OC

Total volatile solids may be required on a permit-specific basis

**Appendix A: Table A-2.** Marine biological criteria (SQS and SIZmax and performance standards) for each biological test. Adverse effects are defined when any of the biological tests show the following:

| Biological Test Endpoint | Performance Standard | | SQS | SIZmax |
|---|---|---|---|---|
| | Control | Reference | | |
| **Amphipod** | | | | |
| **10-Day mortality** | $M_C \leq 10\%$ | $M_R \leq 25\%$ | $M_T > 25\%$ Absolute *and* $M_T$ vs. $M_R$ SD ($p < 0.05$) | $M_T - M_R \geq 30\%$ *and* $M_T$ vs. $M_R$ SD ($p < 0.05$) |
| **Larval** | | | | |
| **Bivalve or echinoderm abnormality / mortality** | $N_C / I \geq 0.70$ | $N_R / N_C \geq 0.65$ | $N_T / N_R < 0.85$ *and* $N_T$ vs. $N_R$ SD ($p < 0.10$) | $N_T / N_R < 0.70$ *and* $N_T$ vs. $N_R$ SD ($p < 0.10$) |
| **Juvenile Polychaete** | | | | |
| ***Neanthes* 20-day growth[a]** | $M_C \leq 10\%$ *and* $MIG_C \geq 0.38$[b] mg/individual/day AFDW | $MIG_R / MIG_C \geq 0.80$ | $MIG_T / MIG_R < 0.70$ *and* $MIG_T$ vs. $MIG_R$ SD ($p < 0.05$) | $MIG_T / MIG_R < 0.50$ *and* $MIG_T$ vs. $MIG_R$ SD ($p < 0.05$) |
| **Microtox** | | | | |
| **Microtox decreased luminescence** | Case-by-case | Case-by-case | $ML_T / ML_R < 0.80$ *and* $ML_T$ vs. $ML_R$ SD ($p < 0.05$) | |
| **Benthic Community** | | | | |
| **Benthic Abundance** | See notes below | | $A_T / A_R < 0.50$ For any one of the three major taxa: Class Crustacea, Phylum Mollusca, or Class Polychaeta | $A_T / A_R < 0.50$ For any two of the three major taxa: Class Crustacea, Phylum Mollusca, or Class Polychaeta |

A = Abundance; C = Control; R = Reference; T = Test; F = Final; M = Mortality; N = Normal Survivorship expressed as actual counts; I = Initial count; MIG = Mean Individual Growth Rate expressed in mg/ind/day Ash Free Dry Weight; ML = Mean Light output; BLD = Blank Corrected Light Decrease; SD = Significantly Different.

For the Amphipod, Juvenile Polychaete, and Microtox tests, a statistical significance is set at $\alpha = 0.05$ (i.e., an exceedance of the criteria occurs when $p < 0.05$). For the Larval test, a statistical significance is set at $\alpha = 0.10$ (i.e., an exceedance of the criteria occurs when $p < 0.10$). These recommended criteria differ slightly from Part V of the SMS. They reflect the standards in Part III of the SMS which represent the clearest interpretation of the criteria and are incorporated in Ecology's MyEIM analytical tool.

a, See Appendix B: 2013. DMMP/SMS Clarification Paper: Bioassay Endpoint Refinements: Bivalve Larval and Neanthes Growth Bioassays. *Neanthes arenaceodentata* is a sediment ingester and when the animals are dried and weighed at the end of the 20 day test, the inorganic sediments in the gut can contribute up to 30% of the weight of the animal, which interferes with test results. The use of Ash Free Dry Weight to more accurately reflect the increase in biomass over the test period was examined and determined to be an appropriate change, with the recognized need to review the performance standard for the negative control.

b, Ecology recommends 0.38 MIG AFDW as the performance standard for negative control. The former performance standard was 0.72 MIG with an allowance for case-by-case approval down to 0.38 MIG. A review of negative controls from all ten test batches from 2013 and later was reviewed. Ten of the 9 test batches met the 0.38 MIG and 8 were below the former performance standard of 0.72 MIG.

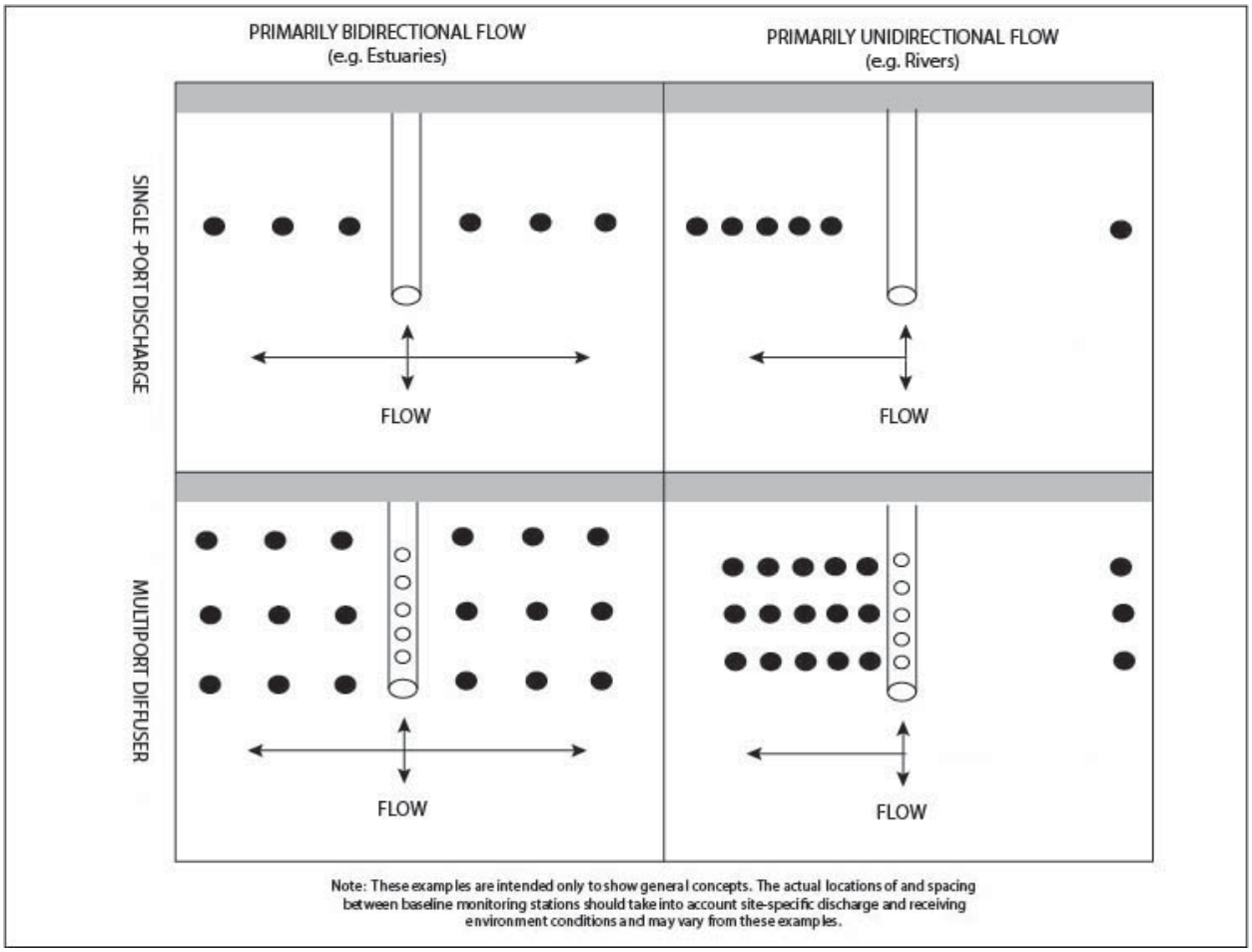
**Appendix A: Table A-3.** Marine biological tests, species, and applicable endpoints.

| Class/Type | Species | Biological Test Endpoint | Acute Effects Test | Chronic Effects Test |
|---|---|---|---|---|
| **Amphipod** | • *Rhepoxynius abronius*<br>• *Ampelisca abdita*<br>• *Eohaustorius estuarius* | 10-Day mortality | x | |
| **Larval** | • *Crassostrea gigas* (Pacific oyster)<br>• *Mytilus (edulis) galloprovincialis* (Blue mussel)<br>• *Strongylocentrotus purpuratus* (Purple sea urchin)<br>• *Dendraster excentricus* (Sand dollar) | Mortality / Abnormality | x | |
| **Juvenile Polychaete** | *Neanthes arenaceodentata* | 20-Day growth | | x |
| **Microtox** | *Vibrio fischeri* | • 15-minute exposure<br>• Decreased luminescence | | x |
| **Benthic Infauna** | Three major taxa, including:<br>• Class Crustacea<br>• Class Polychaeta<br>• Phylum Mollusca | | | x |

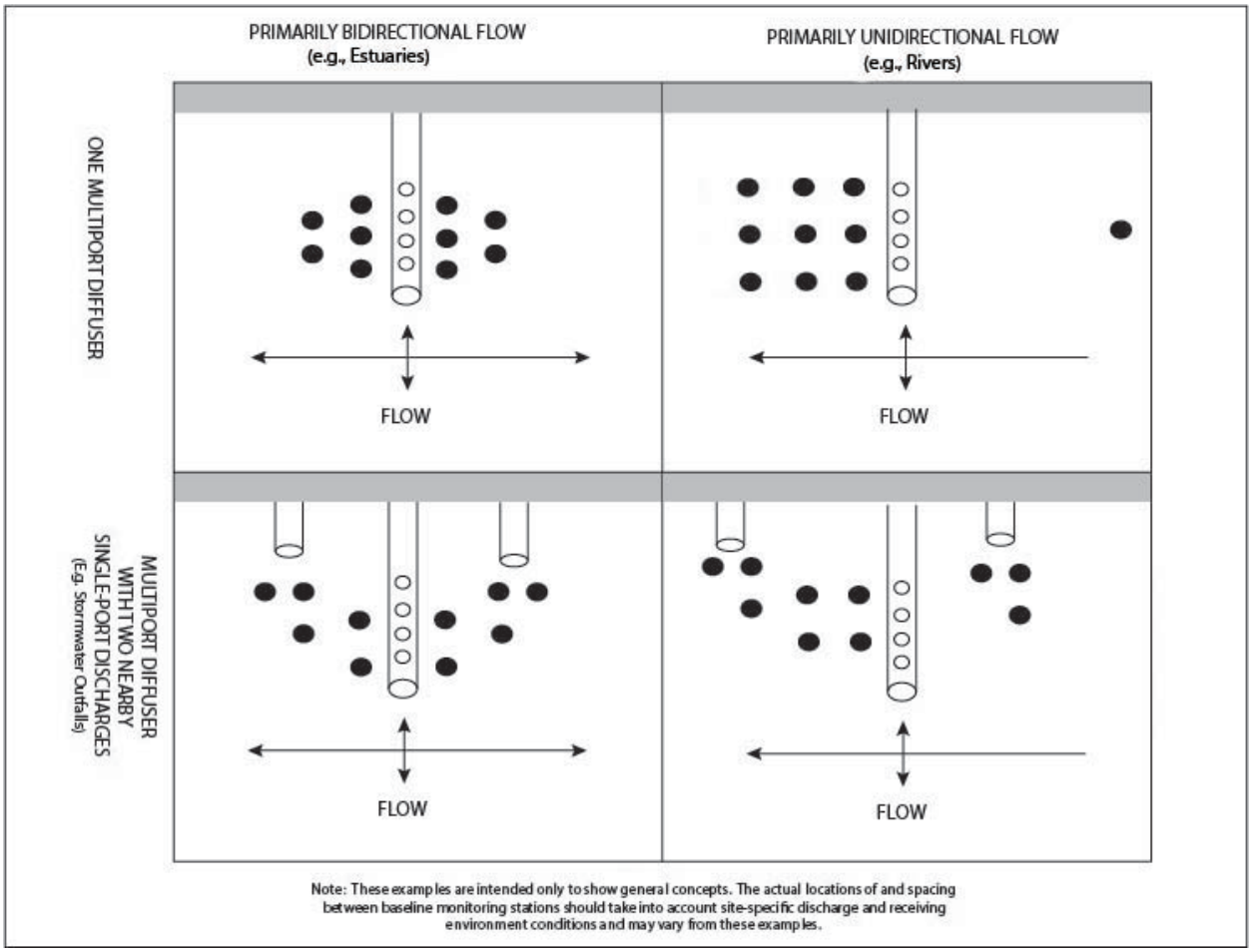
**Appendix A: Table A-4.** Recommended freshwater biological tests, species, and applicable endpoints.

| Species/Endpoint | Acute Effects Biological Test | Chronic Effects Biological Test | Lethal Effects Biological Test | Sublethal Effects Biological Test |
|---|---|---|---|---|
| **Amphipod:** *Hyalella azteca* | | | | |
| 10-Day mortality | x | | x | |
| 28-Day mortality | | x | x | |
| 28-Day growth | | x | | x |
| **Midge:** *Chironomus dilutus* | | | | |
| 10-Day mortality | x | | x | |
| 10-Day growth | x | | | x |
| 20-Day mortality | | x | x | |
| 20-Day growth | | x | | x |

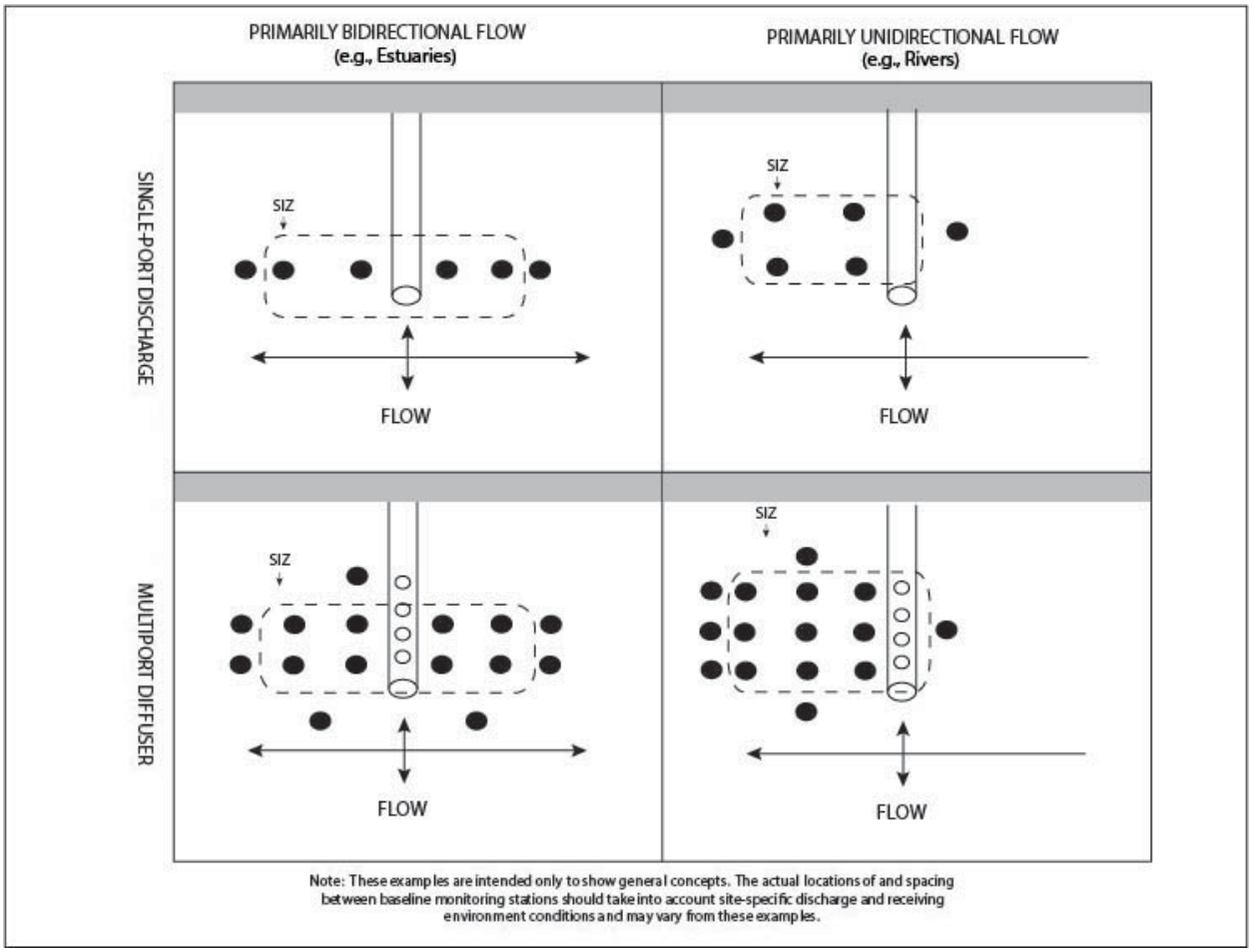
These tests and parameters were developed based on the most current American Society for Testing and Materials (ASTM International) and EPA protocols for establishing appropriate biological tests.




**Appendix A: Figure A-1.** Examples of monitoring station locations using 6 and 18 stations.




**Appendix A: Figure A-2.** Examples of monitoring station locations using 10 stations.




**Appendix A: Figure A-3.** Examples of SIZ maintenance monitoring station locations.

*This page left intentionally blank.*

# Appendix B
# Sediment Management Annual Review Meeting (SMARM) Papers

Below is a list of papers presented at SMARM that have been referenced in this document and are relevant to sediment cleanup. Due to size constraints, the papers are found in a separate attachment that can be downloaded from:

https://fortress.wa.gov/ecy/publications/SummaryPages/1209057.html

## Program development clarification and issue papers

Inouye, L. 2010. Sediments exposed by dredging (Z-Layer) testing. DMMP clarification paper.

Fox, D., Hoffman, E., Gries, T. 2008. Quality of post-dredge surfaces (updated). DMMP clarification paper.

Gries, T. 2005. Evaluation of sediment quality for navigational dredging, contaminated sediment cleanup or both. DMMP/SMS issue paper.

Kendall, D., and Gries, T. 2003. Recency guideline exceedances: Guidelines for re-testing in high ranked areas. DMMP clarification paper.

Gries, T., Benson, T. Barton, J., and Malek, J. 2003. Determining when material above MHW/OHW will be characterized in DMMP. DMMP clarification paper.

Kendall, D. 2001. Clarifications to the DMMP Z-sample analysis guidance and/or post dredge monitoring policy. DMMP clarification paper.

Gries, T. H. 2001. Quality of post-dredge sediment surfaces. DMMP clarification paper.

Kendall, D. and Michelsen, T. 1997. Management of wood waste under Dredged Material Management Program (DMMP) and the Sediment Management Standards (SMS) Cleanup Program. DMMP clarification paper.

Barton, J. 1997. Beneficial use of dredged material. DMMP clarification paper.

## Sampling and testing requirements issue papers

Sternberg, D. 2005. Reporting of sediment-bound contaminants: Standardization of sieving and analytical procedures. DMMP/SMS clarification paper.

Bragdon-Cook, K. 1993. Recommended methods for measuring TOC in sediments. DMMP clarification paper.

Fox, D. 1993. Modifications to sampling requirements for deep native sediments.

## Chemical testing

Michelsen, T. and Asher, C. 2012. Use of practical quantitation limits (PQLs) to establish cleanup standards for contaminated sediment sites under the Sediment Management Standards (SMS). SMS issue paper.

Inouye, L., Fox, D. 2011. Marine sediment quality screening levels: Adopting RSET marine SLs for use in DMMP. DMMP clarification paper.

DMMP. 2010. New interim guidelines for dioxins.

DMMP. 2010. Revised supplemental information on polychlorinated dioxins and furans (PCDD/DF) for use in preparing a quality assurance project plan (QAPP).

Hoffman, E., and Fox, D. 2010. Polychlorinated dioxins and furans (PCDD/DF): Revisions to the supplemental quality assurance project plan (SQAPP). DMMP clarification paper.

Stirling, S. 2008. Update on pyrethroids and PBDE analysis. DMMP status report.

Fox, D. and Hoffman, E. 2007. Chlordane analysis and reporting. DMMP clarification paper.

Betts, B. and Bragdon-Cook, K. 2001. Chemical analysis of archived sediment samples. DMMP/SMS clarification paper.

Kendall, D. R.1999. Blank correction for method blank contaminated chemical samples. DMMP clarification paper.

Hoffmann, E. 1998. TBT analysis: Clarification of interstitial water extraction and analysis methods –interim. DMMP clarification paper.

Michelsen, T., Shaw, T. C., and Stirling, S. 1996. Testing, reporting, and evaluation of TBT data in PSSDA and SMS Programs. PSSDA issue paper.

Betts, B. 1994. Use of alternate technologies under the Sediment Management Standards Chapter 173-204 WAC. DMMP clarification paper.

## Bioassays

Kendall, D., McMillan, R., Gardiner, B., Hester, B., and Word, J.D. 2013. Bioassay endpoint refinements: Bivalve larval and *Neanthes* growth bioassays. DMMP/SMS clarification paper.

Stirling, S. 2008. Reference areas for freshwater bioassays. DMMP clarification paper.

Kendall, D. 2005. Sediment larval test species recommended for toxicity testing by the DMMP program. DMMP clarification paper.

Kendall, D. and Barton, J. 2004. Ammonia and sulfide guidance relative to *Neanthes* growth bioassay. DMMP clarification paper.

Barton, J. 2002. Ammonia and amphipod toxicity testing. DMMP clarification paper.

Cole Warner, L. 2001. Reporting ammonia LC50 data for larval and amphipod bioassays. DMMP clarification paper.

Kendall, D. and McMillan, R. 1999. Clarification on the use of the amphipod, *Eohaustorius estuarius*, relative to grain size and salinity. DMMP clarification paper/SMS draft technical information memorandum.

Fox, F. F. and Michelsen, T. 1997. Selection of negative control sediment and use of control sediments as reference sediments. DMMP clarification paper/SMS draft technical information memorandum.

Michelsen T. and Shaw, T. C. 1996. Statistical evaluation of bioassay results. DMMP clarification paper/SMS draft technical information memorandum.

Kendall, D. 1996. *Neanthes* 20-day bioassay—further clarification on negative control growth standard, initial size, and feeding protocol. PSDDA/SMS clarification paper.

Kendall, D. 1995. In-batch testing for reference sediments for PSDDA bioassays. PSSDA clarification paper.

Peeler, M. 1994. Restriction on exotic species importation. PSSDA clarification paper.

Fox, D. and Littleton, T. 1994. Interim revised performance standards for the sediment larval bioassay. PSSDA revised clarification paper.

Kendall, D. 1993. Species substitution for the 10-day amphipod bioassay. PSDDA clarification paper.

Fox, D. 1993. The *Neanthes* 20-day bioassay—requirements for ammonia/sulfides monitoring and initial weight. PSSDA clarification paper.

Kendall, D. and Fox, D. 1991. Modification to holding time for biological testing. PSSDA issue paper.

Kendall, D. 1991. Echinoderm embryo sediment bioassay protocol. PSSDA clarification paper.

Fox, D. 1991. PSDDA requirement to collect and report amphipod reburial data. PSSDA clarification paper.

Wakeman, J. 1990. Wet sieving method for reference sediment grain size matching. Memorandum for the record.

Kendall, D. 1990. Requirements for analyzing sediment conventional in reference areas and water quality in bioassays. PSSDA clarification paper.

Barton, J. 1990. Activities to provide better reference areas. DMMP status report.

## Bioaccumulation testing

Inouye, L. 2009. Metals BCOC list. DMMP clarification paper.

Kendall, D. and McMillan, R. 2009. Bioaccumulation protocol clarifications. DMMP clarification paper, originally implemented in 2000, includes 2008 and 2009 updates. DMMP Clarification paper.

Hoffman E. 2007. Technical basis for revisions to the DMMP bioaccumulation chemicals of concern list. DMMP technical support document, includes 1998 update.

Hoffman E. 2003. Revisions to the bioaccumulative chemicals of concern (BCOC) list. DMMP issue paper.

Hoffman E. 1998. Technical support document for revision of the DMMP bioaccumulative chemicals of concern list. DMMP technical support document.

Kendall, D. 1996. Sediment bioaccumulation testing refinements: Sample volume requirements, simultaneous co-testing of two species within a single aquarium, and species substitution. DMMP clarification paper.

Kendall, D. 1994. Refinements to bioaccumulation testing requirements: Adoption of a second test species for consistency with national guidance. DMMP issue paper.

*This page intentionally left blank.*

# Appendix C
# Bioassay Methods

## C.1 Marine and Freshwater Microtox® 100 Percent Sediment Porewater Toxicity Test

### C.1.1 Microtox

Microtox® is a rapid method of assessing toxicity in marine and freshwater sediment by using the bioluminescent properties of the marine bacteria *Vibrio fischeri*. The bacteria are exposed to field sediment and the light emitted by the bacteria is used to assess the overall biological condition of the bacteria by comparing to a control. The difference in luminescence is an indication of relative toxicity.

US EPA (1989a) has recommended Microtox® for toxicity evaluations of freshwater, estuarine, and marine sediment. PSEP (1995) recommends organic and saline extraction protocols to assess sediment toxicity. The goal of most sediment toxicity studies is to determine whether significant differences exist between reference and site sediment. This guidance recommends incorporating four significant differences from the PSEP protocols:

- Microtox extraction procedures are 100% porewater extraction, versus PSEP's complex organic and aqueous extractions.
- Serial dilutions are not performed because LC50 calculations are not required to assess differences between reference and site sediment. PSEP requires serial dilutions.
- Microtox Osmotic Adjusting Solution (MOAS) is not utilized. PSEP recommends use of MOAS.
- Analysis of variance (ANOVA) or t-test statistical tests are used. PSEP recommends different statistics.

The luminescent response of *Vibrio fischeri* (often referred to as over-luminescence or light enhancement) is an increase in light output. This is a natural response to a number of unmeasured factors including (but not limited to) hardness, alkalinity, TOC, dissolved energy sources, and colloids, which may cause a decrease or increase in light output. Using reference and control samples will account for these factors, which is why the comparison or response between test sediment (the porewater fraction) and the control/reference is important. It is therefore critical to understand how the Microtox procedure works and what is being measured.

Microtox test results are numbers of light output without units. The first step performed with each batch of vials prior to recording Microtox data is "setting" the machine to a baseline output value. This is a type of calibration to the current bacterial batch being used, as well as to any uncontrolled test conditions. The baseline output value is normally set with a control vial containing 10 µl of bacterial suspension. When this vial is immediately read, its value range is approximately 93–107. For each new batch run, a new "set" procedure is performed.

An increase in light output is a normal biological response and can be expected with similar frequency as that of light reduction in controls, reference, and test porewater, so it is important to compare temporal changes in the reference or control to the test light output. The null hypothesis is no temporal reduction in test light output compared to reference/control light output, assuming that only light reduction (relative to the reference/control) is an indication of toxicity. The alternative hypothesis is a temporal reduction in test light output greater than a temporal reduction in control/reference light output. Since there is only one possibility for the alternative hypothesis, the statistical analysis is a one-tailed t-test.

## C.1.2 Sample collection and holding times

The holding time limit on field samples should not exceed 7 days. Pinza et al. (2009) evaluated the effects of holding time and showed that holding times should be reduced to avoid sulfide and ammonia generation. Exceeding the 7-day holding time results in bacterial decomposition and subsequent production of ammonia and sulfide, potentially resulting in toxicity.

## C.1.3 Microtox test procedure

### C.1.3.1 Porewater extraction and adjustment

The general Microtox® procedure involves centrifugation of 500 milliliters (ml) of both reference and test sediment at approximately 4500 *g* for 30 minutes, resulting in approximately 50 ml of porewater. It is recommended to have minimal disturbance of the field-collected samples prior to centrifugation (e.g., compositing of numerous subsamples followed by homogenization) to reduce volatilization of potential contaminants. After centrifugation, pipette approximately 25 ml of porewater into a clean glass container. Set aside the remaining porewater volume to further reduce initial salinity (at or below 22 ppt) if necessary. Samples should be adjusted and analyzed within approximately three hours of extraction to reduce volatilization of potential contaminants.

The sample is then adjusted for salinity, dissolved oxygen, and pH in the following order:

1. For freshwater and marine test porewater, adjust salinity to 20 ± 2 ppt using commercially-available dry bulk marine aquarium reef salts (e.g., Forty Fathoms Reef®). For marine and estuarine test porewater exceeding 20 ppt salinity, adjust the artificial

seawater control to match the test porewater salinity ±2 ppt (e.g., test porewater 26 ppt, seawater control 24–28 ppt).

2. Adjust the dissolved oxygen (DO) by gentle aeration or agitation until it is between 50 – 100% saturation.
3. The pH adjusted reference and test porewater should not differ by more than 0.4 pH units.
4. If necessary, adjust pH to 7.9 – 8.2 using a micropipette and a dilute solution (0.5 N) NaOH or HCl. Record total volume of NaOH and/or HCl.
5. Calculate final concentration (compared with 100% porewater extracted).
6. Final dilution should not be reduced below 90% of the porewater extract**.**
7. Prepare the control solution using deionized or distilled water and adjusting salinity, DO, and pH as described above.

### C.1.3.2 Preparation of bacterial suspension and bioassay test setup

1. Rehydrate a vial of freeze-dried bacteria with 1.0 ml of Microtox® reconstitution solution, then allow it to equilibrate for 30 to 90 minutes in a 4 °C Microtox Analyzer well.
2. Mix the reconstituted solution with a 1 ml pipette a minimum of 20 times by pipetting.
    a. First, pipette the solution from the bottom of the cuvette and deposit the pipetted solution on the surface of the remaining liquid in the cuvette.
    b. Then, pipette 1 ml of solution from the bottom of the cuvette and slowly pipette the liquid into the bottom of the cuvette.
3. Add 1.0 ml of control solution to 5 test cuvettes and place in 15 °C incubation chambers. Follow this procedure for the control, reference, and test porewater samples for up to 4 per batch (5 pseudo-replicates per site).
4. In each of the test, reference, and control sample cuvettes, add 10 µL of rehydrated bacteria suspension at approximately 10-second intervals.
    a. Mix this immediately using a 1.0 ml pipette and allow to incubate for 5-minutes (Initial Incubation).
    b. It is recommended that two technicians coordinate the addition and mixture of the bacterial suspension (one technician adds the bacterial suspension; another performs the mixing procedure).
5. Begin the 5-minute Initial Incubation timer as soon as the 10 µl bacterial suspension is placed into the cuvette containing the control sample at position A1.
    a. Replace used pipette tips with clean tips after each series of 5 pseudo-replicates (reference, control, and each test series [e.g., A1–A5]).
    b. Use care when pipetting low volumes, as slight residual amounts or the presence of air bubbles in the pipette may cause up to a 100% variation due to procedural error.

### C.1.3.3 Data collection

1. At the end of the 5-minute Initial Incubation period, place the first control vial into the read chamber to "set" the instrument.
2. Start the data collection timer. This is the beginning of the ($I_0$) 5-minute analysis period.
3. At approximately 10-second intervals, place each cuvette (including A1) into the read chamber for the initial reading ($I_0$).
4. After 5 additional minutes, take a second reading ($I_5$) using the above procedure.
5. After 10 additional minutes, take a 15-minute reading ($I_{15}$).

## C.1.4 Data preparation

The following calculations are performed for each replicate to provide a mean ($T_{mean}$):

For example: $(T_1 + T_2 + T_3 + T_4 + T_5) / 5$.

$F_t/I_t = T_1$
$F_r/I_r = R_1$
$F_c/I_c = C_1$

Where:

I = initial light reading ($I_0$)
F = final light reading ($I_5$ or $I_{15}$ above depending upon the endpoint)
C, c = control
R, r = reference
T, t = test (porewater station)
Example: $I_t$ = (initial light output of test sample)

For marine sediment, the endpoint for the test is calculated relative to reference.

**Appendix C: Equation C-1**

$$T_{mean}/R_{mean}$$

For freshwater sediment, the endpoint for the test is calculated relative to control. If performance criteria (Section C.1.7) are not met for control, comparison to reference may be authorized on a case-by-case basis.

**Appendix C: Equation C-2**

$$T_{mean}/C_{mean}$$

## C.1.5 Statistical analysis

### C.1.5.1 Marine and estuarine sediment

Statistical calculations are performed using a standard t-test by comparing reference with test data (Equation C-1). No gamma correction is required. Statistically significant differences with $\alpha = 0.05$ and the following relative differences (C.1.6.1) indicate test failure.

### C.1.5.2 Freshwater sediment

Statistical calculations are performed using a standard t-test by comparing control with test data (Equation C-2). No gamma correction is required. Statistically significant differences with $\alpha = 0.05$ and the following relative differences (Section C.1.6.2) indicate test failure.

## C.1.6 Data interpretation

### C.1.6.1 Marine and estuarine sediment

*An SCO exceedance is defined as:*

- Test mean output ($T_{mean}$) less than 80% of the reference mean output ($T_{mean} / R_{mean} < 80\%$), and
- A statistically significant difference ($\alpha = 0.05$) from reference mean output.

There is no CSL criterion for marine sediment.

### C.1.6.2 Freshwater sediment

*An SCO exceedance is defined as:*

- Test mean output ($T_{mean}$) less than 90% of control/reference mean output ($C_{mean} / T_{mean}$), and
- A statistically significant difference ($\alpha = 0.05$) from control/reference mean output.
- If $T_{mean} / R_{mean} > 1.10$ and/or $T_{mean} / C_{mean} > 1.10$, test procedures may have been compromised. All procedural steps should be reviewed and the test should be reinitiated after procedural corrections have been instituted. If results are verified, Ecology should be consulted for further action or data interpretation.

*A CSL exceedance is defined as:*

- Test mean output less than 75% of control/reference mean output, and
- A statistically significant difference ($\alpha = 0.05$) from control/reference mean output.

## C.1.7 Quality control

In order to be conservative with respect to ecological significance, an established benchmark difference between reference and test must be met. Although statistical differences may exist between test and reference/control, it is generally accepted that no significant ecological difference exists between reference/control and test unless the test indicates a temporal reduction in test light output of greater than 10% compared with the change that has occurred in the reference/control. In other words, 10% is an acceptable range of reduction within the normal bounds of ecological variability (noise).

Because of this 10% benchmark of acceptability for reduction, a 10% increase in temporal light output in the control/reference or test is also within the bounds of normal ecological range. This allows for increases in light output and acceptability up to the following limits:

- $T_{mean} / C_{mean} > 1.10$ is not interpretable and further action is warranted (see Section C.1.6).
- $T_{mean} / R_{mean} > 1.10$ is not interpretable and further action is warranted (see Section C.1.6).

Test procedures or organism performance might be compromised beyond these limits (i.e., above 110% Control ($C_{mean}$) light output, or when the ratio of reference mean ($R_{mean}$) to test mean ($T_{mean}$) temporal change results in a 10% difference).

### C.1.7.1 Marine and estuarine sediment

- Control Final mean output should be greater than or equal to 80% of Control Initial mean output: $F_{c(mean)}/I_{c(mean)} \geq 0.80$.

- Reference Final mean output should be greater than or equal to 80% of Control Final mean output: $F_{r(mean)}/F_{c(mean)} \geq 0.80$. If criteria are not met, the Control output may be used for comparison with the test porewater output.

- Reference Initial mean output ($I_{r(mean)}$) must be greater than or equal to 80% of Control Initial mean output ($I_{c(mean)}$).

    - If the Reference Initial mean output is less than 80% of Control Initial mean output, the Control Initial mean output should be used in place of each of the individual Reference Initial values (e.g., when $I_{r(mean)} < 0.80$ of $I_{c(mean)}$, then $I_{c(mean)}$ is used in place of each $I_r$).

    - This may be necessary when the light reduction response occurs so rapidly that the initial test response falls below 80% before the initial measurement is taken.

- Test Initial mean output ($I_{t(mean)}$) must be greater than or equal to 80% of Control Initial mean output ($I_{c(mean)}$).
    - If Test Initial mean output is less than 80% of Control Initial mean output, the Control Initial mean output should be used in place of each of the individual Test Initial values (e.g., when $I_{t(mean)} < 0.80$ of $I_{c(mean)}$, then $I_{c(mean)}$ is used in place of each $I_t$).
    - This may be necessary when the light reduction response occurs so rapidly that the initial test response falls below 80% before the initial measurement is taken.

**C.1.7.2 Freshwater sediment**

- Control Final mean output should be greater than or equal to 72% of Control Initial mean output (e.g., $F_{c(mean)} / I_{c(mean)} \geq 0.72$). If control performance criteria are not met, reference output may be used for comparison with test porewater light output.

- Reference Final mean output should be greater than or equal to 80% of Control Final mean output (e.g., $F_{r(mean)} / F_{c(mean)} \geq 0.80$).

# C.2 Conducting Bioassays on Sediment Containing Polycyclic Aromatic Hydrocarbons Exposed to Ultraviolet Radiation

When certain polycyclic aromatic hydrocarbons (PAHs) are exposed to ultraviolet (UV) radiation of specific wavelengths and intensities, the result is atomic excitation of electron states known as photo-activation (Kosian et. al., 1998). Photo-activation can result in an increase in molecular reactivity or binding capability to other molecules.

The toxicity to benthic and water column organisms subjected to UV-exposed PAHs may be an order of magnitude greater than organisms exposed to the same concentrations/mixtures of PAHs in the absence of UV (Ahrens and Hickey, 2002). Exposure can result in acute toxicity (death) or sublethal effects (decreased immune response, decreased reproduction or growth, or increased malignant tumor development) (Arfsten, et al., 1996). The overall effect is decreased individual fitness and potentially detrimental population-level effects. The following guidance is recommended under the conditions specified below.

## C.2.1 Conditions determining type of bioassays

**C.2.1.1. Site conditions**

When both of the following site conditions are encountered in either freshwater or marine sediment sites, bioassays should be performed in the presence of full spectrum laboratory

lighting that includes ultraviolet wavelengths of sufficient intensity to mimic the conditions at the site:

1. Water depth (MLLW):

    a) For marine or estuarine sediment, if > 25% of the site sediment or ½ acre of the site sediment have water depths of 4 meters or less.

    b) For freshwater sediment, if > 25% of the surface sediment or ½ acre of the surface sediment at the site have had seasonal water depths at the lowest stage of 4 meters or less in the past 10 years (Kirk 1994a, 1994b).

    c) These depths are relatively conservative but research shows pronounced sensitivity to UV-B radiation and effects throughout the top 10 to 15 meters of the water column, indicating significant penetration to those depths (UNEP, 1998).

2. Presence or presumed presence of any of the photo-activated PAHs (Nagpal, 1993) listed in Appendix C: Table C-1.

#### C.2.1.2. Data conditions

If the site conditions in C.2.1.1 have been met and chemistry data is available:

1. Bioassays should be performed in the presence of full spectrum UV light when:

    a) The SCO or SQS has been exceeded for any PAH listed in Appendix C: Table C-1, or

    b) PAHs or sums of PAHs are exceeded by (> 25%) of the SCO or SQS.

If PAHs are present, or suspected to be present, at the site for which no SMS chemical criteria are available, best professional judgment and best available science should be used on a case-by-case basis.

## C.2.2 Laboratory testing conditions and considerations

Standard fluorescent laboratory lighting fixtures do not produce full spectrum UV light. It is impossible to accommodate both a high visible light emission and a high UV output within the same light source. The more visible light emitted, the less UV-radiation and vice versa. It is recommended that two different tubes with different radiation characteristics be used (see Section C.2.2.1) to produce both adequate visible light output and correct UV spectrum output.

### C.2.2.1 Lamp selection

Four important features for a full-spectrum UV light lamp include:

- UVB output (280nm < λ < 315nm) photo-activating wavelengths.
- UVA output (315nm < λ < 400nm). This may have an effect on burial and feeding behavior of benthic organisms.
- Correct color temperature. Warm red to cold blue expressed in degrees Kelvin (ºK). Daylight at noon is typically estimated at 5,500ºK.
- High color rendering index. Color rendering is the degree to which a light source shows the true colors of the objects it illuminates. This is measured on a color rendering index, rated from 0 -100. For example, a normal fluorescent lamp rates 54 on the CRI scale. High quality fluorescent lamps will rate 90 - 98 on the same scale.

The combination of sufficient UVA content and a natural > 5,500ºK color temperature improves activity patterns and feeding of benthic organisms when high quality full spectrum lighting is used. In addition to the quality of the lamp, proximity to the animal, output intensity, and duration of use are important. The illumination intensity of tubes is primarily dependent upon their size. Typically, a 24" (60 cm) tube produces less than half the light output of a 48" (120 cm) tube. An example of an acceptable UV spectral output is shown in Appendix C: Figure C-1 and Figure C-2. Spectral output will differ depending upon lamp manufacturer specifications and lamp age.

When installing full spectrum or UVB-producing tubes, it is important that nothing is placed between the envelope of the tube and the recipient animal or vessel. UVB is greatly attenuated by glass, plastic and ultra-fine mesh. A normal mesh allows the highest transmission, but the UVB rays are still reduced to about 90% of their normal power. The amount of UVB received also diminishes with distance. It is generally recommended that UVB tubes be no further than 12" (30 cm) from the subject. At distances greater than this, the amount of UVB actually received will be minimal. This may encumber some monitoring activities, so make allowances for temporary vessel or lamp removal.

Tubes also have a limited life and require changing at least every 5000 hours to guarantee continued UVB output. Although there may not be visible deterioration in the performance of the tube, the invisible UV content decays as the tube ages. It is recommended that a small adhesive label be placed near each fitting with the total hours the tube has been used, and that tubes be replaced every 5000 hours.

Most full spectrum fluorescent tubes designed for aquarium use are classified according to their percentage UVB output. The most popular tubes offer 5% to 8% UVB. An exposure duration of

14 to 16 hours is suitable for most species. The higher the UV output (invisible light) the less light (visual) is emitted. For best results, therefore, it is recommended to combine a tube with a high UV output with a tube with a very high visual light output.

**C.2.2.2 Recommended laboratory conditions**

- Light intensity: 50 -100 foot candles
- Light duration: 16/8 (Light/Dark)
- Overlying Water Depth: Not greater than 15 cm (6 inches)
- Lamp to water surface distance: Not greater than 30 cm (12 inches)
- UV wavelength range:
    - 3 to 8% UV-B range (280nm < λ < 315nm) (3-5% preferred)
    - 20 to 35% UV-A (315nm < λ < 400nm)

For additional review, discussion, and examples of laboratory conditions, methods and ambient field considerations (such as oxygenation, mineralization, humic and fulvic acids and presence of primary activators) see: a) ASTM 1997, b) Barron et al. 2003, c) Barron et al. 1999, d) Barron et al. 2000, e) Boese et al. 1997, f) Little et al. 2000, g) Mekenyan et al. 1994, h) Pelletier et al. 1997, and i) Weinstein 2001.

# C.3 Bioassay Reference and Control Sediment

The Sediment Management Standards includes definitions of a "Reference" and "Control" sediment sample. This section describes the purpose of, and difference between, the two concepts.

## C.3.1 Control Sediment Sample

A *negative control* sediment sample is a surface sample that is relatively free of contamination and has the physical and chemical characteristics of the sediment under investigation. Bioassay tests use a control sediment sample to provide information on the test animal's stress tolerance during transport, laboratory handling, and the actual bioassay procedures. To be in compliance with the SMS, control sediment samples must not exceed the benthic criteria (Chapter 8, Tables 8-2 and 8-4).

Similarly, a *negative control* sediment sample is defined by ASTM as sediment that is free of contaminants and is used routinely to assess the acceptability of the test.

#### C.3.1.1 Narrative description of a control sample

Under the classic definition, a control sample should represent toxicity test exposure conditions that essentially duplicate all exposure treatment conditions, except the chemicals or physical conditions the test is designed to evaluate. This scenario is typically used to assess the biological endpoint response caused exclusively by the chemical(s) or physical conditions of interest.

When assessing contaminated sediment sites under the SMS, the effects of other non-toxic abiotic factors that can influence toxicity (e.g., sediment grain size, pH, alkalinity, salinity, TOC, biological oxygen demand) on biological endpoints must also be incorporated in the toxicity test. This can be accomplished using a reference sediment sample (Section C.3.2). Therefore, under the SMS rule a toxicity test using a control sediment sample must include exposure conditions that represent all habitat conditions native to the test organism and/or duplicate the laboratory culture conditions in which that organism was raised and held.

#### C.3.1.2 Purpose of a control sample

A negative control is used in toxicity tests to compare biological endpoint responses in native and/or natural untreated exposure conditions relative to the sediment under investigation (treatment exposure) and is used routinely to assess the acceptability of the test. Organisms exhibit a natural rate of growth, mortality, reproduction, and other species-specific characteristics. To test the biological endpoint response (e.g., mortality, growth) caused exclusively by a chemical(s) on an organism, subtraction of what would be considered the natural or normal response (e.g., growth, mortality) must be performed—which is the purpose of the control. The control must meet specific quality control requirements to meet ASTM test acceptability standards.

### C.3.2 Reference Sediment Sample

A reference sediment sample is a surface sediment sample used as an indicator of a test animal's tolerance to the natural physical and chemical characteristics of the sediment under investigation (e.g., grain size, organic content). Reference sediment samples should represent sediment conditions similar to those of the area under investigation but not affected by contamination (e.g., nonanthropogenically affected background). These conditions cannot exceed the criteria in the SMS (WAC 173-204-320 through 173-204-340 and WAC 173-204-562 through 173-204-563).

#### C.3.2.1 Narrative description of a reference sample

Reference sediment samples are not the same as Reference Toxicant testing. ASTM defines a reference sediment as a whole sediment near the area of interest used to assess sediment conditions exclusive of material(s) of concern.

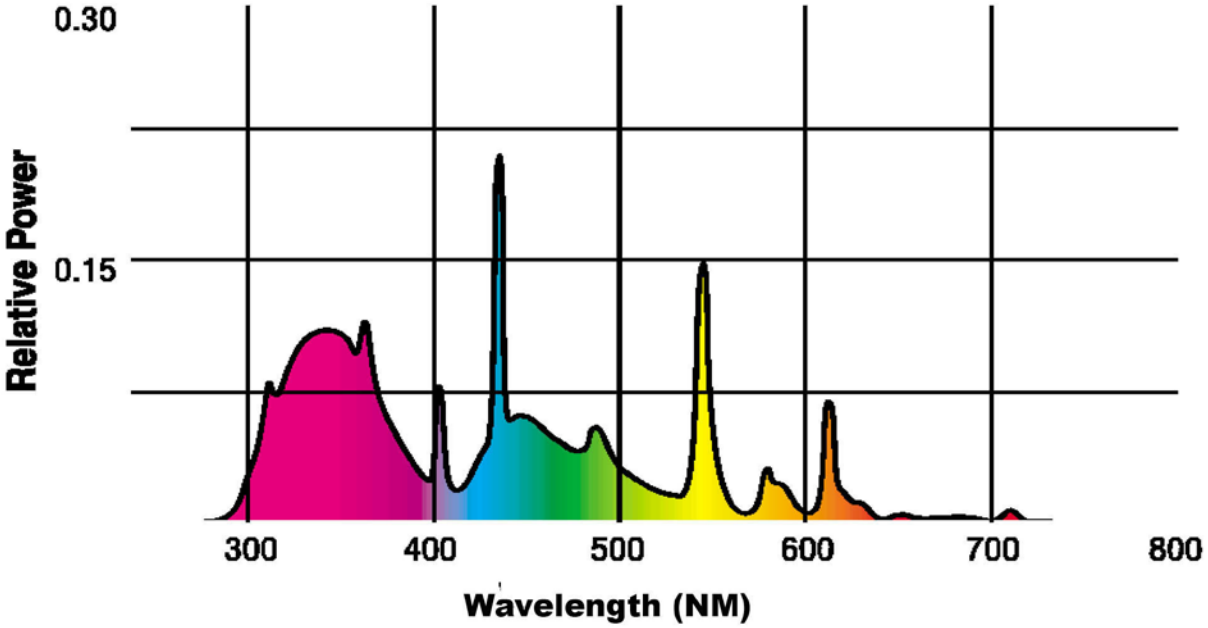
A reference sample is sediment that is essentially devoid of contaminants and has little or no impact upon the test organism. Reference samples should duplicate all the conditions of exposure treatments, but without the effects of contaminants or physical conditions that the test is designed to evaluate. A reference sediment sample is typically used in toxicity tests to assess the specific endpoint response due to *both* the contaminant(s) and the abiotic and biotic factors in the sediment being investigated. When assessing contaminated sediment sites under the SMS, the reference sediment sample should include the effects of non-toxic biotic and abiotic factors (e.g., grain size, pH, alkalinity, salinity, TOC, BOD).

#### C.3.2.2 Purpose of a reference sample

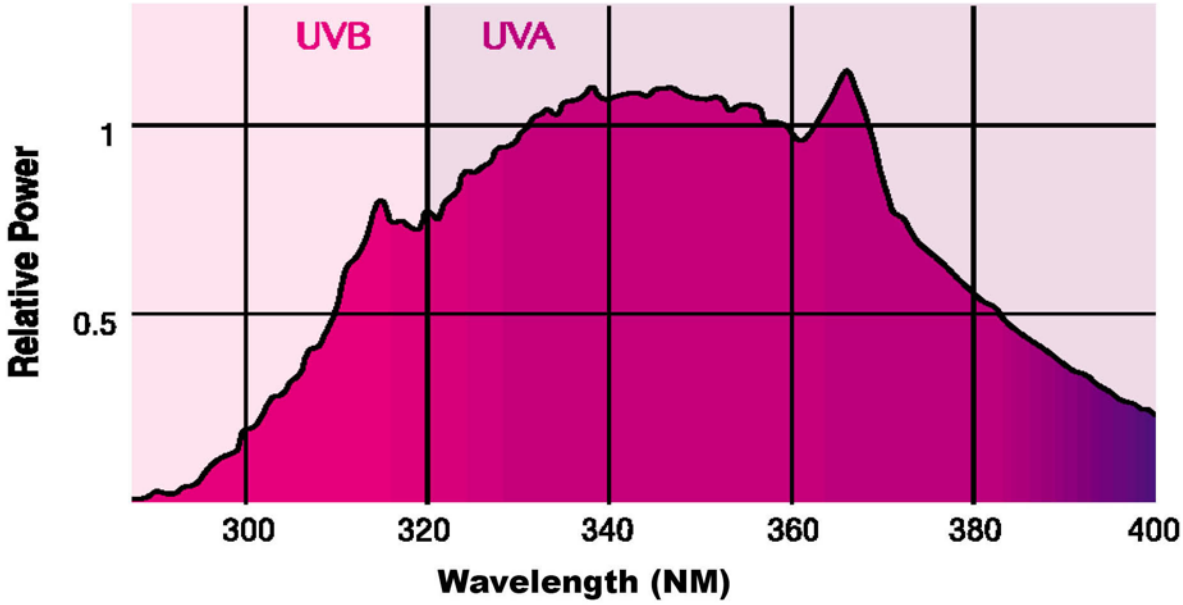
The reference sediment sample is used in toxicity tests to compare the biological endpoint response of organisms exposed to the reference sample to those of the sediment being investigated. To assess the effects of chemical(s) and the biotic and abiotic factors in the sediment being investigated, subtraction of the response of non-toxic biotic and abiotic must be performed—which is the purpose of the reference. The reference must meet specific quality control requirements to meet ASTM test acceptability standards.

**Appendix C: Table C-1.** Photo-activated Polycyclic Aromatic Hydrocarbons.

| | |
|---|---|
| Anthracene | Benz[c]acridine |
| Acridine | Benzathrone |
| Phenazine | Benzo[a]pyrene |
| Fluoranthene | Benzo[e]pyrene |
| 1H-Benzo[a]fluorine | Perylene |
| 1H-Benzo[b]fluorine | Dibenz[a,h]acridine |
| Pyrene | Dibenz[a,h]anthracene |
| Benz[a]anthracene | Dibenz[a,j]anthracene |
| Benz[b]anthracene | Benzo[b]chrysene |
| Chrysene | Dibenz[a,c]phenazine |
| Benzo[k]fluoranthene | Benzo[b]triphenylene |
| Benz[a]acridine | Benzo[g,h,i]perylene |




**Appendix C: Figure C-1.** Example of an acceptable UV spectral output.




**Appendix C: Figure C-2.** Example of an acceptable UV spectral output (0 - 400 nm range).

# Appendix D: Analytical Methods and Detection/Quantitation Limits for Sediment and Tissue

## D.1 Introduction

This appendix includes the laboratory survey data that has been used to:

- Establish programmatic PQLs listed in Chapter 11, Table 11-1. The programmatic PQLs were calculated using the methodology in Chapter 11, and the final median value has been rounded to one significant figure for organics and two significant figures for metals.

- Establish recommended analytical PQLs for the benthic criteria, Chapter 5 Section 5.1.

Surveys of analytical laboratories were conducted in February and March 2011, and November 2014 through January 2015, to assess current laboratory capabilities. The purpose of the surveys was two-fold: 1) to update analytical methods and 2) to identify method detection limits (MDLs) and practical quantitation limits (PQLs) that could be achieved by commercial laboratories on a routine basis (Appendix D: Table D-1) in order for Ecology to establish SCO/CSL values for bioaccumulative CoCs (see Table 11-1 for established PQLs). Some specialty and research laboratories may be able to achieve lower MDLs and PQLs than those routinely obtained by commercial laboratories.

Ecology acknowledges that definitions of various laboratory reporting limits vary. The EPA is currently working on guidance to provide consistent definitions, but until that guidance is available, Ecology will continue to use the definitions in the SMS and MTCA rules. Ecology plans to work with local laboratories to update these definitions based on best available science, when possible.

Ecology-accredited, full-service and specialty analytical laboratories were contacted to obtain their most up to date and consistently achievable MDLs and PQLs for both sediment and tissue. Individual laboratories have not been identified because responses were considered confidential.

The summary of MDLs and PQLs (Appendix D: Table D-1 and Table D-2) is designed to help PLPs select appropriate laboratories and methods with MDLs/PQLs lower than criteria (risk-based concentrations or background concentrations) for SMS chemicals of concern and emerging CoCs.

MDLs and PQLs can vary significantly between laboratories and methods as noted in Appendix D: Table D-1 and Table D-2. As part of the project planning/scoping process, close attention should be paid to the project data quality objectives and MDL/PQL requirements. Discussions with laboratories should be conducted early in the planning/scoping process to select analytical methods and laboratories that can achieve these project objectives. However, some current methods for some analytes still cannot achieve the PQLs and MDLs lower than the risk-based concentrations as noted in Chapter 9.

## D.2 MDL and PQL Definitions

The MDL is defined by USEPA in Appendix B of 40 CFR 136 as "the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero." Methods for estimating MDLs typically involve:

- Measuring the variability of instrument response to replicate analysis of a low-concentration, spiked sample (either clean sand or a sample-specific matrix), or
- Evaluating the signal-to-noise ratio for each analyte on a sample-specific basis.

As typically determined, the MDL accounts only for false positives (i.e., 1% false positive rate). Note that MDLs are laboratory- and instrument-specific and can vary over time. Laboratories typically perform method detection limit studies on an annual basis.

The PQL is defined in the SMS as:

> *The lowest concentration that can be reliably measured within specified limits of precision, accuracy, representativeness, completeness, and comparability during routine laboratory operating conditions, using department approved methods (WAC 173-204-200(35)).*

In practice, the PQL generally corresponds to the lowest concentration instrument calibration standard adjusted to include the sample size (mass or volume); final sample extraction volume; cleanup method (if any); and the volume of sample extract introduced into the instrument.

The quantitation limit procedure must incorporate a measure of accuracy and precision. Procedures for establishing PQLs must:

1) Control false positive and false negative results;
2) Consider and incorporate laboratory method blank results;
3) Incorporate long-term variability; and

4) Include a demonstration of qualitative compound identification capability.

Based on these considerations, a number of alternative methods and definitions have been proposed by different agencies and accrediting organizations for determining MDLs and PQLs. The following terms have been proposed:

- American Chemical Society (ACS): *Level of Detection (LOD)*
- USEPA: *Minimum Level of Quantitation (ML)*
- International Organization for Standardization (ISO): *Limit of Quantitation (LOQ)*
- American Society for Testing and Materials (ASTM): *Interlaboratory Quantitation Estimate (IQE)*
- American Chemical Society (ACS): *Level of Quantitation (LOQ)*
- USEPA Office of Solid Waste and Emergency Response (OSWER): *Lower Level of Quantitation (LLOQ)*
- USEPA Office of Ground Water (drinking water program): *Lowest Concentration Minimum Reporting Levels (LCMRLs)*

There is not a significant difference in numerical values for MDLs and PQLs determined by the different methods. In general, however, MDLs determined by the new procedures may be slightly higher and more reliable than those estimated by the current 40 CFR 136 method commonly employed by laboratories. Ecology recognizes that the PQL, method reporting limit (MRL), and lower level of quantitation (LLOQ) are generally the same concept (i.e., PQL ≈ MRL ≈ LLOQ). Ecology will accept non-detect sample results reporting at LLOQ (SW-846 method) when LLOQ is at or below the regulatory criteria of interested specified in the SAP/QAPP, but will also require reporting of the method detection limit (MDL).

## D.3 Sample Preparation Methods

The sample preparation and extraction methods identified in Appendix D: Table D-1and Table D-2 are not designed to be comprehensive but to reflect methods used by the laboratories in the survey. Other analytical methods and laboratory-specific methods may also be appropriate. When surveyed laboratories did not provide their preparation method, entries were left blank in Appendix D: Table D-1 and Table D-2 columns titled, “Sample Preparation.”

Different preparation methods may have different extraction efficiencies, so it is critical that the same extraction and cleanup methodologies are used for a project to ensure that data are comparable over time and space.

In some cases, such as when samples have low total solids content, altered preparation methods may be advisable to achieve lower PQLs. When total solids are low, the project manager should be consulted to determine whether special handling such as decanting overlaying water, centrifugation to remove water, or freeze drying may be appropriate.

## D.3.1 Inorganic preparation methods

- USEPA Method 3050 acid digestion. This method is a strong acid digestion procedure designed to dissolve most elements that could become "environmentally available." Elements that are bound as part of a mineral silicate structure are not dissolved by this procedure, since they are not usually mobile in the environment. Samples are digested using repeated additions of nitric acid and hydrogen peroxide. For inductively coupled plasma (ICP) analysis by USEPA Method 6010, hydrochloric acid is added to the initial digestate and the sample is refluxed.

- USEPA Method 3051 rapid microwave-assisted acid digestion. Samples are digested with concentrated nitric acid and microwave heating in a pressurized fluorocarbon microwave vessel.

- USEPA Method 3052 is a complete mineral digestion (dissolves the silicate mineral matrix) and are not toxicologically relevant. Therefore, this method is not recommended for sediment cleanup purposes.

## D.3.2 Organic preparation methods

- USEPA Method 3540C soxhlet extraction. This is the most often reported method for sample extraction of organic compounds. The sample is mixed with anhydrous sodium sulfate, placed in an extraction apparatus, and extracted using an appropriate solvent, usually an acetone/hexane or methylene chloride/acetone mixture. The extract is then dried and concentrated.

- USEPA Method 3550B ultrasonic extraction. The sample is mixed with anhydrous sodium sulfate and then solvent extracted three times using an ultrasonic horn. While ultrasonic extraction is faster than soxhlet extraction, it is not as rigorous and may have lower extraction efficiency. Additionally, for samples with elevated chemical concentrations, this method may result in lower values due to supersaturation of the solvent.

- USEPA Method 3545A pressurized fluid extraction. This is not commonly used for sediment extraction. The procedure uses elevated temperature (100 - 180°C) and pressure (1500 - 2000 psi) to extract organic compounds. While this extraction procedure is faster and uses less solvent than soxhlet extraction, it can have poor extraction efficiency for samples containing moderate to high moisture levels even when sodium sulfate is added to the sample. Additionally, for samples with elevated chemical concentrations, this method may result in lower values due to supersaturation of the solvent.

  EPA Method 3546 microwave extraction. This is a relatively recent sample preparation method and is currently used by only a few laboratories. This extraction procedure is faster and uses less solvent than soxhlet extraction. Extraction is performed in sealed containers at lower temperature (110 - 115°C) and pressure (50 - 175 psi) than pressurized fluid extraction. EPA has reported that microwave extraction efficiencies are similar to those found for soxhlet extraction. However, microwave extraction was found to produce higher sediment PAH results than soxhlet or sonication extraction in at least one sediment investigation. Additionally, for samples with elevated chemical concentrations, this method may result in lower values due to supersaturation of the solvent.

## D.4 Analytical Methods

The analytical methods identified in Appendix D: Table D-1 and Table D-2 are intended to reflect methods used by the laboratories surveyed, but are not designed to be comprehensive. Other analytical methods and laboratory-specific methods may also be appropriate.

Most of the analytical method numbers listed in Appendix D: Table D-1 and Table D-2 refer to methods described in *Test Methods for Evaluating Solid Waste* (USEPA SW-846, http://www.epa.gov/osw/hazard/testmethods/sw846/online/index.htm#table).

SW-846 analytical method numbers in Appendix D: Table D-1 and Table D-2 correspond to the following series:

- The 3000 series methods reference procedures for sample preparation and extraction.
- The 6000 series methods refer to ICP and ICP-mass spectrometry (ICP-MS) methods for metals determination.
- The 7000 series methods refer to atomic absorption (AA) methods for metals.
- The 8000 and 8100 series methods are gas chromatography (GC) methods.

- The 8200 series refer to gas chromatography-mass spectrometry (GC MS) methods.
- The 8300 series methods refer to high-pressure liquid chromatography (HPLC) methods.

The 1600 series methods include GC-MS methods with isotope dilution (i.e., isotope-labeled internal standards are used for analyte quantitation) and other performance-based methods (i.e., trace metals and low level mercury). The 1600 series methods were developed by USEPA's Office of Water and can generally achieve lower detection levels than corresponding SW-846 methods.

## D.5 Laboratory Survey Results

Laboratory MDLs and PQLs for sediment and tissue are summarized in Appendix D: Table D-1 and Table D-2 respectively, and include:

- Sample preparation and analytical methods.
- The number of laboratories responding (N) for each analyte.
- Minimum reported MDL and PQL.
- Maximum reported MDL and PQL.
- Average or mean MDL and PQL.

Tabulated sediment MDLs and PQLs are reported on a dry weight basis assuming 100% solids. Sample-specific MDLs and PQLs will be higher depending upon the percent moisture in the sample. Laboratories will often increase the sample mass to adjust for the moisture content. Tissue MDLs and PQLs are reported on a wet weight (as received) basis.

Sample extract cleanup methods were not included because laboratories do not routinely perform these unless there are interferences that make cleanup necessary to achieve project objectives or if cleanup procedures are specified in the analytical method. For example, sulfuric acid and sulfur cleanups are typically performed for PCB analysis.

Laboratories did not report MDLs and PQLs for some analytes. In these cases, the laboratories might not test for these compounds, or the analysis is performed infrequently and the laboratories have not performed recent detection limit studies for these analytes. For PCB and dioxin congener analyses where the MDL is determined by the instrument signal-to-noise ratio on a sample-specific basis, the laboratory may have not reported MDLs. Alternatively, the laboratory may have reported an estimated detection limit rather than an MDL based on analysis of low concentration standards.

In 2017, mercury and dioxins/furans PQLs for tissue were calculated using new data. For dioxins/furans, the PQL was established using EIM reported data, as there were sufficient samples in EIM to calculate a PQL. For mercury, a mixture of data was used including laboratory surveys, EIM reported detection data, and a site-specific PQL for a cleanup site.

# D.6 Example of Establishing PQL-Based Cleanup Levels

## D.6.1 Introduction

This section demonstrates how the recommended protocol detailed in Chapter 11 was used to establish PQL-based SCO/CSLs for bioaccumulative chemicals, which are summarized in Table 11-1. Below is an example using dioxins/furans to demonstrate this process. It includes a summary of currently obtainable PQLs from the surveyed laboratories and the resulting PQL-based cleanup level of 5 ppt TEQ.

## D.6.2 Laboratory surveys

To evaluate dioxin/furan PQLs expected to be routinely achieved by analytical laboratories, Ecology evaluated the survey results in Appendix D: Table D-2. PQLs were provided for EPA methods 1613B and 8290 if the laboratory ran both methods. Most laboratories reported the same PQLs and MDLs for each method. One laboratory provided two sets of PQLs for Method 1613B – their standard "low" level, as well as PQLs that have specifically been requested by Ecology when Ecology contracts for dioxins/furans analyses.

## D.6.3 PQL survey results

PQL and MDL values for the 17 individual dioxin/furan congeners were multiplied by their respective toxicity equivalency factors (TEF) to develop a TEQ value for the PQLs and MDLs provided by the laboratories. Note that when conducting risk assessments, the Kaplan-Meier method is recommended to address undetected values for calculating TEQs. However, this is not a risk assessment, but a determination of the TEQ value equivalent to a set of dioxin/furan congener PQLs. Since the PQL values are always detected, it is not necessary to account for non-detected values in the TEQ calculation.

The TEQ for the standard PQLs for each congener required by EPA Method 1613B is 11.4 ppt. Lower PQLs can be achieved by some laboratories if a specialized lower concentration calibration standard is used. PQLs can also be affected by the quantity of the sample that is used (larger sample sizes result in lower PQLs). Figure D-1 shows the TEQs for each analytical method at each laboratory. To preserve laboratory anonymity, names are not included.

| Method 1613B (TEQ, ppt) | Method 8290 (TEQ, ppt) |
|---|---|
| 11.4 | 11.4 |
| 11.4 | 11.4 |
| 11.4 | 11.4 |
| 11.4 | 6.3 |
| 5.7 | 5.7 |
| 5.7 | 4.6 |
| 4.6 | 2.3 |
| 4.3 | |
| 2.3 | |
| 2.3 | |
| 2.3 | |

**Appendix D: Figure D-1.** TEQs associated with reported PQLs.

Since USEPA Method 1613B tends to be the more accurate and commonly used/required method, it was carried forward for further consideration of PQL values. It should be noted that many laboratories use a combination of methods 1613B and 8290. The preparation and analysis are run using 1613B, while the calculation process from 8290 is used to develop sample-specific estimated detection limits. According to one laboratory manager, the methods are very similar. The primary difference is that Method 1613 uses fifteen $^{13}C$-labeled internal standards, while 8290 uses only nine (one for each level of chlorination, except OCDF).

## D.6.4 Establishing PQLs as cleanup levels

To determine a reasonable PQL to use as a cleanup level, the highest and lowest values were removed from consideration, which allowed for limitations of current laboratory technology.

The highest value of 11.4 ppt is the TEQ based on the levels for each congener required by method 1613B. However, based on discussions with several laboratories, it is feasible to reach a lower PQL, so it would not be unreasonable to require a lower level be used as a cleanup level.

The lowest value of 2.3 ppt may not be reasonable to establish as a cleanup level because:

- The PQL values are non-sample-specific values determined from analysis of a calibration standard. This does not account for real-world sample interferences that would be present when analyzing site samples, which could increase the project-specific reporting level above the PQL and make it very difficult to evaluate results in relationship to the cleanup level.

- At these lower levels, there is an increased possibility that method blank contamination could affect the usability of the data. This is because the samples that contain less than five times the amount found in the blank are flagged as “not detected.” Therefore, real-

world sample results would not be considered to be quantified unless the sample contained more than five times the method blank amount (if there were method blank contamination). If five times the method blank is greater than the PQL, the quantifiable concentration is increased to that amount. This would also make it difficult to evaluate results in relationship to the cleanup level if the level were set at a low PQL.

- Very few laboratories are capable of reaching these levels. This would unreasonably constrain the choices available to agencies and regulated parties, and limit the laboratory's availability and capacity to conduct analysis and monitoring.

## D.6.5 Recommended PQL

The rounded median value of the "mid-range" PQLs for Method 1613B is 5 ppt. This is the recommended PQL to use as a TEQ-based dioxin/furan cleanup level when the calculated human health value and background value are below PQLs.

| Mid-range TEQs/PQLs (ppt) |
|---|
| 5.7 |
| 5.7 |
| 4.6 |
| 4.3 |
| MEDIAN: 5.2 (Rounded to one significant digit: 5) |

**Appendix D: Figure D-2.** Mid-range TEQs/PQLs.

## D.6.6 Comparison of PQLs to MDLs

Ecology compared MDLs to the mid-range PQLs and found that the PQL is less than 10 times the MDL for three of the four laboratories. The median PQL of 5 ppt is less than 10 times the median MDL of 0.6 ppt.

The recommended PQL is also well below the minimum level of 11.4 ppt which is required by EPA Method 1613B. Method 8290 does not refer to reporting limits.

## D.6.7 Notes on terminology

The SMS and MTCA define the PQL as:

> *The lowest concentration that can be reliably measured within specified limits of precision, accuracy, representativeness, completeness, and comparability during routine laboratory operating conditions, using department approved methods (WAC 173-204-505 and 173-340-200).*

In practice, the PQL generally corresponds to the lowest concentration of the instrument calibration standard adjusted for the sample size (mass or volume); final sample extraction volume; cleanup method (if any); and the volume of sample extract introduced into the instrument. Some laboratories use a specialized low calibration standard, and therefore can achieve lower limits of quantitation than required by the EPA laboratory methods. The sample volume used can also affect the mathematical calculation of quantitation limits.

It should be noted that different laboratories often use different terms to describe the quantifiable level, including "reporting limit," "method reporting limit," "lower method calibration limit," "level of quantification," and others. They way in which quantifiable levels are determined can vary between the terms, and the same terms may have slightly different meanings at each laboratory. When discussing quantification limits with laboratories, it is important to ask and understand the specific terminology and methods used by each laboratory to ensure that values are comparable between them.

The MDL is defined by USEPA in Appendix B of 40 CFR 136 as "the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero." The EPA regulation provides methods for determining the MDL. The most common method involves measuring the variability of instrument response to 7 replicate analyses of a low-concentration, spiked sample.

Another term that is often used in relation to dioxin analysis is the "estimated detection limit" (EDL). The EDL is calculated on a sample and analyte-specific basis according to procedures in EPA analytical Method 8290, and is also often applied to samples being run by Method 1613B. The EDL is the concentration of a given analyte that must be present to produce a chromatographic signal with a peak height of at least 2.5 times the background noise signal level. While the EDL is relevant when calculating a sample-specific TEQ for compliance with cleanup levels, it is not relevant to determining a cleanup level based on the PQL.

**Appendix D: Table D-1.** Sediment Method Detection Limits and Practical Quantitation Limits [1]

| Analytes | Preparation Method | Cleanup method | Analytical Method | MDL | | | | PQL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N | Min | Max | Average | N | Min | Max | Average |
| **Metals in mg/kg (ppm) dry weight** | | | | | | | | | | | |
| Antimony | 3050B/3051 | | 6010 | 6 | 0.14 | 3 | 0.7 | 6 | 0.5 | 10 | 4 |
| Arsenic | 3050B/3051 | | 6010 | 7 | 0.17 | 4 | 1 | 7 | 0.5 | 20 | 6 |
| Cadmium | 3050B/3051 | | 6010 | 7 | 0.01 | 0.2 | 0.1 | 7 | 0.0 | 1.0 | 0.5 |
| Chromium | 3050B/3051 | | 6010 | 7 | 0.1 | 0.4 | 0.3 | 7 | 0.5 | 2.0 | 0.9 |
| Copper | 3050B/3051 | | 6010 | 7 | 0.04 | 0.72 | 0.3 | 7 | 0.2 | 2.0 | 0.8 |
| Lead | 3050B/3051 | | 6010 | 7 | 0.04 | 3 | 0.7 | 7 | 0.3 | 20 | 5 |
| Nickel | 3050B/3051 | | 6010 | 7 | 0.04 | 0.86 | 0.4 | 7 | 1.0 | 4.0 | 2 |
| Selenium | 3050B/3051 | | 6010 | 7 | 0.12 | 4 | 1 | 7 | 0.8 | 20 | 7 |
| Silver | 3050B/3051 | | 6010 | 7 | 0.02 | 0.56 | 0.2 | 7 | 0.3 | 2.0 | 0.8 |
| Zinc | 3050B/3051 | | 6010 | 7 | 0.16 | 0.863 | 0 | 7 | 1.0 | 2.5 | 2 |
| Antimony | 3050B/3051 | | 6020 | 12 | 0.002 | 0.25 | 0.04 | 12 | 0.04 | 5.0 | 0.5 |
| Arsenic | 3050B/3051 | | 6020 | 12 | 0.003 | 0.37 | 0.09 | 12 | 0.01 | 10.0 | 1 |
| Cadmium | 3050B/3051 | | 6020 | 12 | 0.001 | 0.02 | 0.01 | 12 | 0.01 | 0.5 | 0.1 |
| Chromium | 3050B/3051 | | 6020 | 12 | 0.001 | 0.14 | 0.06 | 12 | 0.05 | 0.5 | 0.3 |
| Copper | 3050B/3051 | | 6020 | 12 | 0.002 | 0.40 | 0.09 | 12 | 0.04 | 0.5 | 0.2 |
| Lead | 3050B/3051 | | 6020 | 12 | 0.002 | 0.30 | 0.03 | 12 | 0.03 | 5.0 | 0.6 |
| Nickel | 3050B/3051 | | 6020 | 12 | 0.005 | 0.10 | 0.04 | 12 | 0.05 | 2.5 | 0.4 |
| Selenium | 3050B/3051 | | 6020 | 12 | 0.004 | 0.60 | 0.17 | 12 | 0.05 | 10.0 | 1 |
| Silver | 3050B/3051 | | 6020 | 12 | 0.001 | 0.03 | 0.01 | 12 | 0.01 | 0.5 | 0.2 |
| Zinc | 3050B/3051 | | 6020 | 12 | 0.011 | 1.82 | 0.48 | 12 | 0.20 | 5.0 | 2 |
| Mercury | 7471A | | 7471A | 7 | 0.00088 | 0.013 | 0.0048 | 7 | 0.01 | 0.3 | 0.07 |
| Mercury | 1631 | | 1631 | 3 | 0.00024 | 0.050 | 0.017 | 3 | 0.001 | 0.2 | 0.05 |
| Arsenic | 3050B/3051 | | 7010/7060A | 1 | 0.060 | 0.060 | 0.060 | 1 | 1.0 | 1.0 | 1.0 |
| Arsenic | 3050B/3051 | | 7062 | 1 | 0.020 | 0.020 | 0.020 | 1 | 0.10 | 0.10 | 0.10 |
| Selenium | 3050B/3051 | | 7742 | 1 | 0.030 | 0.030 | 0.030 | 1 | 0.10 | 0.10 | 0.10 |
| Selenium | 3050B/3051 | | 7010/7740 | 1 | 0.10 | 0.10 | 0.10 | 1 | 1.0 | 1.0 | 1.0 |
| **Organometallics** | | | | | | | | | | | |
| Tributyltin (ion) in ug/L (ppb) - porewater | Sep Funnel 100 mL -> 0.5 mL | | Krone | 2 | 0.012 | 0.043 | 0.028 | 2 | 0.05 | 0.20 | 0.13 |
| Tributyltin (ion) in ug/L (ppb) - porewater | Sep Funnel 100 mL -> 0.5 mL | | Krone (low level) | 2 | 0.00070 | 0.0027 | 0.0017 | 2 | 0.0020 | 0.0075 | 0.0048 |
| Tributyltin (ion) in ug/kg (ppb) - dry weight | Microwave 5 g -> 0.5 mL | | Krone | 3 | 0.43 | 0.88 | 0.62 | 3 | 1.0 | 4.0 | 2.1 |
| **Semivolatile Organics (SVOC) - dry weight** | | | | | | | | | | | |
| **Phenolics (Acids) in ug/kg (ppb) dry weight** | | | | | | | | | | | |
| Phenol | 3550 | | 8270 | 6 | 2 | 165 | 31 | 6 | 8 | 330 | 72 |
| 2-Methylphenol | 3550 | | 8270 | 6 | 2 | 165 | 31 | 6 | 10 | 330 | 69 |
| 4-Methylphenol | 3550 | | 8270 | 2 | 2 | 5 | 3 | 2 | 10 | 20 | 15 |
| 3+4-Methylphenol (co-elution) | 3550 | | 8270 | 4 | 2 | 330 | 85 | 4 | 10 | 660 | 181 |
| 2,4-Dimethylphenol | 3550 | | 8270 | 6 | 2 | 165 | 36 | 6 | 10 | 830 | 210 |
| Pentachlorophenol | 3550 | | 8270 | 6 | 2 | 850 | 157 | 6 | 20 | 1700 | 355 |
| Benzyl alcohol | 3550 | | 8270 | 6 | 2 | 330 | 66 | 6 | 10 | 660 | 141 |
| Benzoic acid | 3550 | | 8270 | 6 | 26 | 850 | 223 | 6 | 170 | 1700 | 503 |

**Appendix D: Table D-1 (continued).** Sediment Method Detection Limits and Practical Quantitation Limits[1]

| | Preparation Method | Cleanup method | Analytical Method | MDL | | | | PQL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Analytes | | | | N | Min | Max | Average | N | Min | Max | Average |
| **LPAHs in ug/kg (ppb) dry weight** | 3550 | | 8270 | | | | | | | | |
| Naphthalene | 3550 | | 8270 | 6 | 0.5 | 165 | 30 | 6 | 2.0 | 330 | 67 |
| 2-Methylnaphthalene | 3550 | | 8270 | 6 | 0.5 | 165 | 30 | 6 | 2.0 | 330 | 67 |
| Acenaphthylene | 3550 | | 8270 | 6 | 0.5 | 165 | 29 | 6 | 2.0 | 330 | 67 |
| Acenaphthene | 3550 | | 8270 | 6 | 0.5 | 165 | 30 | 6 | 2.0 | 330 | 67 |
| Fluorene | 3550 | | 8270 | 6 | 0.5 | 165 | 29 | 6 | 2.0 | 330 | 67 |
| Phenanthrene | 3550 | | 8270 | 6 | 0.5 | 165 | 29 | 6 | 2.0 | 330 | 67 |
| Anthracene | 3550 | | 8270 | 6 | 0.5 | 165 | 30 | 6 | 2.0 | 330 | 67 |
| Naphthalene | 3550/Microwave | | 8270-SIM PAH | 6 | 0.07 | 7 | 2 | 6 | 0.5 | 13 | 6 |
| 2-Methylnaphthalene | 3550/Microwave | | 8270-SIM PAH | 5 | 0.2 | 7 | 3 | 5 | 0.5 | 13 | 7 |
| Acenaphthylene | 3550/Microwave | | 8270-SIM PAH | 6 | 0.02 | 5 | 2 | 6 | 0.5 | 10 | 5 |
| Acenaphthene | 3550/Microwave | | 8270-SIM PAH | 6 | 0.05 | 5 | 2 | 6 | 0.5 | 10 | 5 |
| Fluorene | 3550/Microwave | | 8270-SIM PAH | 6 | 0.03 | 5 | 2 | 6 | 0.5 | 10 | 5 |
| Phenanthrene | 3550/Microwave | | 8270-SIM PAH | 6 | 0.2 | 5 | 2 | 6 | 0.5 | 10 | 5 |
| Anthracene | 3550/Microwave | | 8270-SIM PAH | 6 | 0.07 | 5 | 2 | 6 | 0.5 | 10 | 5 |
| **HPAHs in ug/kg (ppb) dry weight** | 3550 | | | | | | | | | | |
| Fluoranthene | 3550 | | 8270 | 6 | 0.5 | 165 | 30 | 6 | 2.0 | 330 | 67 |
| Pyrene | 3550 | | 8270 | 6 | 0.5 | 165 | 31 | 6 | 2.0 | 330 | 67 |
| Benz(a)anthracene | 3550 | | 8270 | 6 | 0.5 | 165 | 30 | 6 | 2.5 | 330 | 67 |
| Chrysene | 3550 | | 8270 | 6 | 0.5 | 165 | 30 | 6 | 2.5 | 330 | 67 |
| Benzo(b)fluoranthene | 3550 | | 8270 | 5 | 0.5 | 165 | 35 | 5 | 2.0 | 330 | 76 |
| Benzo(j)fluoranthene | 3550 | | 8270 | 1 | 0.5 | 0.5 | 1 | 1 | 2.0 | 2 | 2 |
| Benzo(k)fluoranthene | 3550 | | 8270 | 5 | 0.5 | 165 | 35 | 5 | 2.0 | 330 | 76 |
| Total Benzofluoranthenes | 3550 | | 8270 | 2 | 1.5 | 5.7 | 3.6 | 2 | 6.0 | 20 | 13 |
| Benzo(a)pyrene | 3550 | | 8270 | 6 | 0.5 | 165 | 30 | 6 | 3.0 | 330 | 67 |
| Indeno(1,2,3-cd)pyrene | 3550 | | 8270 | 6 | 0.5 | 165 | 30 | 6 | 4.0 | 330 | 67 |
| Dibenz(a,h)anthracene | 3550 | | 8270 | 6 | 0.5 | 165 | 30 | 6 | 4.0 | 330 | 67 |
| Benzo(g,h,i)perylene | 3550 | | 8270 | 6 | 0.5 | 165 | 30 | 6 | 2.5 | 330 | 67 |
| Fluoranthene | 3550/Microwave | | 8270-SIM PAH | 6 | 0.087 | 5 | 2 | 6 | 0.5 | 10 | 5 |
| Pyrene | 3550/Microwave | | 8270-SIM PAH | 6 | 0.073 | 3.34 | 0.98 | 6 | 0.5 | 10 | 5 |
| Benz(a)anthracene | 3550/Microwave | | 8270-SIM PAH | 11 | 0.033 | 3.34 | 0.97 | 11 | 0.5 | 50 | 9 |
| Chrysene | 3550/Microwave | | 8270-SIM PAH | 11 | 0.027 | 5 | 1 | 11 | 0.5 | 50 | 9 |
| Benzo(b)fluoranthene | 3550/Microwave | | 8270-SIM PAH | 11 | 0.057 | 3.34 | 1.1 | 11 | 0.5 | 50 | 9 |
| Benzo(j)fluoranthene | 3550/Microwave | | 8270-SIM PAH | 1 | 0.15 | 0.15 | 0.15 | 1 | 0.5 | 0.5 | 1 |
| Benzo(k)fluoranthene | 3550/Microwave | | 8270-SIM PAH | 11 | 0.045 | 3.34 | 1.17 | 11 | 0.5 | 50 | 9 |
| Total Benzofluoranthenes | 3550/Microwave | | 8270-SIM PAH | 3 | 0.45 | 3.41 | 1.90 | 3 | 1.5 | 30 | 12 |
| Benzo(a)pyrene | 3550/Microwave | | 8270-SIM PAH | 11 | 0.036 | 5 | 1 | 11 | 0.5 | 50 | 9 |
| Indeno(1,2,3-cd)pyrene | 3550/Microwave | | 8270-SIM PAH | 11 | 0.064 | 5 | 1 | 11 | 0.5 | 50 | 9 |
| Dibenz(a,h)anthracene | 3550/Microwave | | 8270-SIM PAH | 11 | 0.058 | 5 | 1 | 11 | 0.5 | 50 | 9 |
| Benzo(g,h,i)perylene | 3550/Microwave | | 8270-SIM PAH | 6 | 0.059 | 3.34 | 0.98 | 6 | 0.5 | 10 | 5 |

**Appendix D: Table D-1 (continued).** Sediment Method Detection Limits and Practical Quantitation Limits[1]

| Analytes | Preparation Method | Cleanup method | Analytical Method | MDL | | | | PQL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N | Min | Max | Average | N | Min | Max | Average |
| **Chlorinated Aromatics in ug/kg dry weight** | | | | | | | | | | | |
| 1,3-Dichlorobenzene | 3550 | | 8270 | 6 | 1.5 | 165 | 30.72 | 6 | 5.0 | 330 | 68 |
| 1,4-Dichlorobenzene | 3550 | | 8270 | 6 | 1.5 | 165 | 30.32 | 6 | 5.0 | 330 | 68 |
| 1,2-Dichlorobenzene | 3550 | | 8270 | 6 | 1.5 | 165 | 30.25 | 6 | 5.0 | 330 | 68 |
| 1,2,4-Trichlorobenzene | 3550 | | 8270 | 6 | 1.5 | 165 | 30.65 | 6 | 5.0 | 330 | 68 |
| Hexachlorobenzene | 3550 | | 8270 | 6 | 0.5 | 165 | 29.74 | 6 | 5.0 | 330 | 68 |
| Hexachlorobenzene | 3550 | | PSEP 8081 | 3 | 0.0135 | 1.25 | 0.45 | 3 | 0.1 | 2.5 | 1 |
| **Phthalates in ug/kg (ppb) dry weight** | | | | | | | | | | | |
| Dimethyl phthalate | 3550 | | 8270 | 6 | 0.50 | 150 | 28 | 6 | 10 | 300 | 66 |
| Diethyl phthalate | 3550 | | 8270 | 6 | 1.30 | 165 | 30.9 | 6 | 10 | 330 | 93 |
| Di-n-butyl phthalate | 3550 | | 8270 | 6 | 4.68 | 165 | 33.9 | 6 | 20 | 330 | 76 |
| Butyl benzyl phthalate | 3550 | | 8270 | 6 | 3.20 | 165 | 37.0 | 6 | 10 | 330 | 81 |
| Bis(2-ethylhexyl)phthalate | 3550 | | 8270 | 6 | 5.00 | 165 | 39.0 | 6 | 20 | 330 | 119 |
| Di-n-octyl phthalate | 3550 | | 8270 | 6 | 0.50 | 330 | 63.8 | 6 | 10 | 660 | 137 |
| **Misc. Extractables in ug/kg dry weight** | | | | | | | | | | | |
| Dibenzofuran | 3550 | | 8270/8270LL | 6 | 0.50 | 165 | 29.23 | 6 | 4.0 | 330 | 68 |
| Hexachloroethane | 3550 | | 8270/8270LL | 6 | 1.50 | 165 | 30.84 | 6 | 10.0 | 330 | 69 |
| Hexachlorobutadiene | 3550 | | 8270/8270LL | 6 | 1.50 | 165 | 30.78 | 6 | 5.0 | 330 | 68 |
| N-Nitrosodiphenylamine | 3550 | | 8270/8270LL | 6 | 0.50 | 165 | 32.52 | 6 | 5.0 | 330 | 68 |
| Hexachloroethane | 3550 | | PSEP 8081 | 1 | 0.57 | 0.57 | 0.57 | 1 | 1.0 | 1 | 1.0 |
| Hexachlorobutadiene | 3550 | | PSEP 8081 | 2 | 0.10 | 0.14 | 0.12 | 2 | 0.1 | 1 | 0.3 |
| Hexachlorobutadiene | 3550 | | 8260 | 2 | 0.40 | 50 | 25.20 | 2 | 1.0 | 100 | 51 |
| **PCBs in ug/kg (ppb) dry wt** | | | | | | | | | | | |
| Aroclor 1016 | 3550/PSEP | | 8082 | 5 | 0.32 | 4.24 | 2.0 | 5 | 1.0 | 33.0 | 14 |
| Aroclor 1232 | 3550/PSEP | | 8082 | 4 | 0.70 | 8.39 | 3.4 | 4 | 1.0 | 33.0 | 12 |
| Aroclor 1242 | 3550/PSEP | | 8082 | 4 | 0.21 | 6.30 | 2.8 | 4 | 1.0 | 33.0 | 12 |
| Aroclor 1248 | 3550/PSEP | | 8082 | 4 | 0.30 | 4.79 | 2.4 | 4 | 1.0 | 33.0 | 12 |
| Aroclor 1254 | 3550/PSEP | | 8082 | 4 | 0.21 | 9.34 | 3.5 | 4 | 1.0 | 33.0 | 12 |
| Aroclor 1260 | 3550/PSEP | | 8082 | 5 | 0.30 | 7.69 | 2.8 | 5 | 1.0 | 33.0 | 14 |
| Aroclor 1262 | 3550/PSEP | | 8082 | 4 | 0.19 | 4.07 | 2.2 | 4 | 1.0 | 33.0 | 12 |
| Aroclor 1268 | 3550/PSEP | | 8082 | 4 | 0.21 | 4.16 | 2.2 | 4 | 1.0 | 33.0 | 12 |

**Appendix D: Table D-1 (continued).** Sediment Method Detection Limits and Practical Quantitation Limits[1]

| | Preparation Method | Cleanup method | Analytical Method | MDL | | | | PQL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Analytes | | | | N | Min | Max | Average | N | Min | Max | Average |
| **Chlorinated Pesticides in ug/kg (ppb) dry weight** | | | | | | | | | | | |
| 4,4'-DDE | 3550/PSEP | | 8081 | 5 | 0.014 | 1.25 | 0.41 | 5 | 0.2 | 10.0 | 3 |
| 4,4'-DDD | 3550/PSEP | | 8081 | 5 | 0.015 | 1.25 | 0.37 | 5 | 0.2 | 10.0 | 3 |
| 4,4'-DDT | 3550/PSEP | | 8081 | 5 | 0.015 | 1.25 | 0.41 | 5 | 0.2 | 10.0 | 3 |
| 2,4'-DDE | 3550/PSEP | | 8081 | 4 | 0.030 | 1.25 | 0.58 | 4 | 0.2 | 2.5 | 1 |
| 2,4'-DDD | 3550/PSEP | | 8081 | 4 | 0.030 | 1.25 | 0.53 | 4 | 0.2 | 2.5 | 1 |
| 2,4'-DDT | 3550/PSEP | | 8081 | 4 | 0.030 | 1.25 | 0.47 | 4 | 0.2 | 2.5 | 1 |
| cis-Chlordane (alpha-chlordane) | 3550/PSEP | | 8081 | 4 | 0.013 | 1.25 | 0.35 | 4 | 0.1 | 2.5 | 1 |
| trans-Chlordane (gamma-chlordane) | 3550/PSEP | | 8081 | 4 | 0.013 | 1.25 | 0.36 | 4 | 0.1 | 2.5 | 1 |
| cis-nonachlor | 3550/PSEP | | 8081 | 4 | 0.019 | 1.25 | 0.48 | 4 | 0.2 | 2.5 | 1 |
| trans-nonachlor | 3550/PSEP | | 8081 | 4 | 0.030 | 1.25 | 0.47 | 4 | 0.2 | 2.5 | 1 |
| Oxychlordane | 3550/PSEP | | 8081 | 4 | 0.030 | 1.25 | 0.55 | 4 | 0.2 | 2.5 | 1 |
| Aldrin | 3550/PSEP | | 8081 | 5 | 0.022 | 1.25 | 0.34 | 5 | 0.1 | 5.0 | 2 |
| Dieldrin | 3550/PSEP | | 8081 | 5 | 0.012 | 1.25 | 0.39 | 5 | 0.2 | 10.0 | 3 |
| Heptachlor | 3550/PSEP | | 8081 | 5 | 0.046 | 1.25 | 0.36 | 5 | 0.1 | 5.0 | 2 |
| Lindane (gamma-BHC) | 3550/PSEP | | 8081 | 5 | 0.030 | 1.25 | 0.34 | 5 | 0.1 | 5.0 | 2 |
| 4,4'-DDE | 3550 | | 8270 | 1 | 0.006 | 0.006 | 0.006 | 1 | 0.1 | 0.1 | 0.1 |
| 4,4'-DDD | 3550 | | 8270 | 1 | 0.015 | 0.015 | 0.015 | 1 | 0.1 | 0.1 | 0.1 |
| 4,4'-DDT | 3550 | | 8270 | 1 | 0.014 | 0.014 | 0.014 | 1 | 0.1 | 0.1 | 0.1 |
| 2,4'-DDE | 3550 | | 8270 | 1 | 0.007 | 0.007 | 0.007 | 1 | 0.1 | 0.1 | 0.1 |
| 2,4'-DDD | 3550 | | 8270 | 1 | 0.009 | 0.009 | 0.009 | 1 | 0.1 | 0.1 | 0.1 |
| 2,4'-DDT | 3550 | | 8270 | 1 | 0.006 | 0.006 | 0.006 | 1 | 0.1 | 0.1 | 0.1 |
| cis-Chlordane (alpha-chlordane) | 3550 | | 8270 | 1 | 0.007 | 0.007 | 0.007 | 1 | 0.1 | 0.1 | 0.1 |
| trans-Chlordane (gamma-chlordane) | 3550 | | 8270 | 1 | 0.008 | 0.008 | 0.008 | 1 | 0.1 | 0.1 | 0.1 |
| cis-nonachlor | 3550 | | 8270 | 1 | 0.015 | 0.015 | 0.015 | 1 | 0.2 | 0.2 | 0.2 |
| trans-nonachlor | 3550 | | 8270 | 1 | 0.014 | 0.014 | 0.014 | 1 | 0.1 | 0.1 | 0.1 |
| Oxychlordane | 3550 | | 8270 | 1 | 0.092 | 0.092 | 0.092 | 1 | 0.1 | 0.1 | 0.1 |
| Aldrin | 3550 | | 8270 | 1 | 0.012 | 0.012 | 0.012 | 1 | 0.1 | 0.1 | 0.1 |
| Dieldrin | 3550 | | 8270 | 1 | 0.098 | 0.098 | 0.098 | 1 | 0.1 | 0.1 | 0.1 |
| Heptachlor | 3550 | | 8270 | 1 | 0.009 | 0.009 | 0.009 | 1 | 0.1 | 0.1 | 0.1 |
| Lindane (gamma-BHC) | 3550 | | 8270 | 1 | 0.011 | 0.011 | 0.011 | 1 | 0.1 | 0.1 | 0.1 |
| **VOCs in ug/kg (ppb) dry weight** | | | | | | | | | | | |
| Benzene | | | 8260 | 5 | 0.1 | 6.3 | 1 | 5 | 1.0 | 12.5 | 4.1 |
| Ethylbenzene | | | 8260 | 5 | 0.0 | 12.5 | 3 | 5 | 1.0 | 25.0 | 6.6 |
| Tetrachloroethene | | | 8260 | 5 | 0.1 | 12.5 | 3 | 5 | 1.0 | 25.0 | 6.6 |
| Trichloroethene | | | 8260 | 5 | 0.1 | 18.1 | 4 | 5 | 1.0 | 25.0 | 6.6 |
| m,p-xylene | | | 8260 | 5 | 0.1 | 25.0 | 5 | 5 | 1.0 | 50.0 | 12 |
| o-xylene | | | 8260 | 5 | 0.1 | 12.5 | 3 | 5 | 1.0 | 25.0 | 6.6 |
| Total xylenes | | | 8260 | | | | | | | | |
| Benzene | | | 8021BTEX | 1 | 8.1 | 8.1 | 8.1 | 1 | 50.0 | 50.0 | 50.0 |
| Ethylbenzene | | | 8021BTEX | 1 | 8.4 | 8.4 | 8.4 | 1 | 100.0 | 100.0 | 100.0 |
| m,p-xylene | | | 8021BTEX | 1 | 19 | 19 | 19 | 1 | 100.0 | 100.0 | 100.0 |
| o-xylene | | | 8021BTEX | 1 | 8 | 8 | 8 | 1 | 100.0 | 100.0 | 100.0 |
| Total xylenes | | | 8021BTEX | | | | | | | | |

**Appendix D: Table D-1 (continued).** Sediment Method Detection Limits and Practical Quantitation Limits[1]

| | Preparation Method | Cleanup method | Analytical Method | MDL | | | | PQL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Analytes | | | | N | Min | Max | Average | N | Min | Max | Average |
| **Total Petroleum Hydrocarbons (ppm)** | | | | | | | | | | | |
| TPH-Diesel | 3550 | | NWTPH-Dx | 6 | 0.65 | 5.7 | 2.38 | 6 | 5.0 | 25.0 | 18.3 |
| TPH-Residual | 3550 | | NWTPH-Dx | 4 | 1.31 | 9.1 | 6.23 | 4 | 10.0 | 50.0 | 37.5 |
| **Conventional Parameters** | | | | | | | | | | | |
| Grain size | | | ASTM 422 PSEP Mod | 0 | | | | | | | |
| Percent solids | | | | 0 | | | | 1 | 0.0 | 0.0 | 0.0 |
| Total organic carbon (%) | | | | 3 | 0.003 | 0.010 | 0.007 | 4 | 0.0 | 0.2 | 0.1 |
| Total sulfides | | | PSEP | 2 | 0.348 | 2.400 | 1.374 | 2 | 1.0 | 5.0 | 3.0 |
| Acid volatile sulfides (ppm) | | | | 1 | 0.045 | 0.045 | 0.045 | 1 | 1.0 | 1.0 | 1.0 |
| Ammonia (Auto. Phenate) (ppm) | | | | 1 | 0.007 | 0.007 | 0.007 | 2 | 0.1 | 20.0 | 10 |
| Ammonia (ISE) (ppm) | | | | 1 | 0.122 | 0.122 | 0.122 | 1 | 5.0 | 5.0 | 5.0 |
| **Dioxin/Furan Congeners in ng/kg (ppt) dry weight** | | | | | | | | | | | |
| 2,3,7,8-TCDD | 1613B/3540C | 1613B | 1613B | 5 | 0.03 | 0.41 | 0.16 | 11 | 0.2 | 1.0 | 0.7 |
| 1,2,3,7,8-PeCDD | 1613B/3540C | 1613B | 1613B | 5 | 0.04 | 0.40 | 0.22 | 11 | 1.0 | 5.0 | 2.8 |
| 1,2,3,4,7,8-HxCDD | 1613B/3540C | 1613B | 1613B | 5 | 0.05 | 0.51 | 0.25 | 11 | 1.0 | 5.0 | 3.0 |
| 1,2,3,6,7,8-HxCDD | 1613B/3540C | 1613B | 1613B | 5 | 0.06 | 0.50 | 0.28 | 11 | 1.0 | 5.0 | 3.0 |
| 1,2,3,7,8,9-HxCDD | 1613B/3540C | 1613B | 1613B | 5 | 0.05 | 0.59 | 0.28 | 11 | 1.0 | 5.0 | 3.0 |
| 1,2,3,4,6,7,8-HpCDD | 1613B/3540C | 1613B | 1613B | 5 | 0.10 | 0.61 | 0.34 | 11 | 1.0 | 10.3 | 3.7 |
| OCDD | 1613B/3540C | 1613B | 1613B | 5 | 0.15 | 0.83 | 0.56 | 11 | 2.0 | 21.2 | 7.5 |
| 2,3,7,8-TCDF | 1613B/3540C | 1613B | 1613B | 5 | 0.02 | 0.30 | 0.11 | 11 | 0.2 | 1.0 | 0.7 |
| 1,2,3,7,8-PeCDF | 1613B/3540C | 1613B | 1613B | 5 | 0.03 | 0.40 | 0.18 | 11 | 1.0 | 5.0 | 3.0 |
| 2,3,4,7,8-PeCDF | 1613B/3540C | 1613B | 1613B | 5 | 0.03 | 0.49 | 0.23 | 11 | 1.0 | 5.0 | 3.0 |
| 1,2,3,4,7,8-HxCDF | 1613B/3540C | 1613B | 1613B | 5 | 0.03 | 0.48 | 0.22 | 11 | 1.0 | 5.0 | 2.9 |
| 1,2,3,6,7,8-HxCDF | 1613B/3540C | 1613B | 1613B | 5 | 0.03 | 0.37 | 0.20 | 11 | 1.0 | 5.0 | 2.9 |
| 1,2,3,7,8,9-HxCDF | 1613B/3540C | 1613B | 1613B | 5 | 0.04 | 0.55 | 0.22 | 11 | 1.0 | 5.0 | 3.0 |
| 2,3,4,6,7,8-HxCDF | 1613B/3540C | 1613B | 1613B | 5 | 0.03 | 0.36 | 0.22 | 11 | 1.0 | 5.0 | 3.0 |
| 1,2,3,4,6,7,8-HpCDF | 1613B/3540C | 1613B | 1613B | 5 | 0.04 | 0.73 | 0.28 | 11 | 1.0 | 5.0 | 3.1 |
| 1,2,3,4,7,8,9-HpCDF | 1613B/3540C | 1613B | 1613B | 5 | 0.04 | 0.76 | 0.28 | 11 | 1.0 | 5.0 | 3.2 |
| OCDF | 1613B/3540C | 1613B | 1613B | 5 | 0.11 | 1.24 | 0.63 | 11 | 2.0 | 17.6 | 7.1 |
| 2,3,7,8-TCDD | 3540C | | 8290 | 1 | 0.18 | 0.18 | 0.18 | 1 | 1.0 | 1.0 | 1.0 |
| 1,2,3,7,8-PeCDD | 3540C | | 8290 | 1 | 0.23 | 0.23 | 0.23 | 1 | 5.0 | 5.0 | 5.0 |
| 1,2,3,4,7,8-HxCDD | 3540C | | 8290 | 1 | 0.21 | 0.21 | 0.21 | 1 | 5.0 | 5.0 | 5.0 |
| 1,2,3,6,7,8-HxCDD | 3540C | | 8290 | 1 | 0.26 | 0.26 | 0.26 | 1 | 5.0 | 5.0 | 5.0 |
| 1,2,3,7,8,9-HxCDD | 3540C | | 8290 | 1 | 0.19 | 0.19 | 0.19 | 1 | 5.0 | 5.0 | 5.0 |
| 1,2,3,4,6,7,8-HpCDD | 3540C | | 8290 | 1 | 0.17 | 0.17 | 0.17 | 1 | 5.0 | 5.0 | 5.0 |
| OCDD | 3540C | | 8290 | 1 | 0.36 | 0.36 | 0.36 | 1 | 10.0 | 10.0 | 10.0 |
| 2,3,7,8-TCDF | 3540C | | 8290 | 1 | 0.09 | 0.09 | 0.09 | 1 | 1.0 | 1.0 | 1.0 |
| 1,2,3,7,8-PeCDF | 3540C | | 8290 | 1 | 0.15 | 0.15 | 0.15 | 1 | 5.0 | 5.0 | 5.0 |
| 2,3,4,7,8-PeCDF | 3540C | | 8290 | 1 | 0.11 | 0.11 | 0.11 | 1 | 5.0 | 5.0 | 5.0 |
| 1,2,3,4,7,8-HxCDF | 3540C | | 8290 | 1 | 0.13 | 0.13 | 0.13 | 1 | 5.0 | 5.0 | 5.0 |
| 1,2,3,6,7,8-HxCDF | 3540C | | 8290 | 1 | 0.18 | 0.18 | 0.18 | 1 | 5.0 | 5.0 | 5.0 |
| 1,2,3,7,8,9-HxCDF | 3540C | | 8290 | 1 | 0.12 | 0.12 | 0.12 | 1 | 5.0 | 5.0 | 5.0 |
| 2,3,4,6,7,8-HxCDF | 3540C | | 8290 | 1 | 0.27 | 0.27 | 0.27 | 1 | 5.0 | 5.0 | 5.0 |
| 1,2,3,4,6,7,8-HpCDF | 3540C | | 8290 | 1 | 0.27 | 0.27 | 0.27 | 1 | 5.0 | 5.0 | 5.0 |
| 1,2,3,4,7,8,9-HpCDF | 3540C | | 8290 | 1 | 0.38 | 0.38 | 0.38 | 1 | 5.0 | 5.0 | 5.0 |
| OCDF | 3540C | | 8290 | 1 | 0.64 | 0.64 | 0.64 | 1 | 10.0 | 10.0 | 10.0 |

**Appendix D: Table D-1 (continued).** Sediment Method Detection Limits and Practical Quantitation Limits[1]

| Analytes | Preparation Method | Cleanup method | Analytical Method | MDL | | | | PQL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N | Min | Max | Average | N | Min | Max | Average |
| **Dioxin-like PCB Congeners in ng/kg (ppt) wet weight** | | | | | | | | | | | |
| 3,3',4,4'-Tetrachlorobiphenyl (PCB 77) | 3550 | | 8082 Congeners | 2 | 82 | 650 | 366 | 2 | 500 | 1300 | 900 |
| 3,4,4',5- Tetrachlorobiphenyl (PCB 81) | 3550 | | 8082 Congeners | 2 | 70 | 1000 | 535 | 2 | 500 | 2000 | 1250 |
| 2,3,3',4,4'-Pentachlorobiphenyl (PCB 105) | 3550 | | 8082 Congeners | 2 | 53 | 340 | 197 | 2 | 500 | 670 | 585 |
| 2,3,4,4',5-Pentachlorobiphenyl (PCB 114) | 3550 | | 8082 Congeners | 2 | 68 | 650 | 359 | 2 | 500 | 1300 | 900 |
| 2,3',4,4',5-Pentachlorobiphenyl (PCB 118) | 3550 | | 8082 Congeners | 2 | 78 | 340 | 209 | 2 | 500 | 670 | 585 |
| 2',3,4,4',5-Pentachlorobiphenyl (PCB 123) | 3550 | | 8082 Congeners | 2 | 92 | 650 | 371 | 2 | 500 | 1300 | 900 |
| 3,3',4,4',5-Pentachlorobiphenyl (PCB 126) | 3550 | | 8082 Congeners | 2 | 72 | 340 | 206 | 2 | 500 | 670 | 585 |
| 2,3,3',4,4',5-Hexachlorobiphenyl (PCB 156) | 3550 | | 8082 Congeners | 2 | 73 | 340 | 207 | 2 | 500 | 670 | 585 |
| 2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157) | 3550 | | 8082 Congeners | 2 | 76 | 650 | 363 | 2 | 500 | 1300 | 900 |
| 2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167) | 3550 | | 8082 Congeners | 2 | 88 | 650 | 369 | 2 | 500 | 1300 | 900 |
| 3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169) | 3550 | | 8082 Congeners | 2 | 93 | 340 | 217 | 2 | 500 | 670 | 585 |
| 2,3,3',4,4',5,5'-Heptachlorobiphenyl (PCB 189) | 3550 | | 8082 Congeners | 2 | 68 | 340 | 204 | 2 | 500 | 670 | 585 |
| 3,3',4,4'-Tetrachlorobiphenyl (PCB 77) | 1668 | 1668 | 1668 | 3 | 0.04 | 0.32 | 0.20 | 9 | 0.01 | 50 | 14 |
| 3,4,4',5- Tetrachlorobiphenyl (PCB 81) | 1668 | 1668 | 1668 | 3 | 0.04 | 0.27 | 0.19 | 9 | 0.01 | 50 | 14 |
| 2,3,3',4,4'-Pentachlorobiphenyl (PCB 105) | 1668 | 1668 | 1668 | 3 | 0.10 | 0.26 | 0.20 | 9 | 0.01 | 100 | 26 |
| 2,3,4,4',5-Pentachlorobiphenyl (PCB 114) | 1668 | 1668 | 1668 | 3 | 0.11 | 0.25 | 0.20 | 9 | 0.01 | 50 | 14 |
| 2,3',4,4',5-Pentachlorobiphenyl (PCB 118) | 1668 | 1668 | 1668 | 3 | 0.10 | 0.48 | 0.28 | 9 | 0.01 | 400 | 55 |
| 2',3,4,4',5-Pentachlorobiphenyl (PCB 123) | 1668 | 1668 | 1668 | 3 | 0.11 | 0.25 | 0.20 | 9 | 0.01 | 50 | 14 |
| 3,3',4,4',5-Pentachlorobiphenyl (PCB 126) | 1668 | 1668 | 1668 | 3 | 0.12 | 0.30 | 0.24 | 9 | 0.03 | 50 | 14 |
| 2,3,3',4,4',5-Hexachlorobiphenyl (PCB 156) | 1668 | 1668 | 1668 | 3 | 0.05 | 0.50 | 0.25 | 9 | 0.02 | 100 | 27 |
| 2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157) | 1668 | 1668 | 1668 | 3 | 0.05 | 0.50 | 0.24 | 9 | 0.50 | 80 | 25 |
| 2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167) | 1668 | 1668 | 1668 | 3 | 0.04 | 0.46 | 0.23 | 9 | 0.01 | 50 | 14 |
| 3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169) | 1668 | 1668 | 1668 | 3 | 0.09 | 0.25 | 0.19 | 9 | 0.01 | 50 | 15 |
| 2,3,3',4,4',5,5'-Heptachlorobiphenyl (PCB 189) | 1,668 | 1,668 | 1668 | 3 | 0.02 | 0.27 | 0.18 | 9 | 0.01 | 50 | 14 |

[1] Significant digits are based on laboratory survey reported values

SIM - Selected ion monitoring
LL - Low level modification of method
Mod - Laboratory modification of EPA method
N - Number of laboratories providing information

**Appendix D: Table D-2.** Tissue Method Detection Limits and Practical Quantitation Limits [1]

| Analytes | Analytical Method | MDL | | | | PQL | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | Min | Max | Average | N | Min | Max | Average |
| **Metals in mg/kg (ppm) wet weight** | | | | | | | | | |
| Antimony | 6010/PSEP | 2 | 0.19 | 0.4 | 0.3 | 3 | 1.0 | 5.0 | 3.0 |
| Arsenic | 6010/PSEP | 2 | 0.32 | 0.6 | 0.5 | 3 | 1 | 10 | 5 |
| Cadmium | 6010/PSEP | 2 | 0.2 | 3 | 2 | 3 | 0.04 | 5 | 2 |
| Chromium | 6010/PSEP | 2 | 0.08 | 0.39 | 0.2 | 3 | 0.1 | 1.3 | 0.8 |
| Copper | 6010/PSEP | 2 | 0.2 | 0.72 | 0.5 | 3 | 0.04 | 1 | 0.7 |
| Lead | 6010/PSEP | 2 | 0.15 | 0.2 | 0.2 | 3 | 0.4 | 5 | 2 |
| Nickel | 6010/PSEP | 2 | 0.06 | 0.13 | 0.1 | 3 | 0.2 | 2 | 1 |
| Silver | 6010/PSEP | 2 | 0.1 | 0.56 | 0.3 | 3 | 0.06 | 1 | 0.7 |
| Zinc | 6010/PSEP | 2 | 0.06 | 0.53 | 0.3 | 3 | 0.2 | 2 | 1 |
| Selenium | 6010/PSEP | 2 | 0.12 | 0.7 | 0.4 | 3 | 1 | 10 | 5 |
| Antimony | 6020/PSEP | 8 | 0.0021 | 0.336 | 0.080 | 8 | 0.05 | 0.8 | 0.2 |
| Arsenic | 6020/PSEP | 8 | 0.0032 | 0.368 | 0.11 | 8 | 0.05 | 1.6 | 0.4 |
| Cadmium | 6020/PSEP | 8 | 0.0013 | 0.0592 | 0.013 | 8 | 0.01 | 0.4 | 0.1 |
| Chromium | 6020/PSEP | 8 | 0.0013 | 0.432 | 0.10 | 8 | 0.05 | 1.6 | 0.4 |
| Copper | 6020/PSEP | 8 | 0.0018 | 0.616 | 0.13 | 8 | 0.05 | 1.6 | 0.4 |
| Lead | 6020/PSEP | 8 | 0.002 | 0.05 | 0.01 | 8 | 0.02 | 0.8 | 0.2 |
| Nickel | 6020/PSEP | 8 | 0.0047 | 0.34 | 0.065 | 8 | 0.05 | 1.6 | 0.3 |
| Silver | 6020/PSEP | 8 | 0.0044 | 0.6 | 0.17 | 8 | 0.05 | 1.6 | 0.5 |
| Zinc | 6020/PSEP | 8 | 0.0005 | 0.08 | 0.018 | 8 | 0.01 | 0.5 | 0.2 |
| Selenium | 6020/PSEP | 8 | 0.011 | 1.84 | 0.56 | 8 | 0.5 | 12 | 2.7 |
| Selenium | 7742 | 1 | 0.05 | 0.05 | 0.05 | 1 | 0.1 | 0.1 | 0.1 |
| Mercury | 1631 | 3 | 0.00024 | 0.3 | 0.11 | 3 | 0.001 | 1 | 0.4 |
| Mercury | 7471A | 7 | 0.00088 | 0.08 | 0.01 | 7 | 0.08 | 1 | 0.2 |
| **Organometallics in ug/kg (ppb) wet weight** | | | | | | | | | |
| Tributyltin (ion) | Krone 1989 | 2 | 0.88 | 3.39 | 2.135 | 2 | 1.33 | 8 | 4.665 |
| Tributyltin (ion) | SOC-Butyl | 1 | 0.11 | 0.11 | 0.11 | 1 | 1 | 1 | 1 |
| **Semivolatile Organics (SVOCs) wet weight** | | | | | | | | | |
| **Phenolics (Acids) in ug/kg (ppb) wet weight** | | | | | | | | | |
| Phenol | 8270 | 1 | 15 | 15 | 15 | 1 | 100 | 100 | 100 |
| 2-Methylphenol | 8270 | 1 | 15 | 15 | 15 | 1 | 100 | 100 | 100 |
| 4-Methylphenol | 8270 | 1 | 15 | 15 | 15 | 1 | 200 | 200 | 200 |
| 2,4-Dimethylphenol | 8270 | 1 | 15 | 15 | 15 | 1 | 100 | 100 | 100 |
| Pentachlorophenol | 8270 | 1 | 15 | 15 | 15 | 1 | 200 | 200 | 200 |
| Benzyl alcohol | 8270 | 1 | 15 | 15 | 15 | 1 | 100 | 100 | 100 |
| Benzoic acid | 8270 | 1 | 750 | 750 | 750 | 1 | 2500 | 2500 | 2500 |
| Phenol | 8270 SIM | 1 | 45 | 45 | 45 | 1 | 100 | 100 | 100 |
| 2-Methylphenol | 8270 SIM | 1 | 3.2 | 3.2 | 3.2 | 1 | 40 | 40 | 40 |
| 4-Methylphenol | 8270 SIM | 1 | 11 | 11 | 11 | 1 | 40 | 40 | 40 |
| 2,4-Dimethylphenol | 8270 SIM | 1 | 17 | 17 | 17 | 1 | 40 | 40 | 40 |
| Pentachlorophenol | 8270 SIM | 1 | 30 | 30 | 30 | 1 | 100 | 100 | 100 |
| Benzyl alcohol | 8270 SIM | 1 | 16 | 16 | 16 | 1 | 40 | 40 | 40 |
| Pentachlorophenol | 8041 | 1 | 3.08 | 3.08 | 3.08 | 1 | 5 | 5 | 5 |

**Appendix D: Table D-2** (continued). Tissue Method Detection Limits and Practical Quantitation Limits[1]

| Analytes | Analytical Method | MDL | | | | PQL | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | Min | Max | Average | N | Min | Max | Average |
| **LPAHs in ug/kg (ppb) wet weight** | | | | | | | | | |
| Naphthalene | 8270 SIM | 3 | 0.08 | 2 | 0.8 | 3 | 0.5 | 5 | 2 |
| 2-Methylnaphthalene (not included in PSDDA sum) | 8270 SIM | 3 | 0.1 | 2 | 0.8 | 3 | 0.5 | 5 | 2 |
| Acenaphthylene | 8270 SIM | 3 | 0.05 | 2 | 0.6 | 3 | 0.5 | 5 | 2 |
| Acenaphthene | 8270 SIM | 3 | 0.1 | 2 | 0.6 | 3 | 0.5 | 5 | 2 |
| Fluorene | 8270 SIM | 3 | 0.1 | 2 | 0.6 | 3 | 0.5 | 5 | 2 |
| Phenanthrene | 8270 SIM | 3 | 0.2 | 2 | 0.7 | 3 | 0.5 | 5 | 2 |
| Anthracene | 8270 SIM | 3 | 0.2 | 2 | 0.6 | 3 | 0.5 | 5 | 2 |
| **HPAHs in ug/kg (ppb) wet weight** | | | | | | | | | |
| Fluoranthene | 8270 SIM | 3 | 0.2 | 1.5 | 0.6 | 3 | 0.5 | 5 | 2 |
| Pyrene | 8270 SIM | 3 | 0.1 | 1.5 | 0.6 | 3 | 0.5 | 5 | 2 |
| Benz(a)anthracene | 8270 SIM | 10 | 0.0 | 2.7 | 1.0 | 10 | 0.5 | 50 | 10 |
| Chrysene | 8270 SIM | 10 | 0.0 | 5.0 | 1.3 | 10 | 0.5 | 50 | 10 |
| Benzo(b)fluoranthene | 8270 SIM | 10 | 0.1 | 2.7 | 1.0 | 10 | 0.5 | 50 | 10 |
| Benzo(j)fluoranthene | 8270 SIM | 1 | 1.5 | 1.5 | 1.5 | 1 | 5 | 5 | 5 |
| Benzo(k)fluoranthene | 8270 SIM | 10 | 0.0 | 2.7 | 1.1 | 10 | 0.5 | 50 | 10 |
| Benzo(a)pyrene | 8270 SIM | 3 | 0.1 | 1.5 | 0.6 | 3 | 0.5 | 5 | 2 |
| Indeno(1,2,3-cd)pyrene | 8270 SIM | 10 | 0.0 | 5.0 | 1.4 | 10 | 0.5 | 50 | 10 |
| Dibenz(a,h)anthracene | 8270 SIM | 10 | 0.1 | 5.0 | 1.5 | 10 | 0.5 | 50 | 10 |
| Benzo(g,h,i)perylene | 8270 SIM | 10 | 0.0 | 5.0 | 1.3 | 10 | 0.5 | 50 | 10 |
| Total HPAHs | 8270 SIM | | | | | | | | |
| **Chlorinated Aromatics in ug/kg wet weight** | | | | | | | | | |
| 1,3-Dichlorobenzene | 8270 | 1 | 15 | 15 | 15 | 1 | 50 | 50 | 50 |
| 1,4-Dichlorobenzene | 8270 | 1 | 15 | 15 | 15 | 1 | 50 | 50 | 50 |
| 1,2-Dichlorobenzene | 8270 | 1 | 15 | 15 | 15 | 1 | 50 | 50 | 50 |
| 1,2,4-Trichlorobenzene | 8270 | 1 | 15 | 15 | 15 | 1 | 50 | 50 | 50 |
| Hexachlorobenzene | 8270 | 1 | 5 | 5 | 5 | 1 | 50 | 50 | 50 |
| 1,3-Dichlorobenzene | 8270 SIM | 1 | 8.6 | 8.6 | 8.6 | 1 | 40 | 40 | 40 |
| 1,4-Dichlorobenzene | 8270 SIM | 1 | 7.6 | 7.6 | 7.6 | 1 | 40 | 40 | 40 |
| 1,2-Dichlorobenzene | 8270 SIM | 1 | 6.5 | 6.5 | 6.5 | 1 | 40 | 40 | 40 |
| 1,2,4-Trichlorobenzene | 8270 SIM | 1 | 4.2 | 4.2 | 4.2 | 1 | 40 | 40 | 40 |
| Hexachlorobenzene | 8270 SIM | 1 | 4 | 4 | 4 | 1 | 40 | 40 | 40 |

**Appendix D: Table D-2** (continued). Tissue Method Detection Limits and Practical Quantitation Limits[1]

| Analytes | Analytical Method | MDL | | | | PQL | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | Min | Max | Average | N | Min | Max | Average |
| **Phthalates in ug/kg (ppb) wet weight** | | | | | | | | | |
| Diethyl phthalate | 8270 | 1 | 15 | 15 | 15 | 1 | 100 | 100 | 100 |
| Di-n-butyl phthalate | 8270 | 1 | 50 | 50 | 50 | 1 | 200 | 200 | 200 |
| Butyl benzyl phthalate | 8270 | 1 | 50 | 50 | 50 | 1 | 100 | 100 | 100 |
| Bis(2-ethylhexyl)phthalate | 8270 | 1 | 50 | 50 | 50 | 1 | 1500 | 1500 | 1500 |
| Di-n-octyl phthalate | 8270 | 1 | 5 | 5 | 5 | 1 | 200 | 200 | 200 |
| Dimethyl phthalate | 8270 SIM | 1 | 3.6 | 3.6 | 3.6 | 1 | 40 | 40 | 40 |
| Diethyl phthalate | 8270 SIM | 1 | 9 | 9 | 9 | 1 | 40 | 40 | 40 |
| Di-n-butyl phthalate | 8270 SIM | 1 | 100 | 100 | 100 | 1 | 100 | 100 | 100 |
| Butyl benzyl phthalate | 8270 SIM | 1 | 7.3 | 7.3 | 7.3 | 1 | 40 | 40 | 40 |
| Bis(2-ethylhexyl)phthalate | 8270 SIM | 1 | 66 | 66 | 66 | 1 | 200 | 200 | 200 |
| Di-n-octyl phthalate | 8270 SIM | 1 | 11 | 11 | 11 | 1 | 40 | 40 | 40 |
| **Misc. Extractables in ug/kg wet weight** | | | | | | | | | |
| Dibenzofuran | 8270 | 1 | 5 | 5 | 5 | 1 | 100 | 100 | 100 |
| Hexachloroethane | 8270 | 1 | 15 | 15 | 15 | 1 | 100 | 100 | 100 |
| Hexachlorobutadiene | 8270 | 1 | 15 | 15 | 15 | 1 | 50 | 50 | 50 |
| N-Nitrosodiphenylamine | 8270 | 1 | 5 | 5 | 5 | 1 | 50 | 50 | 50 |
| Dibenzofuran | 8270 SIM | 1 | 2.6 | 2.6 | 2.6 | 1 | 40 | 40 | 40 |
| Hexachloroethane | 8270 SIM | 1 | 12 | 12 | 12 | 1 | 40 | 40 | 40 |
| Hexachlorobutadiene | 8270 SIM | 1 | 6.2 | 6.2 | 6.2 | 1 | 40 | 40 | 40 |
| N-Nitrosodiphenylamine | 8270 SIM | 1 | 3 | 3 | 3 | 1 | 40 | 40 | 40 |
| **Chlorinated Pesticides/PCBs in ug/kg (ppb) wet weight** | | | | | | | | | |
| 4,4'-DDE | 8081 | 3 | 0.14 | 1.00 | 0.69 | 3 | 1 | 5 | 2.7 |
| 4,4'-DDD | 8081 | 3 | 0.15 | 0.47 | 0.34 | 3 | 1 | 5 | 2.7 |
| 4,4'-DDT | 8081 | 3 | 0.15 | 1.00 | 0.72 | 3 | 1 | 5 | 2.7 |
| 2,4'-DDE | 8081 | 2 | 0.21 | 0.30 | 0.26 | 2 | 1 | 2 | 1.5 |
| 2,4'-DDD | 8081 | 2 | 0.30 | 0.38 | 0.34 | 2 | 1 | 2 | 1.5 |
| 2,4'-DDT | 8081 | 2 | 0.12 | 0.3 | 0.21 | 2 | 1 | 2 | 1.5 |
| cis-Chlordane | 8081 | 3 | 0.13 | 0.52 | 0.30 | 3 | 1 | 2.5 | 1.5 |
| trans-Chlordane | 8081 | 3 | 0.13 | 0.33 | 0.22 | 3 | 1 | 2.5 | 1.5 |
| cis-Nonachlor | 8081 | 2 | 0.19 | 0.22 | 0.21 | 2 | 1 | 2 | 1.5 |
| trans-Nonachlor | 8081 | 2 | 0.24 | 0.30 | 0.27 | 2 | 1 | 2 | 1.5 |
| Oxychlordane | 8081 | 2 | 0.29 | 0.30 | 0.30 | 2 | 1 | 2 | 1.5 |
| Aldrin | 8081 | 3 | 0.16 | 0.22 | 0.19 | 3 | 1 | 2.5 | 1.5 |
| Dieldrin | 8081 | 3 | 0.12 | 0.43 | 0.26 | 3 | 1 | 5 | 2.7 |
| Heptachlor | 8081 | 3 | 0.13 | 0.46 | 0.32 | 3 | 1 | 2.5 | 1.5 |
| Lindane | 8081 | 3 | 0.14 | 0.30 | 0.22 | 3 | 1 | 2.5 | 1.5 |
| Toxaphene | 8081 | 2 | 9.30 | 22.8 | 16.1 | 3 | 50 | 250 | 133 |

**Appendix D: Table D-2** (continued)**.** Tissue Method Detection Limits and Practical Quantitation Limits[1]

| Analytes | Analytical Method | MDL | | | | PQL | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | Min | Max | Average | N | Min | Max | Average |
| **Dioxin/Furan Congeners in ng/kg (ppt) wet weight** | | | | | | | | | |
| 1,2,3,7,8-PeCDD | 8290 | 1 | 0.25 | 0.25 | 0.25 | 2 | 5 | 5 | 5 |
| 1,2,3,4,7,8-HxCDD | 8290 | 1 | 0.17 | 0.17 | 0.17 | 2 | 5 | 5 | 5 |
| 1,2,3,6,7,8-HxCDD | 8290 | 1 | 0.19 | 0.19 | 0.19 | 2 | 5 | 5 | 5 |
| 1,2,3,7,8,9-HxCDD | 8290 | 1 | 0.23 | 0.23 | 0.23 | 2 | 5 | 5 | 5 |
| 1,2,3,4,6,7,8-HpCDD | 8290 | 1 | 0.50 | 0.50 | 0.50 | 2 | 5 | 5 | 5 |
| OCDD | 8290 | 1 | 0.76 | 0.76 | 0.76 | 2 | 10 | 10 | 10 |
| 2,3,7,8-TCDF | 8290 | 1 | 0.15 | 0.15 | 0.15 | 2 | 1 | 1 | 1 |
| 1,2,3,7,8-PeCDF | 8290 | 1 | 0.33 | 0.33 | 0.33 | 2 | 5 | 5 | 5 |
| 2,3,4,7,8-PeCDF | 8290 | 1 | 0.28 | 0.28 | 0.28 | 2 | 5 | 5 | 5 |
| 1,2,3,4,7,8-HxCDF | 8290 | 1 | 0.36 | 0.36 | 0.36 | 2 | 5 | 5 | 5 |
| 1,2,3,6,7,8-HxCDF | 8290 | 1 | 0.25 | 0.25 | 0.25 | 2 | 5 | 5 | 5 |
| 1,2,3,7,8,9-HxCDF | 8290 | 1 | 0.24 | 0.24 | 0.24 | 2 | 5 | 5 | 5 |
| 2,3,4,6,7,8-HxCDF | 8290 | 1 | 0.36 | 0.36 | 0.36 | 2 | 5 | 5 | 5 |
| 1,2,3,4,6,7,8-HpCDF | 8290 | 1 | 0.18 | 0.18 | 0.18 | 2 | 5 | 5 | 5 |
| 1,2,3,4,7,8,9-HpCDF | 8290 | 1 | 0.30 | 0.30 | 0.30 | 2 | 5 | 5 | 5 |
| OCDF | 8290 | 1 | 0.16 | 0.16 | 0.16 | 2 | 10 | 10 | 10 |
| 2,3,7,8-TCDD | 1613B | 9 | 0.022 | 0.41 | 0.19 | 11 | 0.05 | 1 | 0.8 |
| 1,2,3,7,8-PeCDD | 1613B | 9 | 0.047 | 1.67 | 0.50 | 11 | 0.05 | 5 | 4.0 |
| 1,2,3,4,7,8-HxCDD | 1613B | 9 | 0.047 | 1.67 | 0.53 | 11 | 0.05 | 5 | 4.0 |
| 1,2,3,6,7,8-HxCDD | 1613B | 9 | 0.045 | 1.67 | 0.50 | 11 | 0.05 | 5 | 4.0 |
| 1,2,3,7,8,9-HxCDD | 1613B | 9 | 0.042 | 1.67 | 0.52 | 11 | 0.05 | 5 | 4.0 |
| 1,2,3,4,6,7,8-HpCDD | 1613B | 9 | 0.021 | 1.67 | 0.53 | 11 | 0.05 | 5 | 4.0 |
| OCDD | 1613B | 9 | 0.022 | 3.33 | 1.11 | 11 | 0.05 | 10 | 8 |
| 2,3,7,8-TCDF | 1613B | 9 | 0.03 | 0.33 | 0.17 | 11 | 0.05 | 1 | 0.8 |
| 1,2,3,7,8-PeCDF | 1613B | 9 | 0.027 | 1.67 | 0.48 | 11 | 0.05 | 5 | 4.0 |
| 2,3,4,7,8-PeCDF | 1613B | 9 | 0.03 | 1.67 | 0.48 | 11 | 0.05 | 5 | 4.0 |
| 1,2,3,4,7,8-HxCDF | 1613B | 9 | 0.026 | 1.67 | 0.48 | 11 | 0.05 | 5 | 4.0 |
| 1,2,3,6,7,8-HxCDF | 1613B | 9 | 0.029 | 1.67 | 0.48 | 11 | 0.05 | 5 | 4.0 |
| 1,2,3,7,8,9-HxCDF | 1613B | 9 | 0.039 | 1.67 | 0.50 | 11 | 0.05 | 5 | 4.0 |
| 2,3,4,6,7,8-HxCDF | 1613B | 9 | 0.027 | 1.67 | 0.50 | 11 | 0.05 | 5 | 4.0 |
| 1,2,3,4,6,7,8-HpCDF | 1613B | 9 | 0.019 | 1.67 | 0.48 | 11 | 0.05 | 5 | 4.0 |
| 1,2,3,4,7,8,9-HpCDF | 1613B | 9 | 0.029 | 1.67 | 0.49 | 11 | 0.05 | 5 | 4.0 |
| OCDF | 1613B | 9 | 0.017 | 3.33 | 0.96 | 11 | 0.05 | 10 | 8 |

**Appendix D: Table D-2** (continued). Tissue Method Detection Limits and Practical Quantitation Limits[1]

| Analytes | Analytical Method | MDL | | | | PQL | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | Min | Max | Average | N | Min | Max | Average |
| **Dioxin-like PCB Congeners in ng/kg (ppt) wet weight** | | | | | | | | | |
| 3,4,4',5- Tetrachlorobiphenyl (PCB 81) | 8082 | 1 | 160 | 160 | 160 | 1 | 500 | 500 | 500 |
| 2,3,3',4,4'-Pentachlorobiphenyl (PCB 105) | 8082 | 1 | 100 | 100 | 100 | 1 | 500 | 500 | 500 |
| 2,3,4,4',5-Pentachlorobiphenyl (PCB 114) | 8082 | 1 | 89 | 89 | 89 | 1 | 500 | 500 | 500 |
| 2,3',4,4',5-Pentachlorobiphenyl (PCB 118) | 8082 | 1 | 110 | 110 | 110 | 1 | 500 | 500 | 500 |
| 2',3,4,4',5-Pentachlorobiphenyl (PCB 123) | 8082 | 1 | 83 | 83 | 83 | 1 | 500 | 500 | 500 |
| 3,3',4,4',5-Pentachlorobiphenyl (PCB 126) | 8082 | 1 | 140 | 140 | 140 | 1 | 500 | 500 | 500 |
| 2,3,3',4,4',5-Hexachlorobiphenyl (PCB 156) | 8082 | 1 | 560 | 560 | 560 | 1 | 1000 | 1000 | 1000 |
| 2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157) | 8082 | 1 | 210 | 210 | 210 | 1 | 500 | 500 | 500 |
| 2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167) | 8082 | 1 | 500 | 500 | 500 | 1 | 500 | 500 | 500 |
| 3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169) | 8082 | 1 | 89 | 89 | 89 | 1 | 500 | 500 | 500 |
| 2,3,3',4,4',5,5'-Heptachlorobiphenyl (PCB 189) | 8082 | 1 | 180 | 180 | 180 | 1 | 500 | 500 | 500 |
| 3,3',4,4'-Tetrachlorobiphenyl (PCB 77) | 1668 | 7 | 0.01 | 250 | 48 | 7 | 0.2 | 250 | 70 |
| 3,4,4',5- Tetrachlorobiphenyl (PCB 81) | 1668 | 7 | 0.01 | 250 | 48 | 7 | 0.2 | 250 | 71 |
| 2,3,3',4,4'-Pentachlorobiphenyl (PCB 105) | 1668 | 7 | 0.01 | 100 | 33 | 7 | 0.2 | 100 | 35 |
| 2,3,4,4',5-Pentachlorobiphenyl (PCB 114) | 1668 | 7 | 0.01 | 250 | 47 | 7 | 0.4 | 250 | 65 |
| 2,3',4,4',5-Pentachlorobiphenyl (PCB 118) | 1668 | 7 | 0.01 | 250 | 48 | 7 | 0.5 | 250 | 74 |
| 2',3,4,4',5-Pentachlorobiphenyl (PCB 123) | 1668 | 7 | 0.01 | 250 | 47 | 7 | 0.3 | 250 | 68 |
| 3,3',4,4',5-Pentachlorobiphenyl (PCB 126) | 1668 | 7 | 0.1 | 250 | 75 | 7 | 0.3 | 250 | 85 |
| 2,3,3',4,4',5-Hexachlorobiphenyl (PCB 156) | 1668 | 5 | 0.1 | 250 | 90 | 7 | 0.3 | 250 | 105 |
| 2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157) | 1668 | 7 | 0.02 | 500 | 94 | 7 | 1.1 | 500 | 210 |
| 2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167) | 1668 | 7 | 0.01 | 250 | 47 | 7 | 0.2 | 250 | 64 |
| 3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169) | 1668 | 7 | 0.01 | 250 | 49 | 7 | 0.2 | 250 | 69 |
| 2,3,3',4,4',5,5'-Heptachlorobiphenyl (PCB 189) | 1668 | 7 | 0.01 | 250 | 47 | 7 | 0.2 | 250 | 71 |
| Dioxin sum TEQ | 1613 | | | | | 269 | 0.03 | 3.2 | 1.3 |
| Mercury | 7471 | | | | | 8 | 0.0012 | 0.02 | 0.01 |

[1] Significant digits are based on laboratory survey reported values.
**SIM** - Selected ion monitoring **LL** - Low level modification of method **Mod** - Laboratory modification of EPA method
**N** - Number of laboratories providing information

**Dioxin PQLs** for EPA 1613b were downloaded from EIM. Data less than 10 years old were considered, and the reported PQLs were averaged within each study. Additionally, data from a DMMP bioaccumulation test that is not in EIM was also added. The following data were used to calculate the PQL:

- AJOH0063 (2010) n=23 average sum TEQ PQL 0.4 ppt
- AJOH0063 (2011) n=11 average sum TEQ PQL 0.4 ppt
- CCOF0003 (2008) n=3 average sum TEQ PQL 0.2 ppt
- FFCMP13 (2013) n=39 average sum TEQ PQL 1.9 ppt
- FFCMP14 (2014) n=39 average sum TEQ PQL 1.9 ppt
- Fidalgo08 (2007) n=44 average sum TEQ PQL 0.1 ppt (low value dropped)
- PASDED08 (2008) n=18 average sum TEQ PQL 3.1 ppt (high value dropped)
- PortGardner08 (2008) n=18 average sum TEQ PQL 0.1 ppt (low value dropped)
- RCOO0008 (2008) n=5 average sum TEQ PQL 1.0 ppt
- WSTMP08 (2008) n=45 average sum TEQ PQL 0.2 ppt
- WSTMP09 (2009) n=25 average sum TEQ PQL 2.2 ppt
- WSTMP10 (2010) n=25 average sum TEQ PQL 1.1 ppt
- WSTMP12 (2012) n=33 average sum TEQ PQL 1.4 ppt
- DMMP (2016) n=8 TEQ PQL 2.8 ppt

*This page left intentionally blank.*

# Appendix E
# Assessing Human and Ecological Health Risks

## E.1 Introduction

This appendix provides additional information for conducting more in-depth risk assessments. For sediment cleanup under the SMS rule, in-depth risk assessments are generally not necessary to complete RI/FS objectives, and the requirements outlined in Chapter 9 will be sufficient. The SMS rule requires a limited risk assessment process for cleanup sites. This process includes establishing risk-based concentrations, based on acceptable risk levels and exposure parameters, for comparison to background and PQL in order to determine the final SCO and CSL (Chapter 7). However, it may be necessary to conduct a more in-depth risk assessment for a complex sediment cleanup site to satisfy specific purposes, such as:

- To communicate risk to the public and highly exposed groups such as tribes.
- More thoroughly understand public health issues before and during cleanup.
- To manage critical natural resources.
- To compare residual risks associated with cleanup alternatives.

The need for more in-depth human health and ecological risk assessments at a particular site will be determined by Ecology with input from stakeholders, tribes, and other agencies responsible for public health and natural resources protection.

## E.2 Human Health Risk Assessment

A human health risk assessment (HHRA) should focus on contaminants and human exposure pathways directly related to site activities (such as excess cancer risk/human health hazards from exposure to contaminated sediment at a site). The HHRA, therefore, should address human health risks/hazards associated with exposure pathways and CoPCs identified in the CSM. However, because natural and regional background concentrations of risk-driver chemicals can pose risk, it may be useful to estimate excess risks by comparing site risk to background risk.

The HHRA may be integrated with the RI Report (as an appendix, for example), and should include the following elements:

- Contaminants of Concern (CoC). A summary of the human health-related CoPCs identified in the CSM in the RI Work Plan should be included. The process for screening CoPCs is discussed in Chapter 3, Section 3.3.6. The human health risk assessment

should include all of the CoPCs identified in the work plan, as well as any unanticipated chemicals found during the RI that could also pose a human health risk. The results of the risk assessment can be used to confirm or modify the final list of CoCs for the RI Report (see Chapter 6, Section 6.4.3).

- Exposure Scenarios. A summary of the exposure scenarios identified in the CSM in the RI Work Plan should be included (Chapter 3, Section 3.3.4). WAC 173-204-561(2)(b)(i) specifies that cleanup standards should be based on a reasonable maximum exposure (RME) scenario that reflects tribal consumption of fish and shellfish. Ecology has defined exposure parameters that represent a tribal RME scenario for typical sediment sites in Washington State (Appendix E: Figure E-1). This exposure scenario includes two main exposure pathways:

    - Fish/shellfish consumption pathway RME scenarios (e.g., Suquamish Tribal Adult, Tulalip Tribal Adult, and Columbia River Tribal Adult).

    - Dermal contact with and incidental ingestion of sediment RME scenarios (e.g., Playing Child, Subsistence Tribal Clam Digging Adult, and Subsistence Tribal Net Fishing Adult).

  The SMS rule also provides the flexibility to establish alternate exposure scenarios using site-specific information (Section E.2.2). The exposure pathways and associated scenarios should be summarized in the CSM.

- Risk Assessment Methods. The HHRA should summarize the assumptions, equations, exposure parameters, and toxicity values used to calculate risks. Risks should be estimated individually for each exposure pathway identified in the CSM, then summed to estimate total risks for each chemical and for all chemicals combined.

- Risk Assessment Results. The results of the risk assessment should be summarized by receptor group, chemical, exposure pathway, and as summary risks across exposure pathways and chemicals. For context, risk assessment results may be compared to natural or regional background risks (as applicable) and excess risks identified. Pie charts or graphs illustrating the components of risk (e.g., sorted by species consumed, chemical, or exposure route) can be very helpful in communicating the results to the public. Conclusions regarding which of the CoPCs should be considered CoCs—based on human health risk associated with the site—should be presented in the RI Report.

- Uncertainty and Variability. The HHRA should identify important sources of uncertainty and variability underlying the risk-based concentrations and cleanup site concentrations. Quantitative and qualitative discussions of both the direction and magnitude of uncertainty should be included, to the extent possible.

## E.2.1 Fish and shellfish consumption – default RME

The following equations are used to calculate single-chemical risks associated with fish and shellfish consumption for carcinogens (Equation E-1) and noncarcinogens (Equation E-2). Use of these equations assumes that tissue concentrations are available and have been appropriately averaged as discussed in Chapter 3, Section 3.4.2.

**Appendix E: Equation E-1.** Calculation of cancer risks for fish and shellfish consumption

$$CR = \frac{Ct \times CPFo \times FCR \times EF \times ED \times FDF}{BW \times AT \times UCF}$$

Where:

*CR* = Cancer risk (unitless)

*Ct* = Area-averaged concentration in tissues (mg/kg dw)

*CPFo* = Cancer potency factor $(mg/kg \cdot day)^{-1}$

*FCR* = Fish consumption rate (g/day)

*EF* = Exposure frequency (day/year)

*ED* = Exposure duration (year)

*FDF* = Fish diet fraction (unitless)

*BW* = Body weight (kg)

*AT* = Averaging time (day)

UCF = Unit conversion factor (1000 g/kg)

**Appendix E: Equation E-2.** Calculation of noncancer risks for fish and shellfish consumption.

$$HQ = \frac{Ct \times FCR \times EF \times ED \times FDF}{RfD \times BW \times AT \times UCF}$$

Where:

*HQ* = Hazard quotient (unitless)

*RfD* = Reference dose (mg/kg·day)

All other factors are the same as in Appendix E: Equation E-1.

The exposure parameters used in these equations will normally be based on the default RME scenario. However, they can be modified, as appropriate, based on site-specific circumstances (see Section E.2.1.6). The default RME scenario exposure parameters for fish and shellfish consumption are defined in Appendix E: Table E-1 and some key parameters are further explained below. These parameters are provided for informational purposes only and represent Ecology policy only when stated. The Ecology default RME exposure parameters described below should be used unless site-specific information indicates that the default RME exposure parameters are inappropriate.

The EPA has determined benzo[a]pyrene is mutagenic—or causes cancer through induction of increased mutations—and that exposure during early life stages has greater potential to cause cancers even though these may not be manifest until years later. The EPA recommends using Age-Dependent Adjustment Factors for calculating risk of excess cancers for benzo[a]pyrene, which are applied to the TEQ derived for the group of cPAHs. The equations for this special case can be found in 9-1b/9-5b and age-dependent adjustment factors in Table 9-1b.

### E.2.1.1 Toxicity parameters

Two types of toxicity parameters are used to calculate human health risks, which are included in the equations above (see WAC 173-340-200 for more detailed MTCA definitions):

- Reference doses (RfDs). An RfD is a benchmark dose, derived from the NOAEL or LOAEL with safety factors and used to estimate an acceptable daily intake dose.
- Cancer potency factors (CPFs). CPFs, also known as slope factors as reported in EPA's Integrated Risk Information System (IRIS) database, are used to estimate the risk of

cancer from exposure to a carcinogenic chemical and represents an upper bound on the increased cancer risk from a lifetime exposure to a carcinogenic chemical.

The SMS rule establishes the following requirements for selecting toxicity parameters:

- If available, toxicological parameters available through the IRIS data base should be used. The IRIS toxicity parameters and background documents are available online at http://www.epa.gov/IRIS/.

- If a toxicological parameter is not available through IRIS, other sources can be used. The SMS rule states that when evaluating the appropriateness of using other sources, Ecology may use the toxicity hierarchy used by the EPA Superfund Program (USEPA 2003b).

EPA's Directive 9285.7-53 provides recommended sources of toxicity data for conducting site-specific human health risk assessments. The hierarchy of toxicity information recommended by OSWER Directive 9285.7-53 is:

- Tier 1: Toxicity values published in EPA's IRIS database.

- Tier 2: The Provisional Peer Reviewed Toxicity Values (PPRTVs) derived by EPA's Superfund Health Risk Technical Support Center.

- Tier 3: Other toxicity parameters including:

  - The Minimal Risk Levels developed by EPA for the Toxic Substances and Disease Registry.

  - The California Environmental Protection Agency Office of Environmental Health Hazard Assessment's Chronic Reference Exposure Levels from December 18, 2008 and the Cancer Potency Values from December 17, 2008.

  - Screening toxicity values found in appendices to certain PPRTV assessments. EPA includes the following statement on their Regional Screening Table webpage:

    > *While we have less confidence in a screening toxicity value than in a PPRTV, we put these ahead of HEAST toxicity values because these appendix screening toxicity values are more recent and use current EPA methodologies in the derivation, and because the PPRTV appendix screening toxicity values also receive external peer review.*

  - Health Effects Assessment Summary Table toxicity values.

Ecology provides access to current toxicity parameters through the Cleanup Levels and Risk Calculation (CLARC) database. The CLARC database is available online at https://fortress.wa.gov/ecy/clarc/CLARCHome.aspx.

EPA also publishes currently recommended toxicity parameters in the Regional Screening Tables. These toxicity values are published on a website maintained by the Oak Ridge National Laboratory (ORNL) under an interagency agreement with EPA. The ORNL works with EPA to update the website on a biennial basis. In general, EPA and ORNL use OSWER Directive 9285.7-53 to prepare the Regional Screening Tables. The Regional Screening Tables are available online at http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/.

### E.2.1.2 Fish consumption rate

The fish consumption rate (FCR) is a key parameter in estimating sediment-related human health risks that should be evaluated on a site-specific basis when developing the RME scenario. WAC 173-204-561(2)(b)(i) specifies that human health risks should be based on an RME scenario that reflects tribal consumption of fish and shellfish. However, an alternate exposure scenario may be approved by Ecology where appropriate (see Section E.2.1.6).

Ecology adopted revisions to the Water Quality Standards for Surface Waters of Washington State Chapter 173-201A WAC (WQS) in 2017 which used an FCR of 175 g/day to develop the standards.

For purposes of sediment cleanup under the SMS rule, a site-specific FCR should be established in consultation with affected tribes (Section E.2.1.2.1) and stakeholders, based on existing studies or after considering a new study (Section E.2.1.2.2). This approach is not intended to exclude other Ecology-approved methods for sediment cleanup under the SMS rule, nor is it intended to be used for other regulatory purposes.

#### *Using established tribal fish consumption rates*

Information on a range of FCRs that reflect differing abundances of fish and shellfish species, diverse habitats, and exposure scenarios typical of Washington State, can be found in the FCR technical support document (Ecology 2013b). Selection of a site-specific FCR should consider habitat quality, abundance, and current and future conditions that support fish and shellfish harvest and consumption in the aquatic environment where the site is located. It is recommended that FCRs be based on fish dietary information from the Pacific Northwest and consider the types of fish (including salmon) and shellfish that exposed populations actually eat.

The FCRs in Ecology (2013b) are applicable to different environments, including marine and large and small freshwater systems. They are based on fish dietary surveys in the Pacific Northwest that apply to:

- Marine environments, which include sediment cleanup sites in Puget Sound and other marine areas.
- Large freshwater environments, which include sediment cleanup sites located in large lakes and rivers.
- Small freshwater environments, which include sediment cleanup sites located in small lakes and streams.

For site-specific evaluations, selection of species groups and the corresponding upper percentile FCR range or rate is a risk management decision that should be made in consultation with tribal representatives and governments and interested stakeholders. Ecology (2013b) includes upper percentile FCR ranges based on existing consumption surveys. These ranges are offered as a guide to: a) help support discussions during tribal consultations; b) facilitate and expedite risk-based management cleanup decisions; c) provide a range of fish consumption estimates that are technically defensible; and d) provide flexibility that helps support cleanup decisions.

***Using new information to establish tribal fish consumption rates***

Appendix E: Table E-2 includes evaluation criteria Ecology will consider when reviewing and approving the use of an alternate tribal FCR based on a fish dietary survey that is not included in Ecology's technical support document (2013b). Several different approaches can be used to collect and evaluate information on fish and shellfish dietary habits and patterns (USEPA 1989b, 1998b, 2007b, 2011). Ecology has reviewed and evaluated these various approaches to conducting fish dietary surveys. To determine the quality and utility of a survey, Ecology will evaluate the:

- Experimental design
- Target population surveyed
- Sample size
- Location of the survey
- Execution of the fish dietary survey, and
- Potential survey bias

It may be inappropriate to conduct a fish dietary survey at a site where fish consumption is currently suppressed due to contamination. It may be more appropriate to conduct the survey with a similar population in a location where uncontaminated fish and shellfish are available.

### E.2.1.3 Fish diet fraction

The fish diet fraction (FDF) is the proportion of fish and shellfish in the RME individual's diet that is obtained from the site or general vicinity of the site. The initial FDF for all sites should be 1 (or 100%) (WAC 173-204-561(2)(b)(i)(C)). When making a site-specific evaluation, however, there is flexibility provided in the rule for Ecology to consider an FDF less than 1 based on:

- The size of the site, or
- Whether the habitat at the site can, or has the potential to, support the species and the established FCR.

An FDF less than 1 is generally inappropriate when using the FCRs published in Ecology (2013b), since those values reflect locally- or regionally-harvested fish and shellfish. In other words, the harvest source of those fish and shellfish has already been taken into account. An FDF of 1 for a tribal RME is consistent with the regulatory policies and procedures in the EPA Region 10 framework that reflects estimates of the amount of fish harvested and consumed from Puget Sound.

However, it may be appropriate to use an FDF less than 1 when extrapolating FCR values that were obtained from surveys conducted in large water bodies to sites located in relatively small water bodies that, even when cleaned up, could not sustain the FCR (particularly when the site is isolated from other contaminated areas). In these cases, an FDF lower than 1 may be justified if:

a) the size of the waterbody is not large enough to provide sufficient fish/shellfish to sustain the FCR for 365 days per year over 70 years (or other exposure frequency and/or duration for the RME scenario), and
b) other nearby sources of fish and shellfish are not similarly contaminated.

An FDF less than 1 would require adjustments to the RME and be based on the CSM developed in Chapter 3.

### E.2.1.4 Body weight

Body weight **(**BW) can vary significantly between various exposed populations, including tribes, Pacific Islanders, and other residents of Washington State. Estimates of body weight in the general population are 75 kg for adults and 15 kg for children (US EPA 2014). Estimates of adult body weight for most tribal populations are also very close to 75-80 kg (Ecology 2013b). However, if site-specific data regarding body weight are available, and they are of acceptable scientific quality and representative of the RME scenario, they should be evaluated and incorporated into the development of risk-based concentrations.

### E.2.1.5 Exposure duration

The exposure duration (ED) is based on the expected residency in the same household. The ED for tribal populations is 70 years, for instance, which is the number of years a tribal member is expected to consume fish and shellfish from a specific site. However, this should be adjusted based upon site-specific data for the exposed population. For example, the ED for the general U.S. population is 30 years based on an estimate that 90% of the U.S. population resides in the same household for 30 years (Ecology 2013b).

### E.2.1.6 Alternate exposure scenarios

Ecology's default RME scenario is based on tribal exposure and should be used to evaluate human health risks at most sediment sites (e.g., anywhere within a Usual and Accustomed fishing area of a tribe). The SMS rule allows Ecology to approve alternate RME scenarios using site-specific information, however, since Ecology's default RME scenario may not be applicable to:

- Some freshwater sites (e.g., alpine lakes that have a reduced fishing season due to extreme weather conditions or are managed for recreation or wilderness).
- Sites with unique site-specific characteristics that may influence human exposure.
- Wetlands or small streams in which fish/shellfish are not present or are limited.
- Sites where access is limited or not possible (e.g., private property or no physical access).

Ecology (2012) identifies recreational FCRs that may be used as a guide, which includes summaries and tabulation of recreational FCRs from various areas in the United States. The fish consumption estimates stem from recreational angler surveys that: a) used different methods to estimate fish and shellfish consumption; b) were conducted for a variety of purposes; c) had different target populations surveyed; and d) reported estimates of fish consumption in a variety of different metrics. Additionally, many of these recreational studies lacked descriptive statistics for the reported estimates. Ecology (2012) includes recreational fish consumption estimates as a range, which best reflects the nature of the surveys.

Consideration of these factors is important to provide some flexibility for defining the RME scenario. The rationale for this decision includes the following:

- This approach is consistent with MTCA, which provides the flexibility to use alternate exposure scenarios. For example, although the MTCA surface water standards are based on a recreational exposure scenario, the rule provides the flexibility to establish more stringent cleanup levels that are based on other exposure scenarios.

- This approach is consistent with (although more constrained than) the approach used at federal Superfund sites. Under the National Contingency Plan, EPA makes site-specific decisions on the appropriate RME scenario.

- Ecology views this provision as a narrow exception to the default RME scenario, given that the majority sediment cleanup sites are located in tribal U & A fishing areas. However, it is important to provide some flexibility to address future sites not located in these areas.

Ecology will work with the PLP, tribes, and stakeholders to develop alternative RME scenarios by evaluating site-specific exposure parameters for potentially exposed populations. This will help facilitate input concerning potentially exposed populations, exposure routes, and likely risks at the site, and allow modifications to the site-specific CSM and RME as needed. The process to develop alternate exposure scenarios is important because a wide range of potential exposures may exist (e.g., adult versus child) that could result in significantly different risks. If the assumptions used to calculate human health risks per the default RME scenario are not consistent with the site-specific RME scenario, then they should be modified to reflect the site-specific RME scenario.

It is also important to evaluate each potential exposure pathway at the site to determine if it is complete or incomplete. In some instances, an exposure pathway may not be complete and should not be included in the risk assessment (e.g., when ingestion of sediment may not be a complete exposure pathway at a specific site due to steep banks or sediment being capped). Specific considerations that Ecology site managers should include when identifying a site-specific RME scenario are presented in Appendix E: Table E-3.

## E.2.2 Direct contact with and ingestion of sediment

The following equations are used to calculate single-chemical risks associated with direct contact with and ingestion of sediment for carcinogens (Equation E-3) and noncarcinogens (Equation E-4). Use of these equations assumes that sediment concentrations have been appropriately averaged, as discussed in Chapter 3, Section 3.4.2.

**Appendix E: Equation E-3.** Calculation of cancer risks for sediment ingestion and dermal contact.

$$CR = \frac{Cs \times EF \times ED[(IR \times AB \times CPFo) + (SA \times AF \times ABS \times CPFd)]}{BW \times AT \times UCF}$$

Where:

*CR* = Cancer risk (unitless)

*Cs* = Area-averaged concentration in sediment (mg/kg dw)

*EF* = Exposure frequency (day/year)

*ED* = Exposure duration (year)

*IR* = Ingestion rate (mg/day)

*AB* = Gastrointestinal absorption factor (unitless)

*CPFo* = Oral cancer potency factor $(mg/kg \cdot day)^{-1}$

*SA* = Dermal exposed surface area ($cm^2$)

*AF* = Sediment to skin adherence factor $(mg/cm^2 \cdot day)$

*ABS* = Dermal absorption factor (unitless)

$CPF_d$ = Cancer potency factor adjusted for dermal exposure $(mg/kg \cdot day)^{-1}$ (see Equation 5)

*BW* = Body weight (kg)

*AT* = Averaging time (day)

UCF = Unit conversion factor (1,000,000 mg/kg)

**Appendix E: Equation E-4. Calculation of noncancer risks for sediment ingestion and dermal contact.**

$$HQ = \frac{Cs \times EF \times ED[\frac{(IR \times AB)}{RfDo} + \frac{(SA \times AF \times ABS)}{RfDd}]}{BW \times AT \times UCF}$$

Where:

*HQ* = Hazard quotient (unitless)

$RfD_o$ = Oral reference dose (mg/kg·day)

$RfD_d$ = Reference dose adjusted for dermal exposure (mg/kg·day) (see Equation 6)

All other factors are the same as in Equation E-3.

The default RME scenario exposure parameters for dermal contact with and ingestion of sediment are defined in Appendix E: Table E-4. Some of these parameters are described in more detail below. The EPA has determined benzo[a]pyrene is mutagenic—or causes cancer through induction of increased mutations—and that exposure during early life stages has greater potential to cause cancers even though these may not be manifest until years later. The EPA recommends using Age-Dependent Adjustment Factors for calculating risk of excess cancers for benzo[a]pyrene, which are applied to the TEQ derived for the group of cPAHs. The equations for this special case can be found in Equations 9-1b and 9-5b and age-dependent adjustment factors in Table 9-1b.

#### E.2.2.1 Exposure frequency

Exposure frequencies will be site-specific, depending on the recreational and fishing/shellfishing uses at the site, factors affecting access such as topography and tides, and other site and exposure pathway-specific attributes. Exposure frequency should be based on discussions with affected users and tribes and approved by Ecology. For example, at the Lower Duwamish Waterway Superfund site in the Seattle area, the following exposure frequencies were selected for the human health risk assessment after discussions between EPA, Ecology, and the Muckleshoot Tribe:

- Child beach play scenario, 65 days
- Adult tribal clam-digging scenario, 120 days
- Adult tribal net-fishing scenario, 119 days.

At other sites, exposure scenarios and frequencies for each scenario may differ from this example.

#### E.2.2.2 Exposure duration

The exposure duration (ED) is based on the expected residency in the same household. The ED for tribal populations is 70 years, which is the number of years a tribal member is expected to consume fish and shellfish from a specific site. This number should be adjusted as appropriate, based on site-specific data for the exposed population. For example, the ED for the general U.S. population is 30 years based on an estimate that 90% of the U.S. population resides in the same household for 30 years (Ecology 2013b). The recommended exposure duration for a child, however, is 6 years, based on a 2 – 8 year-old child.

### E.2.2.3 Soil ingestion rate

Soil ingestion rates for child beach play (200 mg/day) and a clam-digging adult (100 mg/day) are based on the recommended default exposure factors of USEPA (2014). The recommended soil ingestion rate for adult net-fishing (50 mg/day) is based on one-half the subsistence clam-digging ingestion rate, which reflects lower contact with sediment during net-fishing.

### E.2.2.4 Toxicity parameters

The CPFs and RfDs for dermal exposures are the same as those for oral exposures adjusted by a gastrointestinal conversion factor (GI) (WAC 173-340-740, Equation 740-5; Equations 5 and 6 below). These adjustments are as follows:

**Appendix E: Equation E-5:**

$$CPF_d = CPF_o/GI$$

**Appendix E: Equation E-6:**

$$RfD_d = RfD_o \times GI$$

Where:

$CPF_o$ and $RfD_o$ are as defined in Section E.2.1.1

$GI$ = default of 0.2 for inorganic hazardous substances

default of 0.8 for volatile organic compounds and mixtures of dioxins/furans

default of 0.5 for other organic hazardous substances

Alternatively, chemical-specific GIs may be used where known and available in the literature.

### E.2.2.5 Dermal exposure area

The recommended dermal exposure area for a child during beach play is 2,378 $cm^2$. The recommended dermal exposure area for an adult clam-digging or net-fishing is 3,212 $cm^2$, based on the head, hands, and forearms of an adult male. These are based on EPA 2011 Exposure Factors Handbook.

#### E.2.2.6 Sediment-to-skin adherence factor

The recommended value for the sediment-to-skin adherence factor for a child during beach play is 0.2, based on the estimated value for a child playing in wet soil (USEPA 2014). The recommended value for an adult while clam-digging is 0.6, based on the estimated value for an adult engaged in staged activity with intensive contact with wet soil (USEPA 2004c). The recommended value for an adult while net-fishing is 0.02, based on the estimated value for an adult groundskeeper (USEPA 2004c).

#### E.2.2.7 Dermal Absorption Fraction

The dermal absorption fraction can be estimated using the following defaults (WAC 173-340-745, Equation 745-5):

- 0.01 for inorganic hazardous substances
- 0.0005 for volatile organic compounds with vapor pressure ≥ benzene
- 0.03 for volatile organic compounds with vapor pressure < benzene and for mixtures of dioxins/furans
- 0.1 for other organic hazardous substances

Alternatively, the dermal absorption fraction may be based on chemical-specific values where known, such as those listed in USEPA (2004c, Exhibit 3-4).

#### E.2.2.8 Averaging time

The averaging time is equal to the exposure duration for noncarcinogens (6 years for a child, 70 years for an adult). The averaging time is equal to 70 years for all carcinogens, regardless of the exposure duration.

## E.3 Ecological Risk Assessment

Ecological risks at a sediment site will generally be addressed through comparison of numeric chemical or biological benthic criteria (Chapter 8, Table 8-1) at all sites, by water quality criteria where appropriate, and through the higher trophic level screening process described in Chapter 9 for bioaccumulative chemicals. In most cases, site-specific risk-based concentrations that are protective of human health will also be protective of bioaccumulative risks to ecological receptors, because of the protective assumptions used to calculate human health risk-based concentrations. In addition, many risk-based sediment concentrations for higher trophic levels will fall below background concentrations, just as they do for human health. These issues are discussed in greater detail in Chapter 9.

As a result, there will be very few sites at which Ecology expects that site-specific ecological risk assessments will be required. As is true for human health, the SMS requires that benthic species and higher trophic level risks are considered (Chapters 8 and 9), but the rule does not require that a full ecological risk assessment be conducted. Because many MTCA/SMS sites are smaller than typical Superfund sites, they may comprise a small percentage of an organism's home range. As a result, it would be difficult to determine the contribution of that individual site to the ecological risk of the whole region. Therefore, the simpler screening process provided in Chapter 9 can be used at most sites to ensure that sediment cleanup levels for bioaccumulative chemicals are protective of both human health and ecological receptors.

In a few circumstances, an ecological risk assessment may be appropriate to determine whether site-specific criteria need to be developed for particular receptors and/or chemicals. These circumstances will generally be identified through the screening process described in Chapter 9, but could include one or more of the following:

- The site is large enough that it encompasses an entire bay, river system, lake, or other area, and therefore could reasonably be considered to substantially impact much of the home range of one or more higher trophic levels.

- CoPCs are present at the site that are more toxic to ecological receptors than to humans <u>and</u> ecological risk-based sediment concentrations are expected to be above background sediment concentrations.

- Ecological receptors are present at the site that are unique, ESA-listed, or otherwise of special interest or concern, particularly when toxicity benchmarks in tissue or sediment are not immediately available.

Any of the above circumstances could warrant a closer evaluation of ecological risk than a simple screening process would provide. However, such an evaluation should be focused on the particular chemicals and receptors of interest to streamline the ecological risk assessment. It should also avoid complex evaluations for chemicals that are less toxic to wildlife than to human health, or for which risk-based concentrations are likely to fall below background. In addition, literature investigations and/or field work to assess these specific risks should be aimed at supporting derivation of a protective sediment cleanup level for the site.

## E.3.1 Scope of the ecological risk assessment

As noted above, the scope of the ecological risk assessment should focus on specific chemicals and/or receptors identified by the screening process in Chapter 9. Any chemicals or receptors for which existing values are protective do not need to be included (such as benthic standards, water quality standards, or human health risk-based standards). In addition, the option to default to

background sediment concentrations is always available for simpler sites and/or when ecological risk-based sediment concentrations would likely fall below background.

The scope of the risk assessment should be based on the CSM developed in Chapter 3, and should identify specific data gaps that need to be filled to establish protective sediment standards. Questions to ask might include:

- Could PAH concentrations in intertidal sediment be contributing to increased mortality of herring eggs in a large Puget Sound embayment that is important for herring spawning?
- What coverage or depth of wood waste can kelp beds tolerate?
- Are species present in the benthic community at the site that are particularly sensitive to TBT, and if so, what sediment standards would be appropriate?
- What concentration of copper in sediment corresponds to adverse effects on growth, mortality, or reproduction of important shellfish resources at the site?
- What sediment concentration of DDT would be protective of eggshell thinning in piscivorous birds known to nest near the site?

These questions may be designed to: a) determine whether there is a risk that requires sediment cleanup levels be established; b) provide data that can be used to determine an appropriately protective sediment cleanup level; and/or c) design protective cleanup alternatives.

## E.3.2 Ecological risk assessment approach

Risk assessments to fill the types of data gaps described above will typically be very site-specific, and no single approach will fit all cases. However, they may include tasks such as:

- Literature reviews to identify protective tissue and/or sediment concentrations for the specific receptor or similar receptors.
- Specialized toxicity, bioaccumulation, porewater, or other field or laboratory tests to assess bioavailability, site-specific risks, and calculate protective tissue or sediment concentrations.
- Biological surveys to identify the presence or absence of specific resources of interest with respect to habitat features and/or chemical contamination at the site.

General considerations include:

- Focusing on community-level effects for benthic and plant communities, population-level effects for higher trophic level non-listed species, and individual-level effects for ESA-listed species.

- For most species, the assessment should focus on endpoints such as growth, mortality, and reproduction, rather than sublethal or biomarker endpoints that are not clearly related to population- or community-level effects. For ESA-listed species, sublethal effects may also be considered.

- Use of NOAELs and overly conservative safety factors should be avoided in most cases, but may be considered for ESA-listed species when other approaches are not available.

It should be noted that ecological risk assessment is in a state of flux, with newer scientific approaches such as curve-fitting of toxicological data preferred over NOAELs/LOAELs (Suter, 1996; Moore and Caux, 1997; Fox, 2008; Landis and Chapman, 2011). As a result of the changing science, much of the information in the current toxicology database may become difficult to interpret. Therefore, in this guidance, Ecology is not providing firm recommendations on specific approaches, except to emphasize that site-specific field or laboratory data should be gathered to fill specific data gaps when it is possible and when it is not excessively burdensome. Recent aquatic ecological risk assessments (typically conducted under Superfund, e.g., Lower Duwamish Waterway or Portland Harbor) may also be consulted for information that might be applicable for filling data gaps. While these ecological risk assessments are generally more complex and more comprehensive than will be required for state sites, certain assessment procedures or their results may be applicable. For example, it may be helpful to find that protective tissue or sediment concentrations were calculated for nearby geographic areas with similar ecological receptors and food webs.

*This page intentionally left blank.*

**Appendix E: Table E-1.** Recommended exposure parameters for calculating human health risks from consumption of fish and shellfish.

| Abbrev | Parameter Name | Units | Recommended Value |
|---|---|---|---|
| $CPF_o$ | Cancer potency factor (oral) | $(mg/kg \cdot day)^{-1}$ | Chemical-specific (see Section E.2.1.1) |
| $RfD_o$ | Reference dose (oral) | mg/kg·day | Chemical-specific (see Section E.2.1.1) |
| FCR | Fish consumption rate | g/day | To be established on a site-specific basis in consultation with affected tribes. For example, Ecology (2013b) includes rates for establishing the tribal adult RME scenario, including Suquamish, Tulalip, and Columbia River tribal FCRs. (see Section E.2.1.2) |
| EF | Exposure frequency | day/year | 365 |
| ED | Exposure duration | year | 70 (see Section E.2.1.5) |
| FDF | Fish diet fraction | unitless (≤1) | 1 Ecology policy, may be adjusted based on site-specific data (see Section E.2.1.3) |
| BW | Body weight | kg | 85 (Average tribal and general population adult body weight) (see Section E.2.1.4) |
| AT | Averaging time | days | 25,550 (70 year) – cancer<br>25,550 (70 year) – noncancer |

Fish consumption rates and body weights can be obtained from Ecology (2013b). See Appendix C of that document for fish/shellfish consumption rates and Appendix D for body weights.

**Appendix E: Table E-2.** Evaluation criteria Ecology will consider when reviewing and approving a new fish dietary survey to establish a fish consumption rate.

| Criteria | Description |
|---|---|
| Timing of interviews | To adequately capture fish consumption, a survey should include an appropriate timeframe that minimizes the effect of recall bias, yet captures dietary variations.[a] |
| Training of interviewers | Interviewers should be trained for the study protocol to avoid potential interviewer bias. Interviewers must adhere to the questionnaire wording and format and be culturally sensitive when interacting with the study participants. If possible, interviews should be conducted by members of the target population to avoid adverse impacts associated with cultural differences, language barriers, and participation refusals.[a] |
| Consideration of all fish species | The types of fish consumed can be highly variable depending on seasonal and geographic availability, market prices, and cultural preferences. Surveys should identify and record each type of fish consumed and any unique preparation methods.[a] |
| Identification of the source | If known, either the waterbody where the fish was caught or the purchase location (for example, grocery store or fish market) should be identified. To improve exposure assessment, both locally caught fish and store bought fish should be included in fish consumption rate estimates. This distinction allows the risk assessor to better account for regional and seasonal variations in fish consumption estimates.[b] |
| Random selection of participants, sample size, and statistical analysis | During the planning phase, statistical analysis helps identify the ideal sample size and how to randomly select participants. This analysis helps minimize bias and sampling error and ensures statistical rigor. After the data have been collected, sound descriptive statistical analysis should ensure that the data are presented accurately. The range of data should be presented with confidence intervals and appropriate distribution values. Weighting schemes should be clearly described in order to apply survey results to populations of interest. Statistical treatment of perceived outliers should be discussed. |
| Quality assurance and quality control | The study design should include appropriate quality assurance and quality controls in the planning and execution of the survey. For example, quality control measures would include checking questionnaires for completeness and proper entry of recorded responses, verifying correct data entry, and checking the manual coding operations and comparisons of results and error rates. This reduces bias and random error, improving accuracy.[c] |
| Accuracy and precision | The study design can affect the overall accuracy of the study. Accuracy can be split into five components: 1) reliability (the variability or repeatability of the response); 2) validity (the ability of the respondent to provide the correct answer); 3) measurement errors (which are associated with the interviewer, the respondent, the questionnaire, and the mode of data collection); 4) bias (the consistent overestimation or underestimation due to survey design and sample selection); and 5) random errors.[c] |

a, Ecology (1999). b, Ebert et al. (1994). c, USEPA (1998b)

**Appendix E: Table E-3.** Factors to consider when developing a site-specific RME scenario.

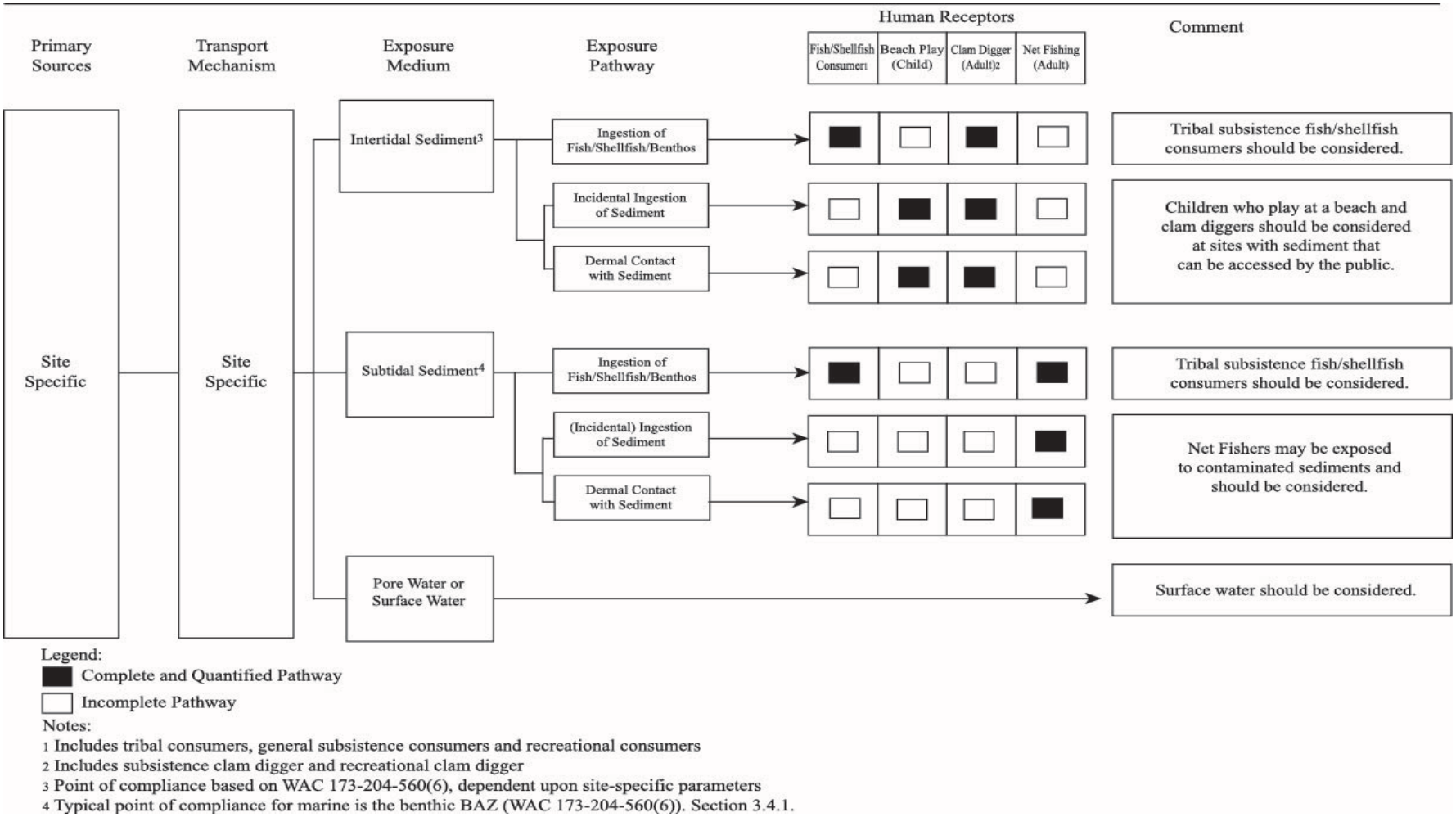
| Factors | Yes/No | Action |
|---|---|---|
| Are all potential receptors included in or protected by the default RME? | *Yes:* | No action is required. |
| | *No:* | Action is required.<br><br>If possible, obtain site-specific information regarding exposure areas and activity patterns for the human population (e.g., fish/shellfish consumption rates, body weights, fishing/harvesting frequencies, etc.) to determine whether Ecology's default RME scenario will be protective of this population or if a site-specific RME scenario needs to be developed. |
| Are all complete exposure pathways identified in the site-specific CSM included in the default RME? | *Yes:* | No action is required. |
| | *No:* | Action is required.<br><br>If there are additional exposure pathways or potential exposure pathways identified in the CSM, then these exposure pathways should be included in the site-specific RME scenario. This may require additional research and information to identify exposure parameters that are appropriate for evaluating the site-specific RME scenario. |
| Are the default RME exposure parameters (Tables E-1 and E-4) appropriate for evaluating the site-specific RME scenario? | *Yes:* | No action is required. |
| | *No:* | Action is required.<br><br>The exposure parameters should be modified as necessary to ensure that the RME scenario is protective of all exposed populations from the site. For example, if a) the site is located in a tribal U&A that is not represented in the default RME scenario, and b) scientific information is available that documents fish/shellfish consumption rates or other parameters (e.g., body weight) for that tribe, then c) site-specific exposure parameters should be used to calculate screening levels and cleanup standards. |

*This page intentionally left blank*

**Appendix E: Table E-4.** Recommended exposure parameters for calculating human health risks from direct contact with and ingestion of sediment.

| Abbrev | Parameter Name | Units | These parameters are provided for informational purposes only and represent Ecology policy only when stated. The Exposure Parameters presented in this table should be used at all SMS sites unless site-specific information indicates Exposure Parameters are inappropriate. | | |
|---|---|---|---|---|---|
| | | | **Beach Play Child** | **Subsistence Clam Digging Adult** | **Subsistence Net Fishing Adult** |
| *EF* | Exposure frequency | day/year | 41 may be adjusted based on site-specific data (see Section E.2.2.1) | 120 may be adjusted based on site-specific data (see Section E.2.2.1) | 119 may be adjusted based on site-specific data (see Section E.2.2.1) |
| *ED* | Exposure duration | year | 6<br>May be adjusted based on site-specific data (see Section E.2.2.2) | 70<br>May be adjusted based on site-specific data (see Section E.2.2.2) | |
| *IR* | Ingestion rate | mg/day | 200<br>(USEPA 2014) | 100<br>(USEPA 2014) | 50<br>(see Section E.2.2.3) |
| *AB* | Gastrointestinal absorption fraction (soil) | unitless | Default is 1, or 0.6 for dioxins/furans[a]<br>(see WAC 173-340-745, Equation 745-5) | | |
| $CPF_o$ | Cancer potency factor (oral) | $(mg/kg \cdot day)^{-1}$ | Chemical-specific (see Section E.2.1.1) | | |
| $RfD_o$ | Reference dose (oral) | mg/kg·day | Chemical-specific (see Section E.2.1.1) | | |
| $CPF_d$ | Cancer potency factor (dermal) | $(mg/kg \cdot day)^{-1}$ | Chemical-specific (see Section E.2.2.4) | | |
| $RfD_d$ | Reference dose (dermal) | mg/kg·day | Chemical-specific (see Section E.2.2.4) | | |
| *SA* | Dermal surface area | $cm^2$ | 2,378<br>(see Section E.2.2.5) | 3,212<br>(see Section E.2.2.5) | |
| *AF* | Sediment-to-skin adherence factor | $mg/cm^2 \cdot day$ | 0.2<br>(see Section E.2.2.6) | 0.6<br>(see Section E.2.2.6) | 0.02<br>(see Section E.2.2.6) |
| *ABS* | Dermal absorption fraction | unitless | Chemical-specific (see Section E.2.2.7) | | |
| *BW* | Body weight | kg | 15<br>(see Section E.2.1.4) | 75<br>(see Section E.2.1.4) | |
| *AT* | Averaging time | day | 2190 (6 year) – noncancer<br>25,550 (70 year) - cancer | 25,550 (70 year) – noncancer<br>25,550 (70 year) – cancer | |

a, When the MTCA Science Advisory Board reviewed this value for dioxins/furans, it applied only to carcinogenic congeners. However, subsequent research suggests that it may also be applicable to noncarcinogenic congeners.




**Appendix E: Figure E-1.** Recommended default RME for evaluating human health risk at sediment cleanup sites.

# Appendix F
# Statistics for Addressing Non-Detects and Evaluating Compliance

This appendix provides more detail on recommendations for addressing non-detects (NDs) when working with remedial investigation (RI) data (Chapter 6) and for using stratified random sampling for evaluating compliance with cleanup standards (Chapter 13). Information on a variety of statistical approaches is provided, even though not all of these statistical approaches are currently required under this guidance.

## F.1 Statistical Methods for Addressing NDs

Non-detects in an environmental dataset represent uncertain values where only the upper bound of the concentrations are known. These are referred to as censored data points. Statistical methods should be used that utilize all the important information in the data, without fabricating patterns that are not actually present. Generally speaking, substitution methods are not a recommended option for dealing with NDs. The purpose of this section is to summarize the best alternative methods for dealing with NDs in the following situations:

- Calculating group sums (e.g., TEQs) for individual samples (Section F.1.1).
- Calculating Kaplan-Meier based TEQ sums using available software tools (Section F.1.2)
- Graphing datasets (Section F.1.3).
- Calculating summary statistics for a dataset (Section F.1.4).

The information in this appendix closely follows Helsel (2005, 2012) and US EPA recommendations as implemented in ProUCL version 5.0 (US EPA 2013). This appendix is a summary of the tools available, and provides brief and simpler explanations of the Helsel and EPA approaches. Details for implementing the approaches can be found elsewhere, e.g., Helsel's textbook (First Edition, 2005, and Second Edition, 2012) and the ProUCL Technical Guide (US EPA 2013).

## F.1.1 Calculating group sums for individual samples

In the situation where group sums of congeners (e.g., total PCBs) or weighted congeners (e.g., toxic equivalents or TEQs) are needed, what is the best way to deal with values below detection limits (DL)? NDs represent uncertain chemical concentrations and the true values could be anywhere from 0 to the DL (or whatever reporting limit is used). Dealing with concentrations that are between the DL and the Practical Quantitation Limit (PQL) is not addressed here, although these data could be analyzed with the Turnbull estimator (a generalization of the Kaplan-Meier (KM) procedure which allows for a non-zero lower bound for the interval in which the true value falls). The Turnbull estimator is available in R, Minitab, JMP, and SAS. It is currently not available in ProUCL (version 5.0).

To calculate sums under MTCA and Ecology policy for soil[1], substitutions of 0, one-half DL, and the full DL have been used for NDs. Although useful for producing minimum-maximum bounds for the true value, substitution at 0 and full DL introduce extreme low and high bias to the sum, respectively. Substitution using one-half the DL introduces uncertainty, and produces variable bias in estimates of the mean depending on the percentage of NDs and skewness in the distribution (Hewett and Ganser 2007). Under certain scenarios, substitution at one-half DL can produce fairly unbiased and stable estimates of the mean, whereas bias in the KM estimate is always positive (Hewett and Ganser 2007). In limited comparison studies, estimates of the mean using substitution at one-half DL have been shown to be very similar to estimates of the mean using KM. However, where the NDs fall in the distribution of reported concentrations and detection limits is relevant to the reliability of the method, as is the number of distinct DLs.

Detection limits that are high relative to the observed range of detected values have more uncertainty than detection limits that are below the observed range of detected values. Consider a value reported as a non-detect at <10. The true concentration for this data point is somewhere between 0 and 10. If all the other detected values range from 10 to 100, then the true value is likely below all of the detected observations, and how this ND is treated has very little influence on the sum. However, if all the other detected values range from 1 to 9, then this ND provides very little information in the context of the rest of the dataset, i.e., only that the value is not detected at a concentration greater than the rest of the data. Using substitution for this uncertain data point will have a lot of influence on the sum, and would have even more influence if the detection limit was 50, even though this higher detection limit doesn't contain any more information. In general, higher ranked values that are not detected do not meet the same quality control standards as the rest of the data and probably should be ignored. However, ignoring high

[1] Source: Ecology memo "Evaluating the Toxicity and Assessing the Carcinogenic Risk of Environmental Mixtures Using Toxicity Equivalency Factors." Can be downloaded at https://fortress.wa.gov/ecy/clarc/FocusSheets/tef.pdf

individual TEQs may not be an acceptable option when estimating total concentrations for risk calculations.

For a given set of data, the mean is equal to the sum divided by a constant (n = the number of observations). When estimating sums of (weighted or unweighted) congeners within individual samples, we cannot use some of the other common methods for estimating means for datasets with NDs (i.e., Maximum Likelihood Estimates [MLE] or Regression on Order Statistics [ROS]). These methods make the assumption that the reported concentrations are independent, identically distributed (i.i.d.) observations from the same population, which is a situation that clearly does not apply to observations from different congener populations within a single sample.

Starting from the idea that the mean is identical to the sum, just scaled differently, Helsel (2010) proposed the use of the KM method to first estimate the mean concentration across congeners within a sample, and then multiply by the number of congeners to calculate the sum. The approach is completely distribution-free (therefore appropriate for the non-i.i.d data of individual TEQs within a sample), based only on observed percentiles, and in some situations can provide a relatively unbiased estimate of the sum. However, the following limitations regarding the KM method should be noted:

- When the lowest detection limit for a non-detect is lower than all detected values (as is often the case), the KM estimate will be biased high. Efron's bias correction should always be used, which treats the lowest ranked value as detected even if it was reported as ND. This modified KM estimator of the mean may still be biased high, but less so.

- The KM sum is known to be biased high when the data are skewed. Zhong and Hess (2009) found that the bias of the KM mean estimate increases with the percentage of NDs, with skewed datasets more affected than other distributions such as the normal distribution. They also found that most distributions had a KM estimate of the mean that was relatively unbiased until about 60% of the observations were NDs. Their simulations used random censoring, which allowed higher values to be NDs at the same rate as lower values. This may be a more realistic scenario for a set of weighted congener TEQs than it is for reported congener concentrations.

- When the highest DL is greater than the highest detected value (a situation that can occur often with individual TEQs at background concentrations), the highest ND provides no information so it is ignored in the KM estimate. For risk calculations, it may not be acceptable to omit this high ND data point, as this may underestimate the true TEQ. The highest TEQ value should always be treated as uncensored in the KM TEQ calculation, and the resultant TEQ qualified with a "less-than" value (L-qualified) if the original value was based on a non-detect. This value would then be treated as a censored value in the calculation of population summary statistics.

- The KM method is not recommended when NDs are greater than 50% (Helsel, 2012) because KM does not provide an estimate of the median. When much more than half the data are uncertain, it is difficult to accurately generate a central estimate of the distribution. With a set of non-i.i.d. data such as individual TEQs within a sample that contain a substantial proportion of NDs (> 50% of the congeners are censored), there is no method that will accurately estimate the sum. The KM method can nearly always provide an estimate, though sometimes with a strong positive bias (Hewett and Ganser, 2007). If the percentage of censored congeners within a sample exceeds 50%, the KM TEQ value should be calculated (using the substitutions specified in the previous bullets) and qualified with an "L," followed by the number of censored congeners: "L*". For example, for dioxin/furan TEQ, if 12 of the 17 congeners were non-detected, the detection frequency is 29% (less than 50%) so the KM TEQ would be calculated and qualified with L12. This value would then be treated as a censored value in the calculation of population summary statistics.

- When all the NDs have the same DL, the KM estimate is equivalent to using substitution at the DL for the NDs. This value should be qualified with an "Lmax" qualifier, and treated as a censored value in the calculation of population summary statistics.

- "L" and "L*" qualified TEQ values represent upper bounds, and as such should be treated as censored in any distributional assessments when calculating summary statistics across samples.

- The "L" qualifier means the value is less than the reported result and the reported result may be biased high.

- The "L*" qualifier means the value is likely less than the reported result, the reported result may be biased high, the sum is based on a KM estimate, and more than 50% of the congeners included in the sum were below detection.

- The "Lmax" qualifier means the values is less than the reported result, and this is an absolute upper bound involving substitution at the detection limit.

- These three separate qualifiers are all biased high, but the bias increases as follows: "L" < "L*" < "Lmax". These qualifiers should be detailed in the data report. However, using an "L" qualifier to replace the "L*" and "Lmax" qualifiers for all EIM submitted data will suffice.

The EPA is currently addressing some of these specific questions regarding the best methods for calculating group sums when NDs are present. At this time, an EPA policy has not been finalized on the preferred way to address non-detected congeners in TEQ calculations. Since censored values represent uncertainty, it is important to understand how this uncertainty may affect

important decisions. EPA provides information and tools (i.e., Excel spreadsheets with macros for calculating TEQ sums and performing sensitivity analyses) on their website[2]. For now, Ecology recommends the following approach to address non-detected congeners when calculating group sums:

- If the highest ND exceeds all the detected values, substitute the DL for this ND and treat it as a detected value in estimating the KM sum. An "L" qualifier should be assigned to the TEQ to indicate this is an upper bound estimate of the total. This qualifier may be over-ridden by the qualifier described in the next bullet.

- For all censoring levels, calculate a KM sum with the knowledge that there is a positive bias that increases with the percentage of NDs. Utilizing Efron's bias correction will reduce the positive bias somewhat, although will not remove it entirely. For censoring levels exceeding 50%, the KM sum should be qualified to indicate there is a positive bias, and could include the number of censored congeners in the sample (e.g., a dioxin/furan TEQ with 12 of the 17 congeners censored would have the KM estimate qualified with "L12").

- If any of the upper bound TEQ sums (with qualifiers described in the previous two bullets) are in a range of concern, then reanalysis of those samples using lower detection limits is strongly recommended.

- If the KM method for estimating the sum is too burdensome, substitution at one-half the DL may be used as a simple alternative, with the knowledge that the generated sums are estimates with unknown bias and precision. The values should be qualified appropriately as estimates with a "K" qualifier to indicate the variable accuracy of the estimated sums. In addition, these estimates should be bounded by reporting sums using substitution at zero and at the full DL.

### F.1.2 Calculating Kaplan-Meier-based TEQ sums using available software tools

This section provides supplementary information for summing TEQs when non-detected congeners are present (Chapter 6). Two examples are provided of how the K-M method may be used to sum dioxin TEQs using 1) EPA's Excel TEQ calculator and 2) R which is free software for statistical computing and graphics (R Core team 2014) using the *cenfit()* function in the NADA package (Lee 2013).

[2] http://www.epa.gov/superfund/health/contaminants/dioxin/pdfs/About_the_TEQ_Calculators.pdf

The EPA calculator has not been fully tested by Ecology, but preliminary testing indicates the user may require some knowledge about Excel macros and possibly visual basic to make the calculator fully functional in the local computing platform. Additionally, modification to the congener qualifiers is required to implement the recommended correction when the highest TEC is based on a non-detected congener and final qualifiers of the TEQs must be manually assigned. This manual correction to the data is a little more time-consuming and hands-on, but the user should have a better understanding of the data and how the presence of non-detects affects the estimated TEQs.

For users familiar with the R software, the R script provided below should be fully functional. It is advantageous because there are no practical sample size limitations; all bias corrections, qualifiers, and rounding are provided by the script; and the results output to a CSV (comma delimited file). For users not familiar with R, this statistical software can be difficult, but there are many web tools available to learn more.

#### F.1.2.1 EPA's Excel TEQ calculator

EPA's website[3] contains several links under their "Dioxin Tool Box" for calculating TEQs. There are two versions of the calculator: Basic and Advanced, with the Advanced calculator performing the KM sums included in the Basic version, along with a 'quasi-sensitivity' analysis. The fact sheet available on the website includes the following disclaimers about these calculators:

[3] http://www.epa.gov/superfund/health/contaminants/dioxin/dioxinsoil.html

Programmed Calculators for Dioxin Toxicity Equivalence (TEQ)

Disclaimers

The Dioxin Toxicity Equivalence (TEQ) Calculators (Calculators) do not set an EPA policy for a preferred way to handle non-detected or rejected congeners in TEQ calculations. The sensitivity analysis provided by the Advanced Calculator allows a decision-maker to observe whether an important decision is impacted by how non-detect or rejected data are handled. If different ways of handling non-detects or rejected data does change important decision outcomes, it may be worthwhile to resolve the decision uncertainty by having the sample(s) re-analyzed or recollected, perhaps using a modified analytical method that has lower detection capability or can avoid the problems that led to rejected data.

The TEQ Calculators assume that a user has experience in the following:

- Performing dioxin TEQ calculations,
- Using Excel spreadsheets,
- Understanding written laboratory reports for dioxin analysis,
- Understanding laboratory quality control (QC) that is part of dioxin analysis, and
- Extracting data from laboratory-provided spreadsheets or databases that contain sample data and QC results.

Both the Basic and Advanced spreadsheets include several tabs with instructions and information pertinent to the calculation, use, and interpretation of TEQs and KM estimates. The spreadsheets are macro driven, with the KM calculator based on the Excel spreadsheet KM calculator developed by Helsel at www.practicalstats.com. Cursory testing of these spreadsheets found that the macros are not fully plug-and-play, and some re-direction of the macros may be necessary to implement the macros.

The macro automatically employs Efron's bias correction when the lowest TEC is based on a non-detect congener; if the highest TEC is based on a non-detect congener, then no KM sum is estimated and an error message is issued. In this case, the user will have to manually remove the non-detect qualifier from the highest TEC for every sample affected, and re-run the macro. The "L" qualifier, and the "L*" qualifiers assigned to TEQs in samples with more than 50% of the congeners not detected, must be manually assigned.

### F.1.2.2 Statistical Package, R

The R script for calculating K-M sums and assigning qualifiers is presented below. Any line preceded by # represents a comment. This script was developed using NADA version 1.5-6, and R version 3.1.1 (2014-07-10).

```
# Example Code Using R to Calculate Kaplan-Meier (KM) Estimate of the Mean
```

```
# This example code provides no warranty or guarantees of any kind.

# a) Assign censored=F to the lowest tec values (Efron's bias correction)
#    otherwise the KM calculation simply ignores this lowest value.

# b) Assign censored=FALSE to the highest TEC value, otherwise the KM
#    calculation ignores this value. In the case of TEQ calcs, we can't
#    ignore this largest value since it is associated with the highest risk
#     concentration.  The final TEQ will be flagged with an
#    "L" if the highest value is an ND. This is an interval censored value, but will
#    likely be treated as a right censored value.

# c) If detection frequency of congeners within a sample is < 50%, values
#    will be flagged with "L*" qualifiers, and treated as censored in analysis
#    of the TEQs. The 'x' value represents the number of censored congeners.

## IMPORTANT NOTES ##
     # The script has been developed to evaluate specifically formatted data
     # See the example file for how to build an appropriate CSV file to
     # work with this script.

###### load libraries:
          library(NADA)

###### dataframe:
#  import data from a CSV (comma delimited) file type, saved from Excel.
DataForTEQs <- read.csv(file= "datafile.csv",  header=TRUE, sep= ",")
names(DataForTEQs)
 [1] "group"   "chem"    "TEF"     "SAMP.01" "Q"       "SAMP.02" "Q.1"
 [8] "SAMP.03" "Q.2"     "SAMP.04" "Q.3"     "SAMP.05" "Q.4"     "SAMP.06"
[15] "Q.5"     "SAMP.07" "Q.6"     "SAMP.08" "Q.7"     "SAMP.09" "Q.8"
[22] "SAMP.10" "Q.9"     "SAMP.11" "Q.10"    "SAMP.12" "Q.11"    "SAMP.13"
[29] "Q.12"    "SAMP.14" "Q.13"    "SAMP.15" "Q.14"    "SAMP.16" "Q.15"
[36] "SAMP.17" "Q.16"    "SAMP.18" "Q.17"    "SAMP.19" "Q.18"    "SAMP.20"
[43] "Q.19"    "SAMP.20.D" "Q.20"    "SAMP.21" "Q.21"    "SAMP.22" "Q.22"
[50] "SAMP.23" "Q.23"    "SAMP.24" "Q.24"    "SAMP.24.D" "Q.25"    "SAMP.25"
[57] "Q.26"    "SAMP.26" "Q.27"    "SAMP.27" "Q.28"    "SAMP.28" "Q.29"
[64] "SAMP.29" "Q.30"    "SAMP.30" "Q.31"
```

A screenshot of what the data table looks like:

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | group | chem | TEF | SAMP.01 | Q | SAMP.02 | Q.1 | SAMP.03 | Q.3 | SAMP.04 | Q.4 | |
| 2 | cpah | Benzo(a)anthracene | 0.1 | 15 | J | 15.6 | | 26.9 | J | 15.5 | | |
| 3 | cpah | Chrysene | 0.01 | 31.1 | J | 27.6 | | 41.4 | J | 28.5 | | |
| 4 | cpah | Benzo(b)fluoranthene | 0.1 | 16.2 | J | 17.3 | | 29.2 | J | 21.2 | | |
| 5 | cpah | Benzo(k)fluoranthene | 0.1 | 7.25 | J | 7.5 | | 12.1 | J | 6.9 | | |
| 6 | cpah | Total Benzofluoranthenes | | 31.7 | J | 33.3 | | 54.6 | J | 35.7 | | |
| 7 | cpah | Benzo(a)pyrene | 1 | 15.5 | J | 14.9 | | 28 | J | 13.4 | | |
| 8 | cpah | Indeno(1,2,3-cd)pyrene | 0.1 | 9.39 | J | 11.8 | | 20.5 | J | 12.5 | | |
| 9 | cpah | Dibenz(a,h)anthracene | 0.1 | 1.73 | UJ | 1.74 | U | 3.46 | UJ | 1.76 | U | |
| 10 | dioxin | 2,3,7,8-TCDD | 1 | 1.1 | | 0.866 | | 1.07 | | 0.334 | | |
| 11 | dioxin | 1,2,3,7,8-PECDD | 1 | 2.94 | | 2.13 | | 2.28 | J | 0.958 | J | |
| 12 | dioxin | 1,2,3,4,7,8-HXCDD | 0.1 | 12.2 | | 8.5 | | 9.59 | | 3.17 | | |
| 13 | dioxin | 1,2,3,6,7,8-HXCDD | 0.1 | 17.6 | | 12.4 | | 13 | | 5.67 | | |
| 14 | dioxin | 1,2,3,7,8,9-HXCDD | 0.1 | 16.1 | | 11.4 | | 9.94 | | 5.01 | | |
| 15 | dioxin | 1,2,3,4,6,7,8-HPCDD | 0.01 | 188 | | 160 | | 153 | | 74.8 | | |
| 16 | dioxin | OCDD | 0.0003 | 892 | | 924 | | 770 | | 461 | | |
| 17 | dioxin | 2,3,7,8-TCDF | 0.1 | 16.3 | | 13.8 | | 17.6 | | 4.86 | | |

```
iter.value <- length(names(DataForTEQs)) # adjusts loops to match data length
# Check for numerical format of concentration columns:
for (i in seq(from=4, to=iter.value, by=2))
    {print(paste(as.character(i), is.numeric(DataForTEQs[,i])))}
    # All values should print as TRUE if data is correctly formatted

## TEQ SUM CALCULATION ##
    # The loop calculates KM estimate of the sum, regardless of the level of non-detects,
    # and assigns qualifiers. Also calculates the sum using substitution at 3 levels:
    # 0DL, halfDL, and fullDL.

#Assign sample names to my.samps, calculate length of the vector
my.samps <- names(DataForTEQs)[seq(from=4, to=iter.value, by=2)]
msl <- length(my.samps)

# NOTE: SPECIAL HANDLING FOR FIELD DUPLICATES #
# Calculate TEQs on individual samples, then average the TEQs
# to get one value for these locations.

levels(DataForTEQs$group)
    #note here levels must be present in the CSV file
  [1] "cpah"   "dioxin" "pcbs"

samp.KMsums.summ <- data.frame(sampleid = (rep(my.samps, 3)),
```

```
            group = c(rep("cpah", msl),  rep("dioxin", msl), rep("pcbs", msl)),
            n.cong = rep(NA, 3*msl),
            n.cens = rep(NA, 3*msl),
            teq.km = rep(NA, 3*msl),
            teq.0dl = rep(NA, 3*msl),
            teq.5dl = rep(NA, 3*msl),
            teq.1dl = rep(NA, 3*msl),
            lowND.flag = rep("", 3*msl),
            hiND.flag = rep("", 3*msl)
)

# the flag columns are factors and need to change them to character:
samp.KMsums.summ$sampleid <- as.character(rep(my.samps, 3))
samp.KMsums.summ$lowND.flag <- as.character(rep(" ", 3*msl))
samp.KMsums.summ$hiND.flag <- as.character(rep(" ", 3*msl))

for (i in 1:nrow(samp.KMsums.summ)) {

# grab group:
    which.grp <- as.character(samp.KMsums.summ$group[i])

    # grab data for this group and the ith sample:
    foo.dat1 <- data.frame(values=DataForTEQs[DataForTEQs$group == which.grp,
                                              as.character(samp.KMsums.summ$sampleid[i])])

    foo.dat1$tec <- foo.dat1[,1]*DataForTEQs$TEF[DataForTEQs$group == which.grp]
    which.col <- grep(samp.KMsums.summ$sampleid[i], names(DataForTEQs))[1] + 1
    foo.det1 <- as.character(DataForTEQs[DataForTEQs$group == which.grp, which.col])

    # get rid of rows without TECs:
    foo.det1 <- foo.det1[!is.na(foo.dat1$tec)]

    # all qualifiers that begin with a “U” or “K” are treated as censored:
    foo.cens1 <- ifelse(substring(foo.det1,1,1) == "U" |
                        substring(foo.det1,1,1) == "K", TRUE, FALSE)

    if(nrow(foo.dat1) == 0) {next} #skip samples with no data for a particular group.

    # Calculate Summary Statistics:
    samp.KMsums.summ$n.cong[i] <- nrow(foo.dat1)
    samp.KMsums.summ$n.cens[i] <- sum(foo.cens1)
```

```
    samp.KMsums.summ$teq.0dl[i] <- sum(foo.dat1$tec[foo.cens1==FALSE])
    samp.KMsums.summ$teq.5dl[i] <- sum(foo.dat1$tec[foo.cens1==FALSE]) +
                                    sum(0.5*foo.dat1$tec[foo.cens1==TRUE])
    samp.KMsums.summ$teq.1dl[i] <- sum(foo.dat1$tec)

    # identify if the highest or lowest value is censored, and assign flag:
    # Lowest ND
    samp.KMsums.summ$lowND.flag[i] <- ifelse(foo.cens1[foo.dat1$tec ==
            min(foo.dat1$tec)] == TRUE, "lowestND", "ok")

    # Highest ND
    samp.KMsums.summ$hiND.flag[i] <- ifelse(foo.cens1[foo.dat1$tec ==
            max(foo.dat1$tec)] == TRUE, "highestND", "ok")

    # Assign censored=FALSE to the lowest tec values (Efron's bias correction)
    # otherwise, KM calculation simply ignores this lowest value:
    foo.cens1[foo.dat1$tec == min(foo.dat1$tec)] <- FALSE

    # assign censored=FALSE to the highest tec value, otherwise the
    # KM calculation ignores this value.
    foo.cens1[foo.dat1$tec == max(foo.dat1$tec)] <- FALSE

    # keep track of progress:
    print(i)

    # calculate the KM mean using cenfit:
    mykm1 <- cenfit(foo.dat1$tec, censored=as.logical(foo.cens1))
    samp.KMsums.summ$teq.km[i] <- mean(mykm1)[1]*nrow(foo.dat1)
}

# Assign Final Qualifiers:
samp.KMsums.summ$final.qual <- ""
samp.KMsums.summ$final.qual[samp.KMsums.summ$hiND.flag == "highestND"] <- "L"
foo <- samp.KMsums.summ$n.cens/samp.KMsums.summ$n.cong
samp.KMsums.summ$final.qual[!is.na(foo) & foo > 0.5] <-
    paste("L", as.character(samp.KMsums.summ$n.cens[!is.na(foo) & foo > 0.5]), sep = "")

# Round to 2 Significant Figures:
foo <- 2-(floor(log10(samp.KMsums.summ$teq.km))+1)  #number of decimal places
```

```
samp.KMsums.summ$teq.km.2sigfigs <- round(samp.KMsums.summ$teq.km, foo)
    #rounded value

# Write the output:
write.csv(samp.KMsums.summ, outfile)

# TEQ used in analyses is always from KM estimate. Qualify the TEQs as "less than"
# values when detection frequency is less than 50%, or highest TEC was based on a non-
# detect. Qualified samples are treated as censored in analysis of the TEQ
# dataset.
```

### F.1.3 Graphing and presenting datasets

Graphing the data is one of the first steps in evaluating a dataset and is an essential part of exploratory data analysis. Proper visualization of data is good way to direct investigations and summaries in the most useful and informative way. Several types of plots are available that have options for properly representing NDs, including:

- Boxplots. Boxplots illustrate the distribution (concentrations and skewness) of the data. Several boxplots placed side-by-side allow visual comparisons of these distributional attributes (e.g., site data and background data). The boxplot shows the 25$^{th}$, 50$^{th}$ (median), and 75$^{th}$ percentiles, along with limits based on the inter-quartile range (the magnitude difference between the 25$^{th}$ and 75$^{th}$ percentiles), range, and extreme values. When there are NDs present, different methods may be used to represent the calculable percentiles, the detected data, and DLs. These vary somewhat by software. At a minimum, the maximum DL should be shown as a horizontal line on the plot, and any features of the distribution that fall below this line should not be interpreted. Examples of boxplots generated in R are shown in Appendix F: Figure F-1. The boxplots generated in ProUCL show the value of the maximum DL, but otherwise compute summary statistics using substitution at the DL for NDs.

- Probability Plots or Quantile-Quantile (Q-Q) Plots. These plots are used to compare an empirical dataset to a specific theoretical distribution (e.g., normal, lognormal, or gamma distribution). The empirical data quantiles are plotted against the theorized quantiles and if the empirical data fit the theorized distribution, then the data points will fall along a straight line. When NDs are present, quantiles are calculated for the detected concentrations only, but these quantiles do consider the number of NDs below each detected concentration in determining the quantile (i.e., similar to KM methods). These plots are the basis for the Regression on Order Statistics (ROS) and robust Maximum Likelihood Estimation (MLE) approaches. The approaches a) fit a distribution for the detected data via the probability plots, and then b) estimate population or sample

parameters assuming the best-fit distribution for the detected values (see Section F.1.4). Appendix F: Figure F-2 and Figure F-3 show probability plots generated in R and ProUCL, respectively.

- Empirical Cumulative Distribution Function (ECDF) Plots. ECDF plots display the percentiles or cumulative probabilities for each observation in the dataset. They are shown as a step function, with a step up at each unique concentration. The stair-step display illustrates the discrete (i.e., non-continuous) nature of the plot and emphasizes sample size (smaller sample sizes have fewer steps). The formulas used to calculate the percentile plotting positions may vary between software applications. Since there is no one "right" way to calculate percentiles, it is important to be aware of how percentile estimates may vary from one software application to the next. For plotting positions shown in censored ECDF plots, percentiles are shown only for detected concentrations, but the number of NDs below each detected concentration is used in determining the percentile (i.e., using KM methods). These plots can facilitate comparisons between two or more distributions by overlaying the ECDFs for multiple datasets on the same plot. These plots allow you to interpret distributional characteristics: steeper curves have less variance; curves shifted to the right have higher concentrations; and specific percentiles can be compared (e.g., median or upper tails). Appendix F: Figure F-4 shows two ECDF plots generated in R.

  A survival function plot is just a mirror image of the ECDF plot, flipped side-to-side: the y-axis shows the percentiles or cumulative probabilities for each observation, but the x-axis shows the "survival time," which could be the "flipped" concentration data (see Kaplan-Meier description in Section F.1.5).

- Bivariate Scatterplots. Scatterplots provide graphical representations of correlation patterns in the data, without emphasizing point locations for the NDs. NDs are indicated by dashed lines that span the width of the interval in which the true value may lie (i.e., between zero and the DL). These plots are used for data interpretation and in support of censored correlations. Most software applications do not perform these effectively if both X and Y variables are censored. The current *cenxyplot()* function in the R NADA package only shows a censored display for one variable at a time (the y-variable). With knowledge of R plotting functions, plots showing censoring on both variables can be generated in R. Appendix F: Figure F-5 shows a censored XY scatterplot generated in R using *cenxyplot()* function.

## F.1.4 Calculating summary statistics for a distribution

The most appropriate method for the calculating summary statistics (e.g., means, medians, upper or lower percentiles, and standard deviations) will vary depending on the sample size and the proportion of censoring. Appendix F: Table F-1 is provided by Helsel (2005, Table 6.11) as a

rule-of-thumb for the recommended method in any situation. Note that these recommendations apply to independent samples collected from a single population. The question addressed in Section F.1.1 is a unique situation, and therefore the recommendations in this table would not apply.

A brief description of each approach is provided below. More detailed descriptions and background information can be found in many statistics books, as well as in USEPA (2013) and Helsel (2005, 2012).

- Kaplan-Meier (KM) estimation. KM is a non-parametric method borrowed from survival analysis. In survival analysis, the observations are "time to an event," and may often be right censored: the event occurred after the study ended, so all you know is that the "time to event" is greater than some maximum time *t*. For environmental data, we have the opposite situation in that the data are left censored: we have observations that are less than some detection limit, the DL. Left-censored data (e.g., environmental data) can be converted to right-censored data by "flipping," i.e., subtracting each observation from some number greater than the maximum concentration.

  With the right-censored data (or the flipped left censored data), percentiles for the detected concentrations are calculated by including the number of censored data below each detected concentration. This information can be plotted on a survival function plot. If the survival function plot is viewed as series of rectangles, the sum of these rectangles (the area under the curve) is the sum of each concentration weighted by the percentage of the dataset with that same concentration, which is the average. The median can easily be estimated from the plot (the concentration associated with a value of 0.5 on the y-axis), as can other percentiles. It must be kept in mind that the data shown on this plot have been flipped, so the calculated values need to be subtracted from the constant that was used to do the "flip" transformation. The standard error at each percentile can be calculated using Greenwood's formula (p. 74, Helsel 2012). Details of the KM calculation procedure applied to environmental data are described in detail in Helsel (2005, 2010, and 2012). The *cenfit()* function in the NADA package for R (Lee 2013) flips the data and provides KM estimates for environmental concentration data. Some additional things to keep in mind about KM estimates:

  - When the lowest DL is less than the all the detected values, there is an increase in the positive bias in the KM mean. This bias can be corrected using Efron's bias correction, which treats the lowest ranked value as detected. The resulting KM estimates are still biased high, but less so.

  - When the highest DL is greater than all the detected data, the KM procedure has a negative bias. This is produced because the maximum value is considered to have no reliable information for the purposes of estimating the survival function, and

so it is ignored in the calculation of the mean. This may rarely happen due to the nature of environmental concentration data (i.e., the highest values in the dataset tend to be detected, except possibly in the situation of calculating the sum of TECs), but in datasets with variable detection limits and generally low concentrations, it is possible. In this case, there is no reliable way to estimate the mean. Substitution at the DL can provide an upper bound on the mean, but this could introduce a substantial amount of positive bias. When the largest concentration is censored, another method that invokes some distributional assumptions is preferred, if the sample size and censoring level allows it.

- Maximum Likelihood Estimation (MLE). MLE requires an assumption that the observed data were derived from a particular parametric distribution (e.g., normal, log-normal, and gamma). The successful outcome of this method relies on an accurate assumption about the underlying distribution. If the assumed distribution is very different in shape than the true underlying distribution, then the parameter estimates can be inaccurate. This is particularly true if normality is assumed but the true distribution is highly skewed. The underlying distribution should be checked using probability plots for censored data (Section F.1.4), and is best applied with large sample sizes (n > 50).

  The Likelihood function is unique to each parametric distribution, and is defined as the probability of having observed the set of data, given some particular values for the population parameters (e.g., the mean and variance for a normal or lognormal distribution). The model parameters that produce values that most closely resemble the observed dataset are the MLEs. These are the parameters that maximize the Likelihood function. The Likelihood function for a set of parameters (μ, σ) given the observed data is calculated as the product of the individual probabilities that each independent data point would have come from that underlying distribution: L(μ, σ | data) = $\prod_{i=1}^{n} f(data_i | \mu, \sigma)$, where $f(data_i | \mu, \sigma)$ is the probability density function specific to the distribution. The probabilities for each independent data point can be calculated and multiplied together to estimate the total Likelihood for any parameter combination of (μ, σ). The (μ, σ) combination that maximizes the Likelihood function are the MLEs.

- Parametric ROS and Robust ROS. Parametric ROS also makes assumptions about the underlying distribution of the data. Regression on Order Statistics (ROS) refers to the regression lines shown in probability plots for data with NDs (Section F.1.3). The probability plots show the theoretical quantiles against the observed quantiles for the detected data only, where the probabilities associated with the observed detected data take into consideration the number of NDs below each detected concentration (similar to KM methods). The slope and intercept of the straight line fitted to the detected data in the probability plot provides parametric estimates of the standard deviation and mean of the underlying dataset, respectively. This is referred to as "parametric ROS." For

environmental concentration data, this method is generally not preferred over other parametric or robust methods for a number of reasons (see for example, appropriate sections in USEPA, 2013; Chapter 6 in Helsel, 2005, 2012).

Robust ROS uses the same regression line as above to impute or extrapolate values for the NDs based on their estimated probabilities. The estimated probabilities (or plotting positions) for the NDs are calculated using the proportion of samples detected above each stated detection limit. The procedure uses simple probability statements and the proportion of values in the dataset that meet or exceed each DL. The method used in ProUCL is described in some detail in Helsel (2005, 2012). The regression line fit to the quantiles for the detected data is then used to predict values for the NDs based on their estimated plotting positions. The combined set of observed detected values, and the predicted values for the NDs is treated as a complete dataset. Summary statistics can be estimated using standard equations for the mean and variance, or bootstrapping methods, for example.

Note that ProUCL allows the user to save imputed ROS values, but these predicted observations should not be used as if they were valid substitution values associated with any particular sample.

The ROS methods require enough detected data to provide confidence in the goodness-of-fit of the distribution and its parameters as derived from the probability plot. ProUCL guidance recommends a minimum of 10 detected concentrations to use this method. The probability plots should be examined to ensure that the detected data appear to be a good fit to the theorized distribution by noting a) how well all the data fall along the straight line in the plot, and b) that no outliers are present. Correlation coefficients for the fit of the detected data to the line can be used to assess the significance of the fit.

The validity of the Robust ROS approach is based on the assumption that the true concentrations of the censored values come from the same distribution as the detected concentrations. The magnitude of difference between the detected concentrations and the stated DLs should be considered. If there is a big jump in concentration, the distribution may be bi-modal or there may be more than one distribution present. In these situations, other methods (e.g., bootstrapping, or allowing for the possibility of multiple strata instead of a single population) might be better.

### F.1.5 Resources

These recommendations, the recommendations by Huston and Juarez-Colunga (2009), and the procedures in the latest version of ProUCL generally closely follow the work of Helsel (2005, 2012). The Huston and Juarez-Colunga (2009) report is available as a .pdf on the web, and can be used as an additional resource that expands on the summary information presented in this

appendix. Of particular value are the instructions these references provide for using R (R Development Core Team 2014), and the NADA package for R (Lee 2013) that facilitates censored data analysis. The ProUCL Technical Guide (USEPA 2013) is also available as a .pdf on the web, and provides alternative descriptions and theories for each of these procedures.

## F.2 Stratified Random Sampling in Compliance Monitoring

After cleanup, the concentrations throughout the site are expected to be similar and fairly homogeneous. However, there may be sub-areas of specific interest due to possible re-contamination or different exposure scenarios. Separate estimates of the mean for these individual sub-areas may be needed to determine compliance. In these cases, it may be appropriate to use a stratified random sample spatially balanced within each strata, and appropriately adapted to the circumstances of the site and each sub-area. In situations where there are no sub-areas of specific concern there would only be one "stratum," and the method would revert to the spatially balanced random sampling strategy described in Chapter 13.

Stratified random sampling is random sampling (e.g., random sampling using a grid, with one sample per grid) applied to discrete strata within the entire site. The strata are typically areas for which unique estimates are required (e.g., specific intertidal exposure areas), or areas that have different characteristics that may cause differences in mean level and variance (e.g., actively remediated areas near a former source). In the latter case, when the sub-area has a different mean and variance, the stratified random sample is more efficient (i.e., requires fewer samples) for estimating the overall mean estimate for the site. The stratified sampling approach is driven by the desire to have specified confidence that the concentrations in the smaller stratum are below clean-up levels, and similar confidence in the site-wide concentrations.

### F.2.1 Identify strata

In compliance monitoring, the entire area of interest will have been cleaned up to at or below a cleanup level, so the distribution of any given contaminant should be relatively homogeneous across the entire site. Individual strata may be identified based on general areas of interest due to levels of contamination prior to the clean-up, i.e., areas that had the highest contamination prior to clean-up and may be susceptible to re-contamination. Or, site-specific concerns regarding ecological or human health risks may result in sub-areas of the site that are identified as ecologically sensitive areas, or areas of higher exposure where separate estimates are needed. The strata boundaries should be drawn with the intent of delineating strata for which separate mean and variance estimates are desired, either for decision making or because of potentially different statistical properties.

Once the strata are defined, spatially balanced random sampling within strata is recommended to provide good spatial coverage within each stratum. The minimum sample size within a stratum

should be 10 samples to estimate parameters and evaluate distributions within strata. A higher sample size will yield a more precise estimate of the stratum mean, reducing false positives and false negatives (Appendix L). The sampling density may be adjusted based on the risk level associated with an individual strata (i.e., sampling density should be higher in areas of greater concern generating a larger sample size to reduce error rates).

## F.2.2 Allocate samples among strata

The best allocation of samples among strata is likely to be constrained by practical considerations of overall cost of the sampling effort, and the desire to have higher sampling density in higher risk strata. If possible, the allocation of samples among strata can be based on the desired properties of the overall estimator. To provide the most efficient estimate of the stratified mean, allocating samples proportional to strata standard deviation is desired (i.e., Neyman allocation; e.g., see Cochran 1963). For example, if there are two strata of equal size, and stratum A is expected to have a standard deviation two times the standard deviation in stratum B, then 2/3 of the total samples should be in stratum A and 1/3 in stratum B. More generally:

$$n_i = n\frac{A_i S_i}{\sum_{i=1}^{k} A_i S_i}$$

Variances are typically unknown prior to sampling, so calculation of the optimal allocation may not be achievable. However, general assumptions about the relative variance properties of the different strata can be made to allocate samples most appropriately. For example, a relative ratio of standard deviations in the two strata could be assumed based on the distribution of pre-cleanup concentrations.

## F.2.3 Estimate population parameters

The stratified sample mean concentration is an unbiased estimate of the site-wide population mean. It is estimated by the weighted mean of the strata mean concentrations, where the weights are the proportion of the total area within each stratum:

$$\bar{\bar{X}} = \sum_{i=1}^{k} w_i \bar{X}_i \qquad [1]$$

where:

$\bar{X}_i$ is the average concentration in stratum *i* (*i* = 1 to *k*),

$w_i = \frac{A_i}{A}$,

$A_i$ is the area of stratum *i*, and

A is the total area.

The sample variance of the stratified mean is:

$$\widehat{Var}(\bar{\bar{X}}) = \sum_{i=1}^{k} w_i^2 S_{\bar{X}_i}^2 \qquad [2]$$

where:

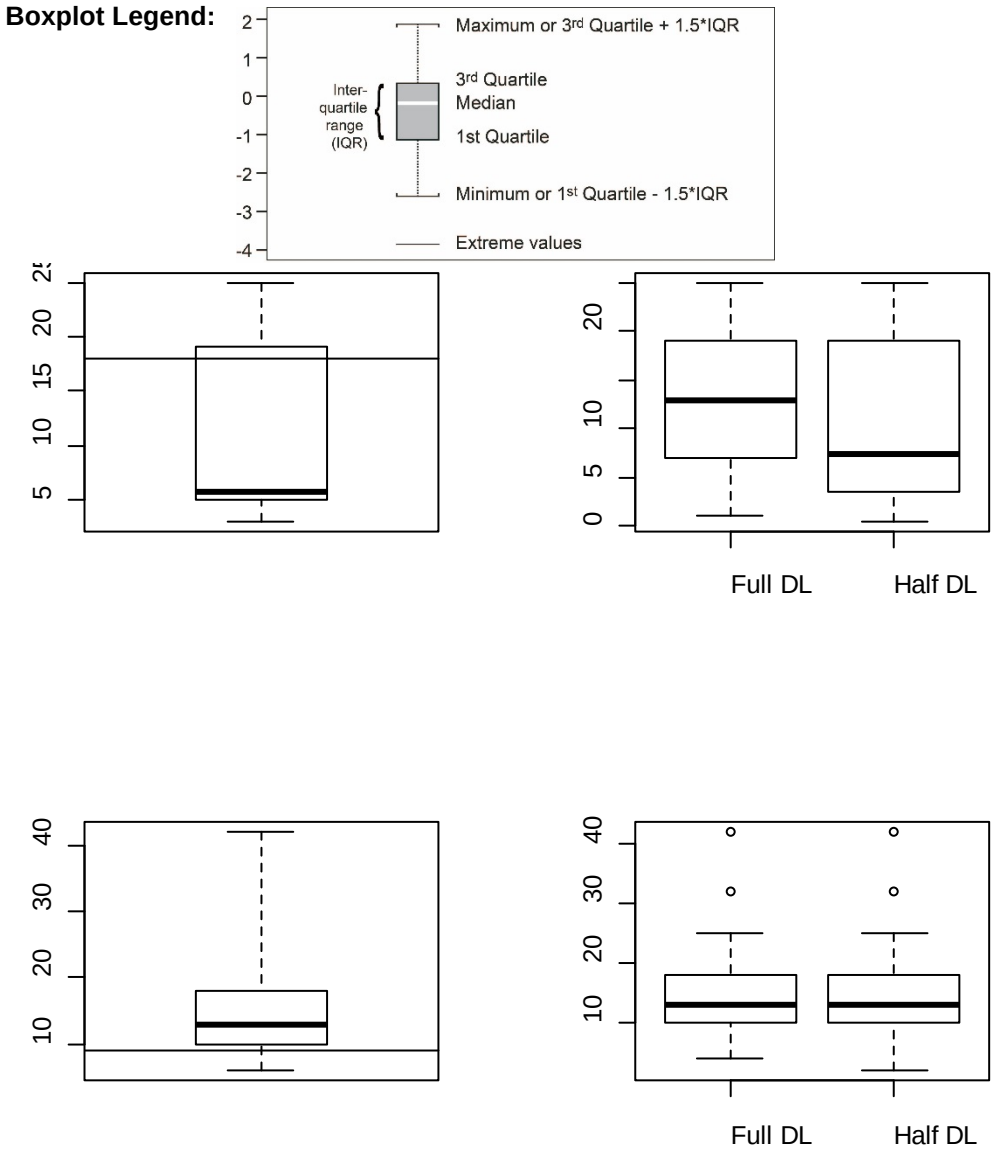
$s_{\bar{X}_i}^2 = \frac{s_i^2}{n_i}$,

$s_i^2$ is the variance estimate of the $n_i$ observations in stratum *i* (*i* = 1 to k), and

$n_i$ is the sample size in stratum *i*.

**Appendix F: Table F-1.** Recommended methods for estimating summary statistics (after Table 6-11, Helsel 2005).

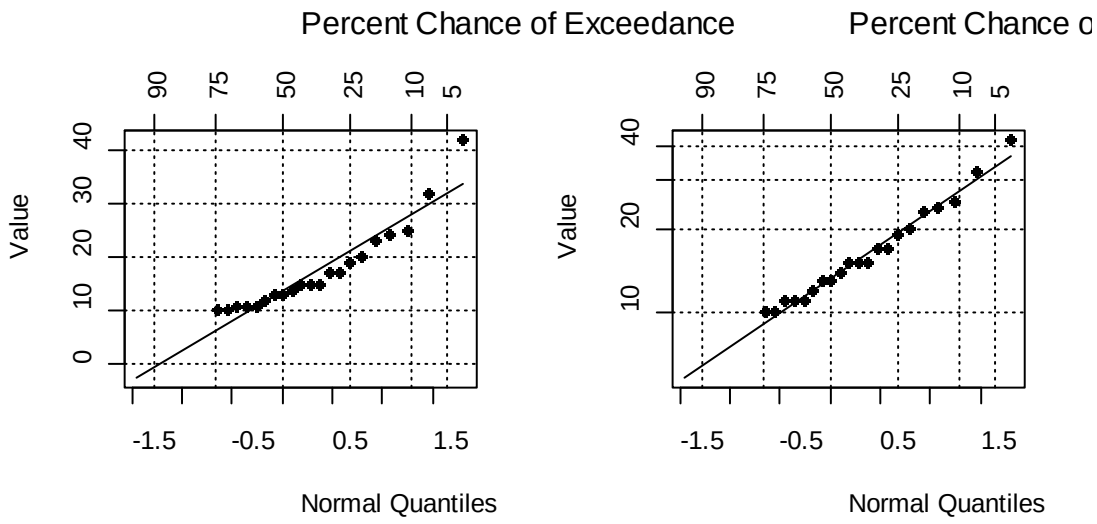
| Amount of Available Data | | |
|---|---|---|
| **Percent Censored** | **< 50 observations** | **> 50 observations** |
| < 50% NDs | Kaplan-Meier | Kaplan-Meier |
| 50 – 80% NDs | Robust MLE or ROS | MLE |
| > 80% NDs | Report only % above a meaningful threshold | May report high sample percentiles (90th, 95th) |




**Appendix F: Figure F-1.** Boxplots for two censored datasets.

The top row dataset has 25 observations: 13 censored data points with DLs ranging from 1 to 18, and 12 detected data points with concentrations ranging from 3 to 25. The bottom row dataset has 27 observations: 6 censored data points with DLs ranging from 4 to 9, and 21 detected data points with concentrations ranging from 10 to 42. Left plots show the distribution of the data with 1st, 2nd, and 3rd quartiles estimated using Kaplan-Meier for censored data; horizontal lines indicate the level of the highest detection limit. Right plots show the distribution of the data ignoring censoring, using two levels of substitution of DLs. Plots generated in R using *cenboxplot()* function (Left plots), and *boxplot()* function (Right plots).

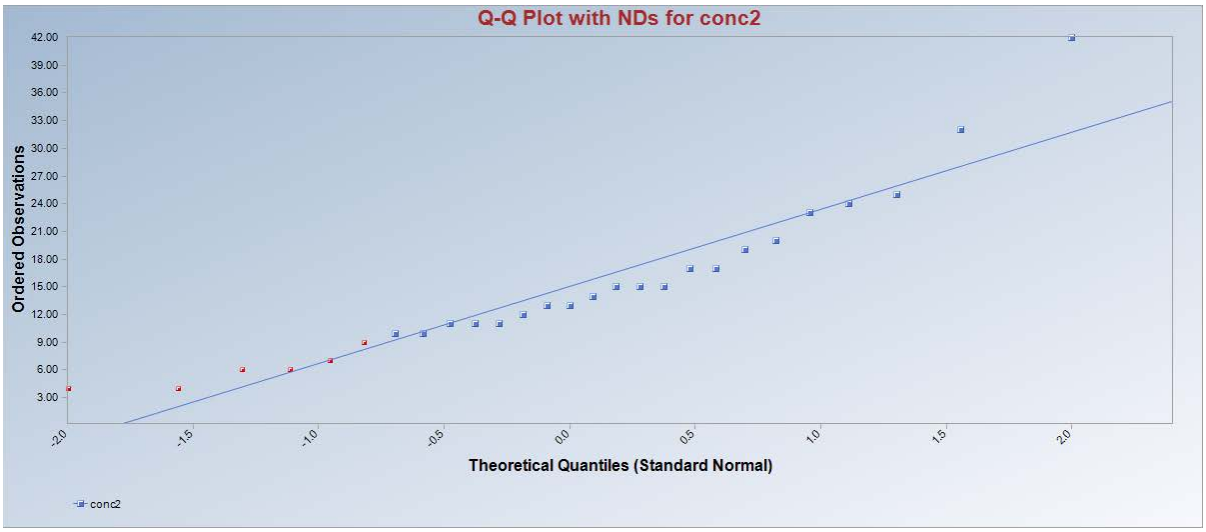
```
> par(mfrow=c(2,2))
> cenboxplot(obs=my.dat$conc, cen=my.dat$conc.cens, log=FALSE)
> boxplot(my.dat$conc, my.dat$conc.halfdl, names=c("Full DL", "Half DL"))
> cenboxplot(obs=my.dat$conc2, cen=my.dat$conc2.cens, log=FALSE)
> boxplot(my.dat$conc2, my.dat$conc2.halfdl, names=c("Full DL", "Half DL"))
```




**Appendix F: Figure F-2.** Probability (or Q-Q) plots for a censored dataset (the same data shown in the bottom row of boxplots in Figure F-1).

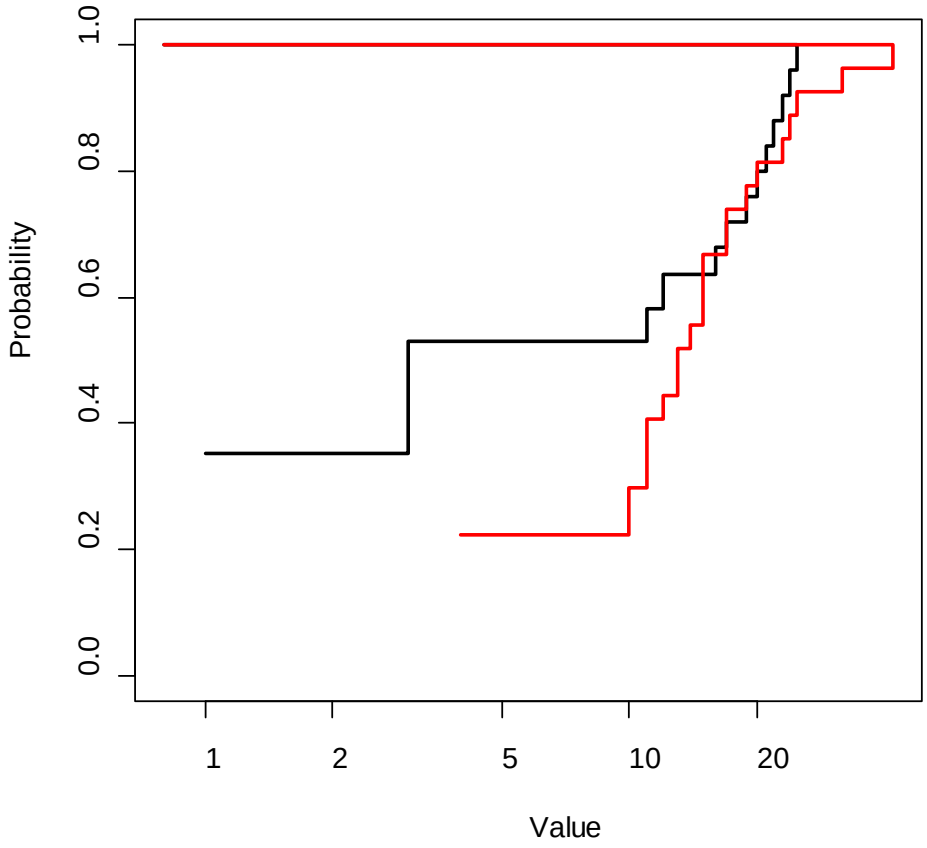
On the left the data are plotted against the Normal Quantiles; on the right the log of the data are plotted against the Normal Quantiles (notice the logarithmic scale on the y-axis of the plot on the right). The lognormal distribution fits the data better (the points are closer to the straight line). Censored data are <u>not</u> shown on the plot, but they <u>are</u> used to calculate the quantiles for the detected observations. The lowest detected observation has a quantile of 25%, corresponding to a percent chance of exceedance of 75$ (top axis). These plots were generated in R on ROS (regression-on-order statistics) objects.

```
> my.ros<- cenros(obs=my.dat$conc2, cen=my.dat$conc2.cens, forwardT=NULL)
                    # set forwardT=NULL to cancel the default log-transformation of the data
> plot(my.ros)
> my.lros <- cenros(obs=my.dat$conc2, cen=my.dat$conc2.cens)
> plot(my.lros)
```




**Appendix F: Figure F-3.** A normal Q-Q plot generated in ProUCL 4.1 under Graphs > Multi-QQ > With NDs.

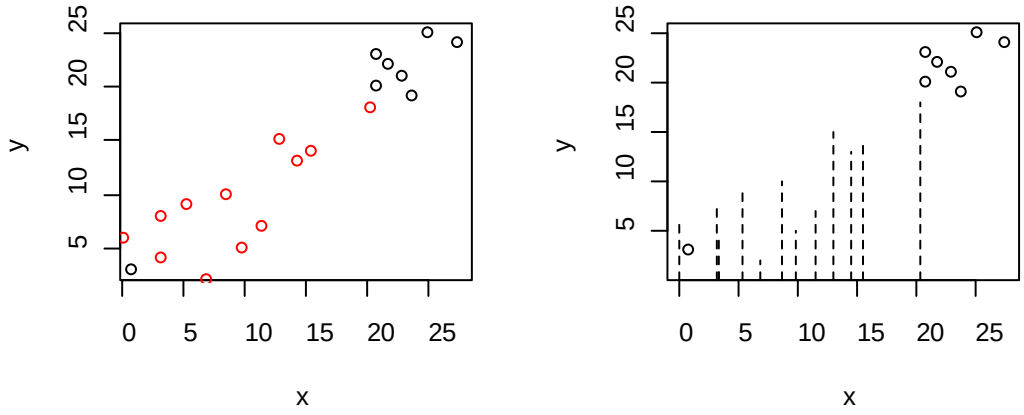
The data shown here are on the original scale (no log transform). Detected values are shown in blue; censored data points are shown in red at their reported values. Note that this is somewhat misleading since the quantiles for the censored data are actually unknown. The optional line, when added, is fit to the entire dataset rather than just the detected blue data points, as is appropriate.




**Appendix F: Figure F-4.** Empirical cumulative distribution function (ECDF) plots for the two datasets shown in the boxplots in Figure F-1.

The ECDF for the data shown in the top row of Figure F-1 is shown in black; the ECDF for the data shown in the bottom row is shown in red. Each step up in these ECDF plots indicates the location of a detected concentration (concentration value on the x-axis) and the proportion of observations both censored and uncensored below this concentration (y-axis). Longer horizontal pieces for a line segment indicate bigger gaps in concentrations between detected data values; taller vertical pieces indicate multiple observations (either censored values, or uncensored values with the same concentrations). These plots were generated in R on Kaplan-Meier estimates of percentiles estimated using the *cenfit()* function.

```
> my.dat.grouped <- data.frame(conc=c(my.dat$conc, my.dat$conc2),
        conc.cens=c(my.dat$conc.cens, my.dat$conc2.cens),
        group=c(rep("A",nrow(my.dat), rep("B",nrow(my.dat))
> my.cenfit <- cenfit(obs=my.dat.grouped$conc, cen=my.dat.grouped$conc.cens,
        group=my.dat.grouped$group)
> plot(my.cenfit, lty=c(1,1), col=c(1,2), lwd=2)
```




**Appendix F: Figure F-5.** Scatterplots of censored dataset.

The left plot shows the censored data in red at their reported DL; the right plot shows the censored data as dashed lines within their reported intervals [0, DL]. From the left plot we might infer that the relationship was linear; from the right plot we see that an exponential relationship may be possible. These plots were generated in R:

```
> par(mfrow=c(2,2))
> plot(foox[!foo.ycens], fooy[!foo.ycens], xlab="x", ylab="y")
> points(foox[foo.ycens], fooy[foo.ycens], pch=1, col=2)
> cenxyplot(foox, foo.xcens, fooy, foo.ycens)
```

# Appendix G
# Potential Best Management Practices for Sediment Cleanup Projects

## G.1 Introduction

This appendix presents information on potential best management practices (BMPs, Appendix G: Table G-1) that may apply when conducting in-water construction (such as dredging or capping) for sediment cleanups. These BMPs may be implemented or required as part of a permit, authorization, or substantive requirement for conducting in-water work. Refer to Chapter 15 for more information on permits, authorizations, substantive requirements, or applicable laws that may apply to sediment cleanup construction projects.

These BMPs are for informational purposes and should be used as a guide and minimum standards for work performed. Specific and potentially more detailed or different requirements may be included in permits, etc., such as a Nationwide Permit 38 or Hydraulic Project Approval.

For further detail on some BMPs listed in Table G-1, refer to the Hydraulic Project Approvals issued by WDFW for removal of beach debris and creosote pilings and EPA Region 10 Best Management Practices for Piling Removal and Placement in Washington State (February 18, 2016) for piling removal and placement.

*This page left intentionally blank.*

**Appendix G: Table G-1.** Best management practices that may be applicable to sediment cleanup projects.

| | Potential BMP for Project Implementation |
|---|---|
| ✓ | **General** |
| | Obtain all necessary permits for cleanup construction and comply with all required BMPs. See Chapter 15 for more detail on permits, authorizations, and applicable laws. |
| | Conduct work in a manner that does not inhibit fish passage. |
| | Use equipment that has the least impact on the environment. |
| | Do not operate or park motorized equipment in the water or in other sensitive areas. |
| | Confine construction impacts to the smallest area necessary to complete the work. |
| | When working in the intertidal area, perform work in the dry at low tide to minimize water quality impacts. |
| | Mark construction limits, stockpiling areas, staging areas, and entries/exits on the site. |
| | Restore all damaged areas to their pre-construction conditions (sediment, vegetation, structures, and systems). |
| | Prevent any petroleum products, chemicals, or other toxic or deleterious materials from entering the water during construction. |
| | Remove soil or debris from equipment (wheels, tires, tracks, undercarriage, etc.) prior to its use in and around water and wetlands. |
| | Use only clean material for fill that meets MTCA and SMS criteria for placement in an aquatic environment and is approved by all applicable permitting agencies. |
| | Do not place fill in spawning areas, areas with submerged aquatic vegetation, wetlands, or sensitive and high-quality habitats. |
| | Dispose of materials at an approved off-site, upland disposal facility unless the material is approved and available for reuse. |
| | Locate staging areas, refueling areas, and material and equipment storage areas above the ordinary high water line. Placement should be at least 50 feet from water and wetlands, and preferably 200 feet away when practical. |
| | Protect vegetation to the extent practicable. Restore disturbed or removed vegetation following construction. |
| | Manage and properly dispose of all construction debris, excess sediment, and other solid waste material at an approved off-site upland facility. |
| | Do not discharge wash water containing oils, grease or other hazardous materials into waters or sensitive areas. Designated areas should be established for cleaning of equipment and tools. |
| | No grounding of barges during in-water construction. |

**Appendix G: Table G-1** (continued). Best management practices that may be applicable to sediment cleanup projects

| | Potential BMP for Project Implementation |
|---|---|
| ✓ | **Health and Safety/Spill Prevention (see Chapter 4 for more detail on Health and Safety Plans)** |
| | Maintain a Spill Prevention Plan and Kit that is available to all contractors and operators for the duration of the project. |
| | Prepare an emergency plan or contingency measures and communicate this information to contractors and operators. |
| | Prepare a site-specific Health and Safety Plan and communicate this information to contractors and operators. Ensure workers have proper training and are wearing personal protective equipment. |
| | Properly maintain and check equipment regularly for drips or leaks. Clean up any chemical leaks or spills immediately. |
| ✓ | **Sediment Dredging and Excavation (from the water)** |
| | Submit a Dredging and Disposal Workplan to applicable regulatory agencies at least 30 days prior to dredging. |
| | Use an environmental or clamshell bucket when determined appropriate and consult with Ecology before implementing other methods. |
| | Use equipment and a dredge bucket appropriate to the volume of work to be performed. |
| | Confine all dredging to the footprint authorized for cleanup. |
| | Conduct dredging during approved in-water work windows. |
| | Do not anchor or “spud down” in sensitive habitats (e.g., eelgrass beds). |
| | Remove anchors slowly to minimize resuspension of sediment. |
| | Work in appropriate water depths and avoid grounding of vessels. |
| | Limit the vertical rate of lifting and lowering the bucket. |
| | Do not take multiple bites of bottom sediment to achieve a full bucket. Do not overfill the bucket. |
| | To release excess water, pause the bucket as it breaks the water's surface. |
| | Do not stockpile material underwater. Bring the bucket to the water’s surface each time it is closed. |
| | Do not level bottom sediment to smooth contours. |
| | Do not overtop sideboards of the barge or allow material to spill from the barge. |
| | Use silt curtains, drop curtains, and other BMPs depending on site conditions. |
| ✓ | **Sediment Excavation (from land or intertidal water)** |
| | Use equipment and a dredge bucket appropriate to the volume of work to be performed. |
| | Do not overtop sideboards of the truck or allow material to spill from the truck. Cover the load during transport. |
| | Start at the top of the slope and work away from the shoreline. |
| | Work during low tides to the extent possible. |
| | Backfill the excavation area in the same tidal cycle to minimize exposure to potentially contaminated sediment and resuspension of sediment. |

**Appendix G: Table G-1** (continued). Best management practices that may be applicable to sediment cleanup projects

| | Potential BMP for Project Implementation |
|---|---|
| ✓ | **Sediment Dewatering** |
| | Pause the bucket as it breaks the water's surface to release excess water. |
| | Equip the barge with scuppers and sideboards. Cover the scuppers with filter fabric or similar material to filter water and retain sediment. |
| | Inspect the filter material and devices daily to ensure the integrity and proper functioning of BMPs. |
| | Stabilize entrained water, or capture and treat any decant water. |
| | Use equipment (such as a sludge pump) to withdraw pooled water from the barge onto a closed barge or upland holding/treatment facility. |
| | Do not dewater at the offloading and/or transloading site. |
| | Do not allow any free water in the barge during over-water transport for disposal. |
| | Follow transit and transloading BMPs. |
| | Remove all debris larger than 2 feet in any dimension from dredged sediment for disposal. |
| | Contain material using sidewalls. Do not overtop or overfill sideboards. |
| ✓ | **Transit and Transloading** |
| | Submit a Transload, Transport and Disposal Workplan to applicable regulatory agencies at least 30 days prior to dredging. |
| | Contain all material, water, and sediment during transit. Dewatering is not allowed during transit. |
| | Do not overtop sideboards during transit. |
| | Do not dewater at the offloading and/or transloading site. |
| | Ensure that all surfaces in contact with dredged sediment and associated water are solid and impermeable. |
| | Place sheeting or impermeable lining under travel area(s) to capture spills. |
| | Control sediment dockside using a sweeper truck, shoveling, sweeping, and/or wash down as often as necessary to avoid release of sediment. |
| | Equip the transloading crane with a spill apron and wing walls between the barge and shore to collect all spilled material. Route any spilled material to the barge or a dockside containment structure. |
| | Decontaminate the spill apron and bucket before moving the crane or excavator. |
| | Secure the barge to the dock in a manner to resist tidal fluctuations. |
| | Seal or line all railcars or trucks and visually inspect the liner prior to loading. |
| | Wash trucks and tires prior to leaving the loading area and contain all wash material and water. Do not allow wash water to enter surface water or storm drains. |
| | Load near the centerline of the truck and ensure there is freeboard left at the end of loading. |
| | Install a berm and cover stockpiled dredged or capping material. |
| | Locate stockpile areas on an impervious surface and inspect daily and after rain events. |
| | Implement a process for treating and testing water from the stockpile area in compliance with the Water Pollution Control Act. |

**Appendix G: Table G-1** (continued)**.** Best management practices that may be applicable to sediment cleanup projects

| | Potential BMP for Project Implementation |
|---|---|
| ✓ | **Piling Removal and Post-Processing** |
| | Vibratory extraction is preferred, followed by a direct pull. Consult with Ecology and other agencies before using other extraction methods. |
| | Slowly initiate extracting the pile to break the bond with sediment prior to removal. |
| | Remove pile slowly to minimize turbidity. |
| | Following removal, move pile directly onto a barge into a containment basin or to an upland handling area. |
| | Do not shake, hose off, hang, or attempt to remove attached sediment. |
| | Place containment booms and absorbent pads around perimeter of work area to capture debris, oil, and other materials. |
| | Do not anchor or “spud down” in sensitive habitats (e.g., eelgrass beds). |
| | Dispose of piling debris at an approved upland disposal site. |
| | Manage all water on the barge and do not discharge unfiltered water into the water. |
| | Perform work in low currents to the extent practicable. |
| | Fill holes left by creosoted pilings with clean sand or gravel unless the area will be capped, or unless the hole will naturally fill within 24 hours. |
| | Cut removed pilings into maximum lengths of 4 feet. Contain all sawdust from cutting, and dispose of pilings, sawdust, and attached sediment at an approved upland disposal facility. |
| ✓ | **Piling Installation** |
| | Place sand on the sediment surface in the area where pile driving will occur to prevent suspension of potentially contaminated sediment during pile driving activities. |
| | Prevent uncured concrete, debris, oil, and grease from entering the water. |
| | Place sand (6 inches vertically and 3 times the horizontal diameter of the pile) in the new pile footprint and drive the pile. |
| | Monitor turbidity during pile installation. If turbidity monitoring detects exceedances of permitted criteria, halt pile driving and consult with Ecology. |
| ✓ | **Structure Removal** |
| | Break monolithic concrete structures (such as cast-in-place boat ramps and abutments) into manageable pieces and remove from the water. |
| | For elevated structures, install or place a catchment device underneath to capture falling debris. |
| | Remove individual concrete components as a whole (such as concrete ramp planks) to the extent practicable. |
| | Do not drag wood, structures, or debris on the beach. |

**Appendix G: Table G-1** (continued). Best management practices that may be applicable to sediment cleanup projects

| | Potential BMP for Project Implementation |
|---|---|
| ✓ | **Marine Debris Removal** |
| | Hand haul materials when it is practical and safe. Lift, rather than drag, logs and debris on the beach. |
| | Manually rake any tracks on the beach. |
| | Use small tracked equipment to mobilize larger debris to a staging area above the ordinary high water line. |
| | Keep equipment stationary when grabbing debris to reduce movement on the beach. |
| | Limit access to a single point or a corridor no wider than 15 feet below wood/marine wrack. Operate equipment in areas with packed sand or with a sand/gravel/cobble composition. |
| | Avoid areas with sensitive vegetation or habitat (e.g., eelgrass beds, forage fish spawning beaches, migratory corridors). |
| | Change fluids and refuel above the ordinary high water line. |
| | To transport to the barge or dock, either hand haul materials; use a chain or similar device for lifting; float to the vessel and lift into the barge; or lash debris together. |
| | When possible, use highest daytime fall and winter tides when using a skiff/tug/barge combination. |
| | If practical, remove creosoted material in the cooler months to minimize leaching. |
| | Use small boats in areas without access roads to tow debris to an area for removal. |
| | Hand carry (do not drag) treated wood or debris to the vessel or staging area. |
| | For materials too large to carry and not accessible to equipment: roll treated wood or debris onto a tarp, cut with a chainsaw or by hand, collect all wood and debris, and dispose of properly. |
| | Do not drag sunken vessels or underwater structures along the bottom bed. |
| ✓ | **Water Quality Protection and Monitoring** |
| | Prepare and implement a Water Quality Monitoring and Protection Plan (WQMPP) that complies with the state water quality standards in WAC 173-201A for the duration of the project. The plan will address monitoring frequency, location(s), distance from activity, depth, and other relevant information. |
| | Initiate a water quality monitoring program to evaluate the effectiveness of BMPs and maintain water quality standards during construction. |
| | Assign a person to monitor water quality during construction. |
| | Use a direct-measurement field meter or automated device/system to monitor turbidity (measured in nephelometric turbidity units [NTU]). |
| | Document visual observations of petroleum sheens, floating wood debris, silt plume, or other elements that may affect water quality. |

**Appendix G: Table G-1** (continued). Best management practices that may be applicable to sediment cleanup projects

| | Potential BMP for Project Implementation |
|---|---|
| ✓ | **Placement of Capping Material** |
| | Apply placement methods that minimize disturbance of bottom sediment. |
| | Prior to full material placement, conduct a test placement to confirm equipment operations and project requirements. |
| | Using a dredge re-handling bucket, lower material through the water column and release the bucket above the mud line to place material. |
| | Using a clamshell bucket, release material in a sweeping motion and controlled manner at the water surface. |
| | Using a bottom dump barge, release material in a controlled manner while the barge moves slowly over placement area. |
| | Using a conveyor system, load the hopper and place the material in a steady manner. |

Note: This is not an exhaustive list of activities and associated BMPs. There may be site- or project-specific requirements or exceptions to BMPs. Always consult a permit or project specialist if you are unsure which BMPs are applicable to your site or project.

# Appendix H
# Remedy Selection Case Studies

This appendix provides five case studies of how the cleanup action alternatives analysis, or *remedy selection process*, may be done for a sediment cleanup site. See Chapter 12 for further detail on the remedy selection process. These case studies are from actual sediment cleanup sites, but have been modified to reflect the revised SMS rule. These case studies illustrate different ways to evaluate alternatives for simple and complex sites:

- Two complex sites using a full disproportionate-cost analysis (Case Studies #1 and #2).
- A simple site using risk reduction as a metric to evaluate alternatives (Case Study #3).
- A simple site using minimal alternatives and a simplified disproportionate-cost analysis (Case Study #4).
- A sediment cleanup unit using minimal alternatives and a simplified disproportionate-cost analysis (Case Study #5).

## H.1 Case Study #1: Complex Site Evaluation

The intertidal part of the site is contaminated with PCBs, metals, and wood waste above cleanup levels. The subtidal part of the site is contaminated with wood waste above cleanup levels. The criteria in Chapter 12, Sections 12.4 – 12.5, were used to evaluate each cleanup action alternative then compared to the others relative to their expected performance under each criterion. Section H.1.1 provides detail on which cleanup action alternatives were considered. Evaluation and results are outlined in Appendix H: Table H-1 through Table H-4.

Each alternative must meet the minimum requirements in Chapter 12, Section 12.4.2 or it will not be further evaluated in the DCA. To simplify this case study, the full range of alternatives that were identified and eliminated (because they did not meet the minimum requirements) is not included.

### H.1.1 Description of cleanup action alternatives

Two alternatives were carried through this cleanup action alternatives analysis:

***Alternative 1:***

- Intertidal:
    - Remove surficial debris and piling along shoreline.
    - Excavate buried wood waste to facilitate placement of 2-foot-thick cap.

    - Dispose excavated debris at upland landfill.
    - Dispose suitable dredge material at open-water disposal site.
    - Place clean cap material within area of excavation.
- Subtidal:
    - Excavate surface and subsurface wood waste and sediments that exceed SCO benthic criteria.
    - Dispose excavated debris at upland landfill.
    - Dispose suitable dredge material at open-water disposal site.
    - Backfill excavation with clean sand and gravel.
    - Place a cover over the post-dredge residuals to 100 feet beyond the waterside edge of the dredge footprint.
- Estimated volume of sediment removed is 19,900 cubic yards.

***Alternative 2*:**

- Intertidal:
    - Remove surficial debris and piling along shoreline.
    - Excavate buried wood waste for placement of 2-foot-thick cap.
    - Dispose excavated debris at upland landfill.
    - Dispose suitable dredge material at open-water disposal site.
    - Place clean cap material within area of excavation.
    - Protect shoreline from erosion by installing an armored cap and creating an offshore wave structure to dissipate the wave energy to protect the shoreline
- Subtidal:
    - Excavate surface and subsurface wood waste and sediments that exceed CSL benthic criteria.
    - Dispose excavated debris at upland landfill.
    - Dispose suitable dredge material at open-water disposal site.
    - Backfill excavation with clean sand and gravel.
    - Place post-dredge residuals cover to 100 feet beyond the waterside edge of the dredge footprint.
- Estimated volume of sediment removed is 31, 900 cubic yards.

## H.1.2 Screening cleanup action alternatives against minimum requirements

Under the SMS, each alternative must meet the minimum requirements outlined in Chapter 12, Section 12.4.2 or it will not be further evaluated in the DCA. Each alternative must therefore be evaluated against the following minimum criteria, found in WAC 173-204-570(3) and Chapter 12 Section 12.4.2:

- Protection of human health and the environment.
- Compliance with all applicable laws.
- Compliance with sediment cleanup standards.
- Use of permanent solutions to the maximum extent practicable.
- Reasonable restoration timeframe.
- Source control measures, if applicable.
- Issuance of a sediment recovery zone, if applicable.
- Compliance with institutional controls.
- Public review and comment provided.
- Compliance monitoring.
- Periodic review, if applicable.

The two alternatives in Case Study #1 met these minimum requirements and were further evaluated for: a) permanent solutions to the maximum extent practicable; b) relative benefit ranking; and c) scoring. This screening process for the two alternatives is explained below and the results are summarized in Appendix H: Table H-1.

### H.1.3 Evaluation and screening of alternatives using benefits criteria

For the purposes of this case study, numeric scores are used as a way to quantify the benefits of the two alternatives. The following benefits criteria were scored on a scale of 1 to 5 (low to high benefits), per WAC 173-204-570(4) and WAC 173-340-360(3):

- Protectiveness
- Permanence
- Long-term effectiveness
- Management of short-term risks
- Technical and administrative implementability
- Consideration of public concerns

The scale used for ranking should be large enough to clearly differentiate between the alternatives. A scale of high, medium, and low may be adequate if there are few alternatives and the benefits between alternatives vary significantly from one another. But for sites where multiple alternatives are being compared, a scale of 1 to 10 may be necessary to distinguish between the benefits of the alternatives. Rankings and weighting factors will typically involve a degree of best professional judgment.

## H.1.4 Evaluation and relative benefits criteria ranking of alternatives

### H.1.4.1 Comparison of alternatives by criteria

Because not all benefits are equal for sediment cleanup, relative weights were assigned to each benefit criterion:

| | |
|---|---|
| Protectiveness | Weighted 30% |
| Permanence | Weighted 20% |
| Long-term effectiveness | Weighted 20% |
| Short-term risks | Weighted 10% |
| Technical and administrative implementability | Weighted 10% |
| Consideration of public concerns | Weighted 10% |

Weighting factors for each of the benefits criteria should reflect site-specific criteria considerations. Protectiveness, permanence, and long-term effectiveness benefits criteria are typically weighted more heavily, however, since they are core to protecting human health and the environment.

To develop a "benefits score" for each alternative, the weighting and relative ranking factors were multiplied together for each category then summed, resulting in a final numerical "benefits score" for each alternative. A higher score would reflect greater benefits for a remedy.

Protectiveness. At this site, a weighting factor of 30% is assigned for this criterion, which represents the greatest value of all categories. This is justified based on its overarching importance relative to the ultimate goal of environmental cleanup and protection of human health and the environment. It is especially critical, given the importance for restoring the health of Puget Sound and the uses of the waterway. The weighting factor also incorporates concerns brought forward by the public that were related to overall protectiveness.

Both alternatives are protective and provide risk reduction because contamination is removed. Alternative 1 ranks higher than Alternative 2 because a greater volume of contaminated sediment is removed.

Permanence. A weighting factor of 20% is assigned for this criterion. This weighting factor is associated with the need (or lack thereof) for further action in the future. This factor, along with long-term effectiveness, is of second-greatest importance, given the significance of restoring the health of Puget Sound and the uses of the waterway. A high level of certainty must accompany the final environmental cleanup so that future actions will be minimized. This criterion is also associated with overall protectiveness, but incorporates a greater factor of time.

Neither of the alternatives achieves permanent destruction of metals or organic constituents (wood waste). However, both alternatives achieve a permanent risk reduction by removing contaminated sediment. Alternative 1 achieves marginally greater permanence because it removes sediment above the SCO but the greater increment of permanence is achieved at additional cost (see Appendix H: Table H-4). Both alternatives require placement of a 0.5-foot-thick sand layer to ensure a clean post-dredge surface and achieve cleanup standards in a reasonable restoration timeframe.

Long-Term Effectiveness. A weighting factor of 20% is assigned for this criterion. This weighting factor is associated with a measure of certainty related to the robustness of the action, as well as the confidence in the technology used for protection of human health and the environment. For this site, a high level of certainty must accompany the final environmental cleanup, so that future actions will not be necessary. Another factor also considered is the probability that the current physical and biological processes present at the site will respond in a predictable way as measured by past occurrences. This includes such factors as currents, ocean levels, erosion, seismic activity, etc. Long-term effectiveness, along with permanence, is of second-greatest importance at this site for the same reasons expressed above. The criterion is similar to permanence in that it is closely associated with overall protectiveness, but incorporates a greater degree of predictability and consistency of natural processes over time.

Alternative 1 is considered slightly more effective than Alternative 2 because more contaminated material is removed. However, the potential is higher for a greater amount of dredge residuals. Both alternatives would manage residuals using a post-dredge cover of clean material.

Management of Short-Term Risks. A weighting factor of 10% is assigned for this criterion. This lower rating is based upon the limited temporal aspect associated with the short-term risks at this site. Generally, short-term risk is actively monitored while the risk exists, which allows for a relatively quick correction or remediation of potential risk as it occurs. Because the risk is short-lived, its overall environmental risk to human health and the environment is limited. At this particular site, short-term risks are less important when selecting an alternative, because each alternative can be easily modified to reduce short-term risk.

Alternative 1 includes a greater dredge volume and post-dredge cover and the construction duration is longer. There would also be a greater potential for short-term water quality impacts and the potential for increased tissue concentrations associated with re-suspension of contaminants from dredging, backfilling, capping, and cover placement. Alternative 2 has a lower volume of dredging and ranks slightly higher (i.e., better) than Alternative 1 for managing short-term risks.

Implementability. A weighting factor of 10% assigned for this criterion. Although an important consideration, implementability is less associated with environmental concerns than the above-mentioned factors. Cost is an issue within this category but it is captured in the cost category.

Technical and administrative implementability are less important when selecting an alternative for this site, because each alternative can be more easily be modified to improve implementability.

Both alternatives are technically possible to implement relative to complexity; administrative and regulatory requirements; size; access; and integration with existing operations. Alternative 1 has a greater volume of dredging so it requires more management of excavated material for disposal and beneficial reuse. Both alternatives are equally ranked in the *absence of beneficial reuse* consideration. If a beneficial reuse option were available and practicable, then Alternative 1 would rank lower for implementability because as the dredge volume increases, more upland space would be needed for staging beneficial reuse activities.

Consideration of Public Concerns. A weighting factor of 10% is assigned for this category. Most of the issues brought up during public comment have already been incorporated in other criteria but are also included under this factor to emphasize the importance of public input under MTCA and the SMS.

Remedy Costs. The analysis of costs encompasses all costs associated with implementing the alternative, including design, construction, long-term monitoring and institutional controls (WAC 173-340-360(3)(f)(iii)). Costs are intended to be comparable among different project alternatives to help analyze their relative costs and benefits. Costs are evaluated against remedy benefits in order to assess cost-effectiveness and remedy practicability. It should be noted that costs for habitat enhancement, redevelopment and other non-cleanup related shoreline stabilization are not included. No weighting factor is applied to this quantitative category.

### H.1.4.2 Disproportionate-cost analysis and discussion

Alternative 1 removes a greater volume of contaminated sediment than Alternative 2. Both alternatives are protective of human health and the environment because both will meet the final sediment cleanup standards. The costs and benefits are summarized in Appendix H: Table H-3. The overall benefits associated with each alternative are shown using a composite "benefits score."

The calculated benefits include the categorical weighting factors and integrate the rankings for individual evaluation criteria, which are multiplied by the weighting within that category, then summed to reach the benefits total. The estimated costs are expressed in current dollars without adjustment for cost inflation and without present-value discount of future costs. The probable remedy costs are expected to vary with a range of + 50% to - 30%. The overall environmental benefit score for Alternative 1 is approximately 20% higher than Alternative 2, but Alternative 2 is approximately 20% lower in cost.

#### H.1.4.3 Conclusions

Based on the DCA evaluation, Alternative 2 is identified as the preferred remedy (Appendix H: Table H-4). This alternative: a) uses high performance technologies; b) provides a high level of calculated ranking; and c) achieves the best environmental benefits that are proportionate to the unit incremental costs while remaining practical.

## H.2 Case Study #2: Complex Site Evaluation

The intertidal part of the site is contaminated with PCBs, metals and wood waste above cleanup levels. The subtidal part of the site is contaminated with metals above cleanup levels. The criteria in Chapter 12, Sections 12.4 – 12.5 were used to evaluate each cleanup action alternative then were compared to the others relative to their expected performance under each criterion. Section H.2.1 provides detail for each cleanup action alternative considered. For the sake of simplicity, the full range of alternatives was not included. Evaluation and results are in Appendix H: Table H-5 through Table H-7.

### H.2.1 Cleanup action alternatives

Four alternatives were carried through this analysis:

***Alternative 1:***

- Dredging and capping adjacent to terminal and planned inner waterway channel.
- Capping and MNR in outer waterway.
- Dispose ~86,000 cubic yards of excavated sediment at upland landfill.
- Dispose ~125,000 cubic yards of suitable dredge material at open-water disposal site.
- Place clean cap material within area of excavation.
- Cap ~43 acres of sediment.
- Estimated volume of sediment removed is ~211,000 cubic yards.

***Alternative 2:***

- Dredging and capping adjacent to terminal and planned inner waterway channel.
- Capping and MNR in outer waterway.
- Dispose ~133,000 cubic yards of excavated sediment at upland landfill.
- Dispose ~125,000 cubic yards of suitable dredge material at open-water disposal site.
- Place clean cap material within area of excavation.
- Cap ~32 acres of sediment.
- Estimated volume of sediment removed is ~258,000 cubic yards.

***Alternative 3:***

- Dredging and capping adjacent to terminal and historic inner waterway channel.
- Capping and MNR in outer waterway.
- Dispose ~530,000 cubic yards of excavated sediment at upland landfill.
- Dispose ~125,000 cubic yards of suitable dredge material at open-water disposal site.
- Place clean cap material within area of excavation.
- Cap ~36 acres of sediment.
- Estimated volume of sediment removed is ~654,000 cubic yards.

***Alternative 4:***

- Dredging and capping adjacent to terminal and historic inner waterway channel.
- Capping and MNR in outer waterway.
- Dispose ~1,385,000 cubic yards of excavated sediment at upland landfill
- Dispose of ~125,000 cubic yards of suitable dredge material at open-water disposal site.
- Place clean cap material within area of excavation.
- Cap ~23 acres of sediment.
- Estimated volume of sediment removed is ~1,500,000 cubic yards.

## H.2.2 Screening cleanup action alternatives against minimum requirements

Under the SMS, each alternative must meet the minimum requirements in Chapter 12, Section 12.4.2 or it will not be further evaluated in the DCA. Thus, each alternative must be evaluated against the minimum criteria found in WAC 173-204-570(3); Chapter 12, Section 12.4.2; and Section H.1.2.

Alternatives that meet the minimum requirements are further evaluated for permanent solutions to the maximum extent practicable, relative benefit ranking, and scoring. All of the alternatives meet the minimum requirements (see Appendix H: Table H-5) and further evaluated below.

## H.2.3 Evaluation and screening of alternatives using benefits criteria

For the purposes of this case study, numeric scores are used as a way of quantifying benefits of the various alternatives. The following benefits criteria were scored on a scale of 1 to 10 (low to high), per WAC 173-204-570(4) and WAC 173-340-360(3):

- Protectiveness
- Permanence
- Long-Term effectiveness
- Management of short-term risks

- Technical and administrative implementability
- Consideration of public concerns

The scale used for ranking should be large enough to clearly differentiate between the alternatives. A scale of high, medium, and low may be adequate if there are few alternatives and if the benefits between alternatives vary significantly from one another. For sites where multiple alternatives are being compared, a scale of 1 to 10 may be necessary to distinguish between the benefits of the alternatives. Rankings and weighting factors will typically involve a degree of best professional judgment.

## H.2.4 Evaluation and relative benefits criteria ranking of alternatives

### H.2.4.1 Comparison of alternatives by criteria

Because not all benefits are equal, relative weights were assigned to each benefit criterion:

| | |
|---|---|
| Protectiveness | Weighted 30% |
| Permanence | Weighted 20% |
| Long-term effectiveness | Weighted 20% |
| Short-term risks | Weighted 10% |
| Technical and administrative implementability | Weighted 10% |
| Consideration of public concerns | Weighted 10% |

Weighting factors for each of the benefits criteria should reflect site-specific criteria considerations, but protectiveness, permanence, and long-term effectiveness benefits criteria are typically weighted more since they are core to protecting human health and the environment.

To develop a “benefits score” for each alternative, the weighting and relative ranking factors are multiplied together for each category then summed, which results in a final numerical rank for that alternative.

Protectiveness. At this site, a weighting factor of 30% is assigned for this criterion, which represents the greatest value of all categories. This is justified based on its overarching importance relative to the ultimate goal of environmental cleanup and protection of human health and the environment. It is especially critical, given the importance for restoring the health of Puget Sound and the uses of the waterway. The weighting factor also incorporates concerns brought forward by the public that were related to overall protectiveness.

The ranking order of overall protectiveness from highest to lowest is 4, 3, 2, and 1. Alternative 4 has the highest use of dredging and upland disposal. The benefits of further reductions in residual sediment concentrations and volumes are offset slightly by the increase in short-term risks associated with the construction of the remedy.

Permanence. A weighting factor of 20% is assigned for this criterion. This weighting factor is associated with the need (or lack thereof) for further action in the future. This factor, along with long-term effectiveness, is of second-greatest importance given the significance of restoring the health of Puget Sound and uses of the waterway. A high level of certainty must accompany the final environmental cleanup, so that future actions will not be necessary. This criterion is intimately associated with overall protectiveness, but incorporates a greater factor of time.

Alternative 4 is ranked an 8 for permanence, because it has the highest use of dredging and upland disposal. The majority of material removed under Alternative 4 comes from areas with low-level contaminated sediment beneath clean surface sediments. Removal will not affect residual surface sediment concentrations in the near-term and provides the least incremental benefit in terms of contaminant removal. However, because Alternative 4 makes the greatest use of high-preference removal technologies, it receives the highest ranking for remedy permanence.

Long-Term Effectiveness. A weighting factor of 20% is assigned for this criterion. This weighting factor is associated with a measure of certainty related to the robustness of the action, as well as the confidence in the technology used for protection of human health and the environment. For this site, a high level of certainty must come with the final environmental cleanup, so that future actions will not be necessary. Another factor also considered is the probability that current physical and biological processes present at the site will respond in a predictable way as measured by past occurrences. This includes such factors as currents, ocean levels, erosion, and seismic activity, as well as others. This factor, along with permanence, is of second-greatest importance at this site for the same reasons expressed above. The criterion is similar to permanence in that it, too, is intimately associated with overall protectiveness, but incorporates a greater degree of predictability and consistency of natural processes over time.

Alternatives 1 and 2 remove smaller volumes of sediment and thus are assigned a ranking of 7 and 8, respectively. Alternatives 3 and 4 are assigned a ranking of 9 because they remove significant volumes of contaminated sediment for disposal into a permitted upland disposal facility, and each uses treatment and reuse technologies.

Management of Short-Term Risks. A weighting factor of 10% is assigned for this criterion. This lower rating is based upon the limited temporal aspect associated with the short-term risks at this site. Generally, short-term risk is actively monitored throughout the entire time the risk exists. This allows for relatively quick correction or remediation of the potential risk as it occurs. Because the risk is short-lived, its overall environmental risk to human health and the environment is limited. At this site, short-term risks are less important when selecting an alternative, because each alternative can be easily modified to reduce short-term risk.

Alternative 4 has the lowest ranking of 4 because it includes the highest amount of dredging and the longest season of construction, with a significant risk of water quality and recontamination impacts. Shorter construction seasons reduce temporal risk.

Implementability. A weighting factor of 10% assigned for this criterion. Although an important consideration, implementability is less associated with environmental concerns than the above-mentioned factors. Cost is an issue within this category but it is captured in the cost category so is not addressed here. Technical and administrative implementability are less important when selecting an alternative for this site, because each alternative can be easily modified to improve implementability.

All four alternatives in Case Study #2 are implementable and pass the minimum criteria. However, Alternative 4 is ranked a 3 for implementability because of the logistical complexity of the project; the need for extensive multi-year dredge seasons, and shoreline stabilization requirements; and dredging conflicts with planned land uses.

Consideration of Public Concerns. A weighting factor of 10% is assigned for this category. Most of the issues brought up during public comment have already been incorporated into other criteria, but are also included under this factor to emphasize the importance of public input under the SMS and MTCA.

Remedy Costs. The analysis of costs encompasses all costs associated with implementing the alternative, including design, construction, long-term monitoring and institutional controls (WAC 173-340-360(3)(f)(iii)). Costs are intended to be comparable among different project alternatives to help analyze their relative costs and benefits. Costs are evaluated against remedy benefits in order to assess cost-effectiveness and remedy practicability. It should be noted that costs for habitat enhancement, redevelopment and other non-cleanup related shoreline stabilization are not included. No weighting factor is applied to this quantitative category.

### H.2.4.2 Disproportionate-cost analysis and discussion

The costs and benefits are summarized in Appendix H: Table H-7. The overall benefits associated with each alternative are summarized using a composite "benefits score." This score includes the rankings for individual evaluation criteria, which are multiplied by the weighting within that category and summed to reach the benefits total.

The estimated costs are expressed in current dollars without adjustment for cost inflation and without present-value discount of future costs. The probable remedy costs are expected to vary with a range of + / - 30%.

The relative benefits and costs of each alternative are compared to Alternative 4. Alternative 4 makes the greatest use of high-preference cleanup technologies, and represents the most permanent cleanup action alternative of the four. It therefore provides the benchmark against which the relationship between incremental remedy benefits and incremental costs are evaluated.

The relative benefits and costs of each alternative are compared to Alternative 4 because Alternate 4 makes the greatest use of high-preference technologies and represents the most permanent alternative evaluated.

Since the cost of Alternative 4 is substantially higher than that of Alternative 3, and the level of benefit is slightly greater, the incremental cost of Alternative 4 is considered disproportionate. Because the cost of Alternative 3 is substantially higher than that of Alternative 2, and the level of benefit is lower, the incremental cost of Alternative 3 is considered disproportionate. The costs of Alternatives 1 and 2 are $42 and $44 million respectively. Since the incremental costs of Alternatives 1 and 2 are proportionate to increases in benefits, the incremental costs are considered disproportionate. But because Alternative 2 has a greater degree of overall benefit than Alternative 1, Alternative 2 is considered permanent to the maximum extent practicable.

#### H.2.4.3 Conclusions

Alternative 2 is identified as the preferred alternative, based on the disproportionate cost analysis. This alternative makes the greatest use of high-preference technologies and has the highest calculated ranking score while remaining practicable. The high-cost dredging and removal actions performed under this alternative are appropriately targeted at the materials that: a) have the highest constituent levels; b) conflict with land use and navigation needs, and are likely to be disturbed in the future; c) can be removed safely without an excessive level of short-term risk; and d) consider community concerns raised during public involvement activities for the site. Alternative 2 is permanent to the maximum extent practicable under MTCA, and is identified as the preferred alternative.

Alternatives 3 and 4 both receive high benefit rankings but, the proportion of costs compared to the benefits gained is significantly greater and is therefore considered disproportionate. The additional removal activities conducted in Alternatives 3 and 4 expand the use of high-preference technologies, but apply these additional efforts only to subsurface sediments with low contaminant levels that are safely managed using other technologies in the preceding alternatives. The incremental costs of these alternatives are substantial and disproportionate relative to the degree of contaminant removal achieved and to the incremental remedy benefits that are achieved. Based on the environmental protections present in the other alternatives, there is only slightly greater reduction in residual risk in Alternatives 3 and 4, despite a doubling or tripling of cleanup costs. Therefore, the costs of Alternatives 3 and 4 are considered disproportionate to the benefits.

# H.3 Case Study #3: Simple Site Evaluation Considering Risk Reduction

Unlike Case Studies #1 and #2, Case Study #3 employs a method that does not use weighting factors to conduct remedy selection and a disproportionate analysis.

The intertidal and subtidal parts of the site are contaminated with wood waste, large amounts of construction debris, hundreds of pilings, and dioxin above cleanup levels. The highest concentrations of dioxin are found in the nearshore and taper off to lower levels as one moves further offshore into the subtidal. The greatest risk to biological resources is found in the intertidal due to the greater biomass of shellfish in these areas. The overall area generally supports large amounts of eelgrass and those species reliant upon eelgrass. The criteria in Chapter 12, Sections 12.4 – 12.5 were used to evaluate each cleanup action alternative, then compare to the others relative to their expected performance under each criterion. Section H.3.1 provides detail on each cleanup action alternative that was considered. Five alternatives were considered and evaluated against the totality of site-specific issues, including the potential for permitting under federal ESA regulations and WDFW habitat requirements, as well as mitigation costs. Tribal fish consumption scenarios and human health impacts, as well as tribal Usual & Accustomed interests were also a top consideration. Open-water disposal was not considered because average dioxin levels of dredged areas exceeded DMMP's open-water disposal criteria.

## H.3.1 Cleanup action alternatives

***Alternative 1***: No active cleanup. Uses long-term monitoring and institutional controls. This scenario does not meet minimum requirements and therefore was not evaluated further in the disproportionate cost analysis.

***Alternative 2***: Removal of high concentration areas and use of MNR for the remainder of the site.

- Intertidal:
  - Remove surficial construction debris and pilings along shoreline.
  - Excavate buried wood waste and dioxin to 6 feet with placement of 6-foot-thick cap and backfill.
  - Dispose excavated debris at upland landfill.
  - Place clean cap material within area of excavation.
- Nearshore Subtidal:
  - Long-term monitored natural recovery in areas between 25 ppt TEQ dioxin and natural background.

- Offshore Subtidal:
    - Long-term monitored natural recovery in areas between 25 ppt TEQ dioxin and natural background.
- Total percent site risk reduction: 45%.

***Alternative 3***: Removal in areas of higher contaminant concentrations in the intertidal and enhanced natural recovery in the subtidal in areas above 10ppt (through thin layer capping).

- Intertidal:
    - Remove surficial construction debris and pilings along shoreline.
    - Excavate buried wood waste and dioxin to 6 feet with placement of 6-foot-thick cap and backfill.
    - Dispose excavated debris at upland landfill.
    - Place clean cap material within area of excavation.
- Nearshore Subtidal:
    - Excavate and dredge surface and subsurface wood waste and sediments exceeding 25 ppt TEQ dioxin to 3 feet.
    - Dispose excavated debris at upland landfill.
    - Backfill excavation with clean sand and gravel.
- Offshore Subtidal:
    - Enhanced natural recovery in areas between 10 and 25 ppt TEQ dioxin.
    - Long-term monitored natural recovery in areas between 10 ppt TEQ dioxin and natural background.
- Remaining Subtidal:
    - Monitored natural recovery in areas less than 10 ppt dioxin.
- Total percent site risk reduction: 85%.

***Alternative 4***: Removal of high concentration areas and capping of the remainder of the site.

Intertidal:

- Remove surficial construction debris and pilings along shoreline.
- Excavate buried wood waste and dioxin to 6 feet with placement of 6-foot-thick cap and backfill.
- Dispose excavated debris at upland landfill.
- Place clean cap material within area of excavation.

- Nearshore Subtidal:
    - Excavate and dredge surface and subsurface wood waste and sediments exceeding 25 ppt TEQ dioxin to 3 feet.
    - Dispose excavated debris at upland landfill.
    - Backfill excavation with clean sand and gravel.

- Offshore Subtidal:
    - Enhanced natural recovery in areas between 10 ppt TEQ dioxin and natural background
- Total percent site risk reduction: 75%.

***Alternative 5***: Complete removal of contaminated sediment via dredging and upland disposal.

- Intertidal:
    - Remove surficial construction debris and pilings along shoreline.
    - Excavate buried wood waste and dioxin to native sediment layer and facilitate placement backfill material.
    - Dispose excavated debris at upland landfill.
    - Backfill material within area of excavation.
- Nearshore Subtidal:
    - Excavate and dredge surface and subsurface wood waste and sediments to native sediment layer.
    - Dispose excavated debris at upland landfill.
    - Backfill excavation with clean sand and gravel.
- Offshore Subtidal:
    - Excavate and dredge surface and subsurface wood waste and sediments to native sediment layer.
    - Dispose excavated debris at upland landfill.
    - Backfill excavation with clean sand and gravel.
- Total percent site risk reduction: 100%.

## H.3.2 Screening cleanup action alternatives against minimum requirements

Each alternative is evaluated against the minimum criteria found in WAC 173-204-570(3); Chapter 12, Section 12.4.2; and Section H.1.2.

Alternatives that meet the minimum requirements are further evaluated for permanent solutions to the maximum extent practicable, relative benefit ranking, and scoring. Alternatives 2 through 5 meet the minimum requirements and are further evaluated below.

## H.3.3 Evaluation and screening of alternatives using benefits criteria

Alternatives were evaluated relative to each other (low to high) using the following benefits criteria per WAC 173-204-570(4) and WAC 173-340-360(3). Note that these do not include cost:

Protectiveness
Permanence
Long-term effectiveness
Management of short-term risks
Technical and administrative implementability
Consideration of public concerns

### H.3.3.1 Comparison of alternatives by criteria

Protectiveness. This represents the greatest importance of all categories and is justified based on its overarching importance relative to the ultimate goal of environmental cleanup and protection of human health and the environment, especially given the importance for restoring the health of Puget Sound and considering the uses of the water body. This also incorporates those concerns brought forward by the public that were related to overall protectiveness.

Four of the five alternatives are protective and provide risk reduction because contamination is removed from the aquatic area. Alternative 3 ranks higher than Alternative 2 because a greater volume of impacted sediment is removed. Alternative 3 ranks higher than Alternative 4 because of greater overall risk reduction. Alternative 5 ranks highest because of greatest risk reduction.

Permanence. This factor is associated with the need (or lack thereof) for additional action in the future. This factor, along with long-term effectiveness, is of second-greatest importance given the significance of restoring the health of Puget Sound and uses of the waterway. A high level of certainty must accompany the final environmental cleanup, so that future actions will not be necessary. This criterion is intimately associated with overall protectiveness, but incorporates a greater factor of time.

Alternatives 2 through 5 achieve permanent reduction of differing masses of wood waste and dioxin risk reduction. The permanence rank in order of lowest to highest is alternatives 2, 4, 3 and 5. Alternative 5 meets the greatest level of permanent risk reduction in the aquatic environment by removing all contaminated sediment. In order of listing, the other alternatives decrease in permanence by having less removal.

Long-Term Effectiveness. This factor is associated with a measure of certainty related to the robustness of the action, as well as the confidence in the technology used for protection of human health and the environment. For this site, a high level of certainty must accompany the

final environmental cleanup, so that future actions will not be necessary. Another factor also considered is the probability that the current physical and biological processes present at the site will respond in a predictable way as measured by past occurrences. This includes such factors as currents, ocean levels, erosion, and seismic activity. Long-term effectiveness, along with permanence, is of second-greatest importance at this site for the same reasons expressed above. This criterion is similar to permanence in that it, too, is closely associated with overall protectiveness, but incorporates a greater level of predictability and consistency of natural processes over time.

The alternatives' ranking for long-term effectiveness from high to low is: 5, 3, 4 and 2. The full-removal Alternative 5 is considered most effective. However, Alternative 3 provides an immediate and significant risk reduction that, with continued natural recovery, should effectively continue to reduce risks more quickly than alternatives 2 and 4.

Management of Short-Term Risks. This criterion possesses a slightly lower rating than the previous three. Generally, short-term risk is actively monitored during the entire period the risk exists. This allows for relatively instantaneous correction or remediation of the potential risk as it occurs. Because the risk is short-lived, its overall environmental risk to human health and the environment is limited. At this site, short-term risks are less important when selecting an alternative because each alternative can be easily modified to reduce short-term risk.

Alternative 5 has the greatest dredge volume and post-dredge cover and the construction duration is longer. There would also be greater potential for short-term water quality impacts and for increased tissue concentrations associated with re-suspension of contaminants from dredging. Alternative 5 therefore has the greatest short-term risks. Ranked in order of highest to lowest for short-term risk are alternatives 3, 4 and 2. Each of these alternatives has a lower total dredge volume that ranks slightly higher than the subsequent remedy, with lesser dredging/capping/backfilling.

Implementability. Although an important consideration, implementability is associated less with environmental concerns than the above-mentioned factors. Cost is an issue within this category but it is captured in the cost category so is not addressed here. Technical and administrative implementability are less important when selecting an alternative for this site, because each alternative can be easily modified to improve implementability.

These four alternatives are technically possible to implement relative to complexity; administrative and regulatory requirements; size; access; and integration with existing operations. Alternative 5 has a greater volume of dredging so it requires more management of excavated material for disposal and beneficial reuse. Alternative 4 also ranks relatively low although higher than 5, because capping (as well as dredging) in extensive areas would necessitate significant mitigation for the potential destruction of eelgrass. Ranked in order of

highest to lowest for implementability are alternatives 2, 3, 4, 5, based on these factors, as well as technical and engineering certainty.

Consideration of Public Concerns. Most of the issues raised during public comment have already been incorporated in other criteria but are included under this criterion to emphasize the importance of public input under the SMS and MTCA.

Remedy Costs. The analysis of costs includes all costs associated with implementing the alternative, including design, construction, long-term monitoring and institutional controls (WAC 173-340-360(3)(f)(iii)). Costs are intended to be comparable among different project alternatives to assist in analyzing the relative costs and benefits. Costs are evaluated against remedy benefits in order to assess cost-effectiveness and remedy practicability. It should be noted that costs for habitat enhancement, redevelopment and/or other non-cleanup related shoreline stabilization are not included. No weighting factor is applied to this quantitative category.

### H.3.3.2 Disproportionate-cost analysis and discussion

Using the criteria above relative to cost, and incorporating overall risk reduction in the context of these criteria, Appendix H: Figure H-1 demonstrates the relative ratio of the post-remediation risk reduction, as well as long-term risk reduction at the site relative to costs. Alternatives 2 through 5 are protective of human health and the environment because both are designed to meet the final sediment cleanup standards. The risk reduction benefits combined with the criterion discussed above integrate the rankings for each alternative. The estimated costs are expressed in current dollars without adjustment for cost inflation and without present-value discount of future costs. The probable remedy costs are expected to vary with a range of + 50% to - 30%.

### H.3.3.3 Conclusions

Based on the DCA evaluation, Alternative 3 is identified as the preferred remedy. This alternative uses high performance technologies and provides a high level of permanent and long-term risk reduction. It achieves the highest environmental benefits (including preserving current, biologically productive eelgrass areas) that are proportionate to the unit incremental costs while remaining practical (Figure H-1).

# H.4 Case Study #4: Simple Site Evaluation with Minimal Cleanup Action Alternatives

The site consists of an upland portion and in-water portion located along the shore of a freshwater river. It is used for large vessel traffic primarily for shipping cargo and raw materials. The upland portion is a contaminated former industrial facility that is no longer in operation. The river has minor tidal range fluctuations but no saltwater intrusion, therefore it remains as freshwater at all times. The shoreline areas are relatively uncontaminated. However, approximately two-thirds of the downstream portion of the intertidal and subtidal areas of the site contains elevated concentrations of PAHs and PCBs.

Confirmational sediment bioassay tests were conducted at three sampling stations. Bioassay results indicated an exceedance for both the amphipod and midge bioassays at a single station located immediately downstream from one of the two major outfalls permitted at the site.

Although fewer than three bioassays failed criteria, it was determined that WAC 173-204-510 (*identifying clusters of potential concern*) did not apply because the facility was already determined to be a designed cleanup site that required remediation.

The site evaluation involved screening of PCB compounds against the practical quantitation limit (PQL) and completing a human health risk evaluation for cPAH compounds. It was determined that the concentrations of PCB compounds were less than the applicable PQL, and health risks associated with detectable cPAH compounds were less than risk levels defined as protective in the SMS rule.

A sediment trend analysis indicated that chemical concentrations (both PAH and PCB concentrations) were significantly lower in surface sediment concentration (0 - 2 cm interval) than in the deeper sediment interval (0 - 10 cm). Results confirmed that, due to normal erosional and scouring processes in the river surface, sediment concentrations have migrated downstream and the elevated chemical concentrations are not the result of an ongoing release.

## H.4.1 Cleanup action alternatives

The two alternatives that were carried through this analysis are described below. Active removal (i.e., dredging) was determined to be the only alternative that met the minimum criteria (Chapter 12, Section 12.2), primarily due to the heavy erosional and depositional nature of the river. The criterion that most heavily influenced the benefits criteria was “use of permanent solutions to the maximum extent practicable.” Since capping was not considered permanent due to the erosional and depositional conditions, it was not further evaluated.

***Alternative 1:***

- Implement source control, clean outfall pipe and lines.
- Excavate surface and subsurface sediments that exceed SCO benthic criteria.
- Dispose excavated debris in an approved upland area of the site and cap with clean soil.
- Backfill excavation with clean sand and gravel.
- Place post-dredge residuals cover 80 feet to the downstream end of outfall/excavation area.
- Estimated volume of sediment removed is 3600 cubic yards.
- Estimated volume of sediment backfill material is 4200 cubic yards.

***Alternative 2:***

- Implement source control, clean outfall pipe and lines.
- Excavate surface and subsurface sediments that exceed SCO benthic criteria.
- Dispose excavated debris at upland landfill and cap with clean soil.
- Backfill excavation with clean sand and gravel.
- Place post-dredge residuals cover 80 feet to the downstream end of outfall/excavation area.
- Estimated volume of sediment removed is 3600 cubic yards.
- Estimated volume of sediment backfill material is 4200 cubic yards.

## H.4.2 Screening cleanup action alternatives against minimum requirements

Each alternative must meet the minimum requirements in Chapter 12, Section 12.1.2 or it will not be further evaluated in the DCA. Therefore, each alternative must be evaluated against the minimum criteria found in WAC 173-204-570(3); Chapter 12, Section 12.4.2; Section H.1.2.

Alternatives that meet the minimum requirements are further evaluated for permanent solutions to the maximum extent practicable, relative to their benefit ranking and scoring. A complex screening process was unnecessary due to the similarity of alternatives (disposal of contaminated sediment was the only difference) and the cost difference associated with the two disposal options. Benefits were nearly identical, as described below.

## H.4.3 Evaluation and screening of alternatives using benefits criteria

Because these two alternatives were nearly identical with the only difference being the disposal option for the dredged sediment, it was determined that a complex DCA was unnecessary to

effectively differentiate between the two alternatives. The following benefits criteria were determined for each alternative and simply evaluated on their strengths relative to each other:

- Protectiveness
- Permanence
- Long-term effectiveness
- Management of short-term risks
- Technical and administrative implementability
- Consideration of public concerns

### H.4.4 Evaluation and relative benefits criteria ranking of the alternatives

#### H.4.4.1 Disproportionate-cost analysis and discussion

Both alternatives are protective of human health and the environment because both will meet the final sediment cleanup standards. The overall benefits associated with each alternative are nearly identical, with only slightly increased benefit for off-site disposal (although transportation risks increase for that alternative). Using nearly identical qualitative rankings, the major difference is cost. Cost for off-site disposal does not provide significant benefits relative to on-site disposal.

#### H.4.4.2 Conclusions

Based on the overall simplified DCA evaluation, Alternative 1 is identified as the preferred remedy. This alternative uses high performance technologies and provides a high level of benefits that are proportionate to the unit incremental costs while remaining practical.

## H.5 Case Study #5: Sediment Cleanup Unit Evaluation

This site is owned in part by a major port, as well as the State of Washington under DNR management. The upland portions of the site have previously been remediated with no identified ongoing sources. During the RI/FS process, the Port identified the need to fulfill contractual obligations to one of its clients on an expedited basis. This required an area of greater draft-depth near a berth to accommodate longer vessels with similar draft-depth. Ecology agreed to assist the Port with the expedited cleanup and to take advantage of the Port's willingness to expedite cleanup.

Although this was not a cleanup for the larger site, it was determined that this focused area could be defined as a sediment cleanup unit (WAC 173-204-505(20); Chapter 12 Section 12.3) with the benefit of remediating a large volume of highly contaminated sediment in the nearshore environment, thereby significantly reducing risk to human health and the environment. The in-

water portion of the sediment cleanup unit consists of a small intertidal area less than 1/3 acre and a subtidal area of approximately 7 acres.

The sediment cleanup unit is contaminated with wood waste, dioxin, PCBs, PAHs, and metals. The larger site boundary containing the nature and extent of all contaminants has yet to be determined. However, time was the critical component for cleanup of the sediment cleanup unit, and the Port determined that the future site use dictated a full removal alternative.

Future site use narrowed those alternative choices to the full removal to native sediment, which is also consistent with the benefits criteria. The alternatives were limited to full removal, with backfill used only for residual management. The alternatives scenario was modified based upon the options for dredge material disposal. Sediment dredge disposal options were limited to upland off-site disposal at a certified landfill and/or in-water disposal. Ecology determined that these two alternatives were actually a single option with different dredge units identified for separate disposal. The decision was therefore made to provide DMMP with the necessary coring data to evaluate authorized disposal options and provide Ecology with Z-layer (post-dredge exposed layer) information. A majority of the sediment cleanup unit was expected to be dredged to native. Where clean native sediment was not encountered, additional dredging to remove non-native material and additional backfilling were also considered.

## H.5.1 Cleanup action alternatives

The single alternative outlined above and the rational for the single alternative approach did not require a full DCA. Cost was not considered for cleanup because future site use dictated the alternative, which met the minimum requirements in Section H.5.2, in particular, “use of permanent solutions to the maximum extent practicable.”

***Alternative 1***:

- Intertidal and Subtidal:
  - Dredge surface and subsurface sediments that exceed SMS screening levels for benthic, human health, and higher trophic level ecological receptors.
  - Dispose contaminated dredged material at upland landfill.
  - Dredge surface and subsurface sediments that meet SMS criteria and DMMP screening requirements to specified required ship draft-depth.
- Estimated volume of sediment removed is 33,440 cubic yards.

## H.5.2 Screening cleanup action alternatives against minimum requirements

Under the SMS, each alternative must meet the minimum requirements found in WAC 173-204-570(3); Chapter 12 Section 12.4.2, or it will not be further evaluated in the DCA.

## H.5.3 Evaluation and screening of alternatives using benefits criteria

Because there was a single alternative, it was determined that a DCA was unnecessary. The following benefits criteria were determined for the alternative and simply evaluated based upon the overall merits of the entire project. It was determined that: a) this alternative was the sole alternative that would allow the intended future site use; b) the alternative met the "permanent solution to the maximum extent practicable" criteria; and c) scored very high on the benefits criteria for:

- Permanence
- Long-term effectiveness
- Management of short-term risks
- Technical and administrative implementability
- Consideration of public concerns

## H.5.4 Evaluation and relative benefits criteria ranking of alternatives

### H.5.4.1 Disproportionate-cost analysis and discussion

The alternative was determined to be protective of human health and the environment because it met the final sediment cleanup standards and was permanent to the maximum extent practicable. The overall benefits associated with the most permanent action were very high. In addition, future site use is determined by the site owner (the Port) as Ecology has no legal authority over future site use. The alternative was therefore the only viable option to meet the Port's future site use needs.

### H.5.4.2 Conclusions

Based on the rationale discussed above, the full dredge option was identified as the remedy that met all parties' needs. This alternative uses high performance technologies and provides a high level of benefits that consider the owner's future site use needs.

**Appendix H: Table H-1.** Case Study #1. Screening of cleanup action alternatives against minimum requirements.

| Criteria | Alternative 1 | Alternative 2 |
|---|---|---|
| **Protection of human health and the environment** | Yes. Alternative will protect human health and the environment without site use restrictions. | Yes. Alternative will protect human health and the environment without site use restrictions. |
| **Compliance w/applicable laws** | Yes. Alternative complies with applicable state and federal regulations. | Yes. Alternative complies with applicable state and federal regulations. |
| **Compliance w/cleanup standards** | Yes. Alternative is expected to comply with marine (SCO) benthic cleanup standards to be selected by Ecology. | Yes. Alternative is expected to comply with marine (CSL) benthic cleanup standards to be selected by Ecology. |
| **Permanence** | | |
| **Reasonable restoration timeframe** | This alternative is expected to require two to three years for design, permitting and construction. | This alternative is expected to require two to three years for design, permitting and construction. |
| **Preference for most effective source control measures** | Yes – Alternative includes most effective source control measures necessary. | Yes – Alternative includes most effective source control measures necessary. |
| **Issuance of SRZ** | Not necessary. Cleanup standards will be met within a reasonable restoration timeframe. | Not necessary. Cleanup standards will be met within a reasonable restoration timeframe. |
| **Compliance w/institutional controls** | Yes | Yes |
| **Provision for public review** | Yes | Yes |
| **Provision for compliance monitoring** | Yes. Alternative includes provisions for compliance monitoring. | Yes. Alternative includes provisions for compliance monitoring. |
| **Provision for periodic review** | Yes | Yes |

**Appendix H: Table H-2.** Case Study #1. Benefits criteria scoring.

| Criteria | Alternative 1 | Alternative 2 |
|---|---|---|
| **Protectiveness** | Score = 5<br>Achieves a high level of overall protectiveness by removal of sediment that poses risk to human and ecological receptors and addressing sediments exceeding SCO benthic criteria. | Score = 4<br>Achieves a medium level of overall protectiveness by removal of sediments that pose risk to human and ecological receptors and addressing sediments exceeding CSL benthic criteria. |
| **Permanence** | Score = 5<br>Achieves risk reduction through direct removal and disposal of the excavated material at appropriate off-site facilities. However, landfill disposal precludes the MTCA preference for destruction of contaminants. | Score = 4<br>Achieves risk reduction through direct removal and disposal of the excavated material at appropriate off-site facilities. However, landfill disposal precludes the MTCA preference for destruction of contaminants. The quantity of impacted sediment allowed to remain on-site is greater than with Alternative 1 and will require periodic monitoring. |
| **Long-term effectiveness** | Score = 5<br>Residual contaminant concentrations and associated risks are anticipated to be low. This alternative removes hazardous substances from the marine area to the greatest degree possible and utilizes approved off-site disposal facilities for final disposition. If hazardous substances remain at the site (such as deeply buried wood waste) they will pose little risk to human health and the environment. Wave attenuation structures and armored caps will reduce the potential for contaminant exposure associated with cap erosion along the transitional slope. | Score = 4<br>Removes the majority of hazardous substances from the marine area and utilizes approved off-site disposal facilities for final disposition, but leaves some sediment in the marine area that exceeds the SCO benthic criteria. Wave attenuation structures and armored caps will reduce the potential for contaminant exposure associated with cap erosion along the transitional slope. |
| **Management of short-term risks** | Score = 3<br>Involves extensive sediment removal with a potential for generating dredge residuals. However, the excavation methods required to achieve the level of removal under this alternative are well-established and capable of minimizing short-term risks. | Score = 3<br>Involves sediment removal with a potential for generating dredge residuals. However, the excavation methods required to achieve the level of removal under this alternative are well-established and capable of minimizing short-term risks. |
| **Implementability** | Score = 5<br>Involves extensive sediment removal, with dredge residuals potential. Dredge residuals are managed with a post-dredge cover of clean material. The excavation would need equipment/staging/phasing compatible for a shallow, tidally-influenced environment. | Score = 5<br>Involves less sediment removal, with dredge residuals potential. Dredge residuals are managed using a post-dredge cover of clean material. The excavation would need equipment/staging/phasing compatible for a shallow, tidally-influenced environment. |
| **Consideration of public concerns** | Score = 4<br>Provides for complete removal of contaminated sediment from the subtidal portion of the site, addressing public concerns associated with exposure to contaminants and restriction on future use and development of the site. However, the excavation volume is greater than Alternative 2, so local traffic impacts from upland disposal activities would be greater. | Score = 3<br>Addresses the highest level sediment that poses the greatest risk to human health and the environment. However, sediments below the CSL benthic criteria would remain on-site. |

*This page intentionally left blank*

**Appendix H: Table H-3.** Case Study #1. Comparison of costs and benefits of alternatives.

| Criteria | Alternative 1 | Alternative 2 |
|---|---|---|
| Protectiveness (30%) | 1.5[a] | 1.2 |
| Permanence (20%) | 1 | 0.8 |
| Long-term effectiveness (20%) | 1 | 0.8 |
| Management of short-term risks (10%) | 0.3 | 0.3 |
| Implementability (10%) | 0.5 | 0.5 |
| Consideration of public concerns (10%) | 0.4 | 0.3 |
| **Overall Weighted Benefit Scores** | **4.7** | **3.9** |

a, Alternative 1 Protectiveness Score = 5 (from Table I-2) X 30% (weighting factor) = 1.5

**Appendix H: Table H-4.** Case Study #1. Summary of the alternatives evaluation and ranking.

| Criteria | Alternative 1 | Alternative 2 |
|---|---|---|
| Compliance with minimum requirements | Yes | Yes |
| DCA relative benefits ranking | 1st | 2nd |
| Protectiveness (30%) | 1.5 | 1.2 |
| Permanence (20%) | 1 | 0.8 |
| Long-term effectiveness (20%) | 1 | 0.8 |
| Management of short-term risks (10%) | 0.3 | 0.3 |
| Implementability (10%) | 0.5 | 0.5 |
| Consideration of public concerns (10%) | 0.4 | 0.3 |
| Overall weighted benefit scores | 4.7 | 3.9 |
| **Disproportionate cost analysis** | | |
| Estimated cost of alternative | $7.1 M | $5.8 M |
| Ratio of cost to overall benefits score[a] | $1.51 M per benefit | $1.49 M per benefit |
| Cost disproportionate to incremental benefits | No | No |
| Alternative permanent to the maximum extent practicable | Yes | Yes |
| Practicability of remedy | Practicable | Practicable |
| **Overall Alternative Ranking** | **2nd** | **1st** |

a, Ratio = $7.1 M / $4.7 M = $1.51 Million per benefit

*This page intentionally left blank*

**Appendix H: Table H-5.** Case Study #2. Screening of cleanup action alternatives against minimum requirements.

| Criteria | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| **Protection of human health/environment** | Yes. Alternative will protect human health and the environment without site use restrictions. | Yes. Alternative will protect human health and the environment without site use restrictions. | Yes. Alternative will protect human health and the environment without site use restrictions. | Yes. Alternative will protect human health and the environment without site use restrictions. |
| **Compliance w/applicable laws** | Yes. Alternative complies with applicable state and federal regulations. | Yes. Alternative complies with applicable state and federal regulations. | Yes. Alternative complies with applicable state and federal regulations. | Yes. Alternative complies with applicable state and federal regulations. |
| **Compliance w/cleanup standards** | Yes. Alternative is expected to comply with cleanup standards to be selected by Ecology. | Yes. Alternative is expected to comply with cleanup standards to be selected by Ecology. | Yes. Alternative is expected to comply with cleanup standards to be selected by Ecology. | Yes. Alternative is expected to comply with cleanup standards to be selected by Ecology. |
| **Permanence** | See below. | See below. | See below. | See below. |
| **Reasonable restoration timeframe** | This alternative is expected to require 5 - 6 years for design, permitting and construction. | This alternative is expected to require 5 – 6 years for design, permitting and construction. | This alternative is expected to require 5 - 8 years for design, permitting and construction. | This alternative is expected to require 8 - 13 years for design, permitting and construction. |
| **Preference for most effective source control measures** | Yes. Alternative includes most effective source control measures necessary. | Yes. Alternative includes most effective source control measures necessary. | Yes. Alternative includes most effective source control measures necessary. | Yes. Alternative includes most effective source control measures necessary. |
| **Issuance of SRZ** | Not necessary. Cleanup standards will be met within a reasonable restoration timeframe. | Not necessary. Cleanup standards will be met within a reasonable restoration timeframe. | Not necessary. Cleanup standards will be met within a reasonable restoration timeframe. | Not necessary. Cleanup standards will be met within a reasonable restoration time frame. |
| **Compliance w/institutional controls** | Yes | Yes | Yes | Yes |
| **Provision for public review** | Yes | Yes | Yes | Yes |
| **Provision for compliance monitoring** | Yes. Alternative includes provisions for compliance monitoring. | Yes. Alternative includes provisions for compliance monitoring. | Yes. Alternative includes provisions for compliance monitoring. | Yes. Alternative includes provisions for compliance monitoring. |
| **Provision for periodic review** | Yes | Yes | Yes | Yes |

**Appendix H: Table H-6.** Case Study #2. Benefits criteria scoring.

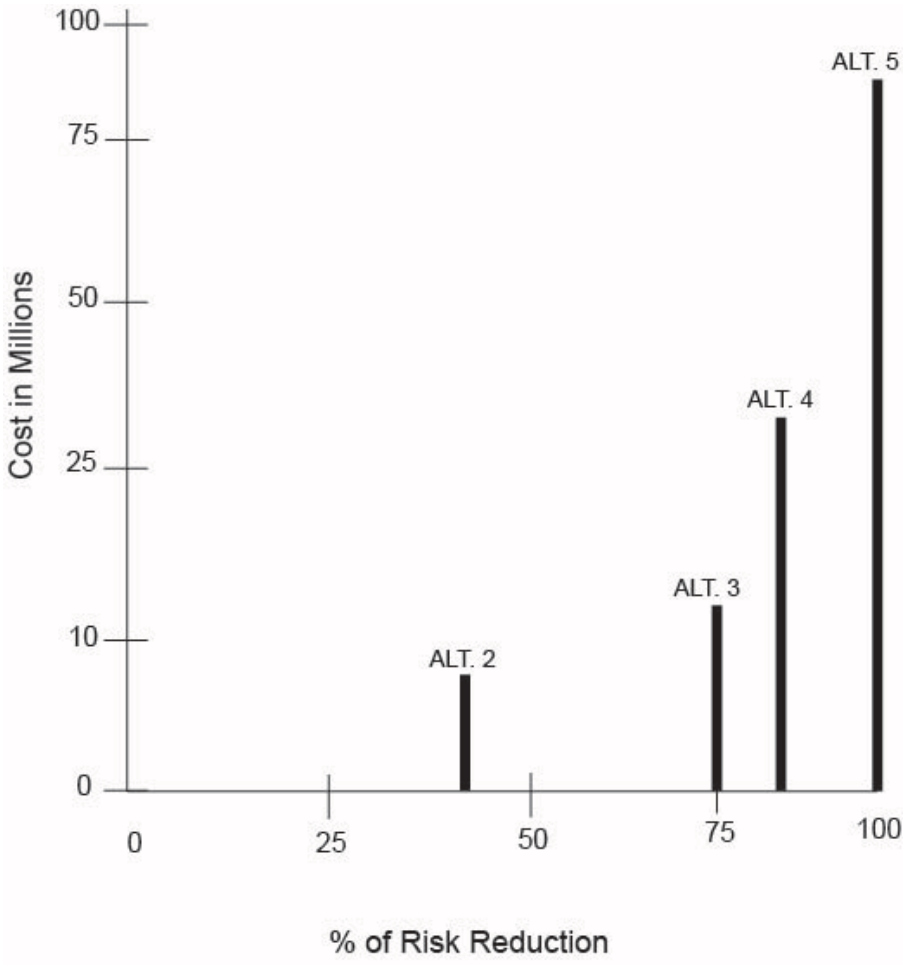
| Criteria | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| **Protectiveness** | Score = 5<br>Achieves a medium level of overall protectiveness. Some residual sediment would remain under this alternative and require greater reliance on capping and institutional controls for protectiveness. | Score = 6<br>Achieves a medium level of overall protectiveness. The protectiveness of Alternative 2 is slightly higher than Alternative 1, because removal and upland disposal is expanded in the outer waterway. Some residual sediment would remain under this alternative and require greater reliance on capping and institutional controls for protectiveness. | Score = 7<br>The protectiveness of Alternative 3 is slightly higher than both 1 and 2, because it uses more active remediation (dredging) and off-site disposal, and relies less on temporal cap stability. The benefits of additional contaminant removal are partially offset by the increased levels of short-term risk due to the additional dredging activity, although short-term risks are included in short-term risk rankings. Some residual sediment would remain under this alternative and require greater reliance on capping and institutional controls for protectiveness. | Score = 9<br>Achieves the greatest use of dredging and upland disposal. The benefits of further reductions in residual sediment concentrations and volumes are offset slightly by the increase in short-term risks associated with the construction of the remedy. This alternative would require about 7 in-water construction seasons to complete dredging. Because the additional subsurface sediments removed have the lowest concentrations of all site materials, the removal amount results result in negligible significant improvement in overall protectiveness over Alternative 3. |
| **Permanence** | Score = 5<br>Alternatives 1, 2 and 3 are ranked 5, 6, and 7, respectively, for permanence for similar reasons stated for Alternative 4. Since Alternative 4 includes the greatest volume of contaminated sediments, the permanence of these alternatives is ranked based upon the extent to which they remove contaminated sediment. Alternative 2 removes additional contaminated material relative to Alternative 1 and Alternative 3 removes additional material relative to Alternative 2. | Score = 6<br>See Alternative 1 discussion | Score = 7<br>See Alternative 1 discussion | Score = 8<br>Has the highest use of dredging and upland disposal. The majority of material removed comes from areas with low-level contaminated sediment beneath clean surface sediments. The removal of this high-volume, low-concentration material will not affect residual surface sediment concentrations in the near-term and removal is not required to prevent exposure of buried contaminated sediments due to navigation or land-use conflicts. Removal of sediment in these areas provides the least incremental benefit in terms of the mass of contaminant removal achieved, due to the low average concentration of contaminants. However, because Alternative 4 makes the greatest use of high-preference removal technologies, it receives the highest ranking for remedy permanence. |

| Criteria | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| **Long-term effectiveness** | Score = 7<br>Alternatives 1 and 2 remove lesser volumes for upland disposal. | Score = 8<br>Alternatives 1 and 2 remove lesser volumes for upland disposal. | Score = 9<br>Alternatives 3 and 4 have a ranking of 9 because they include removal of significant volumes of contaminated sediment for disposal into a permitted upland disposal facility, and each uses treatment and reuse technologies. Alternatives 1 and 2 remove lesser volumes for upland disposal. | Score = 9<br>See Alternative 3 discussion. |
| **Management of short-term risks** | Score = 8<br>Alternatives 1 through 3 are scored due to a progressively greater use of dredging and their relative increasing risk of recontamination. As a result, Alternative 3 will require up to 4 construction seasons for in-water dredging and construction, while Alternatives 1 and 2 are expected to require 2 in-water construction seasons. Fewer construction seasons reduces temporal risk. | Score = 7<br>See Alternative 1 discussion.<br>. | Score = 6<br>See Alternative 1 discussion. | Score = 4<br>While this alternative has the highest permanence ranking, it has the highest amount of dredging, with a significant risk of water quality and recontamination impacts. Alternative 4 is estimated to require between 5 and 7 construction seasons to complete in-water dredging. |
| **Implementability** | Score = 8<br>Like the other alternatives, these actions will involve complex construction activities and require the development of appropriate permits and institutional controls. However, all the construction methods used rely on available technologies for which experienced contractors are available within the region. The administrative implementability of these alternatives is relatively high, because these alternatives are consistent with identified land use, navigation, and habitat enhancement plans. The habitat restored as a consequence of these cleanup alternatives also improves the permitting implementability relative to other project alternatives. There is an insignificant difference in implementability between these two alternatives. | Score = 8<br>See Alternative 1 discussion.<br>. | Score = 4<br>Alternative 3 is ranked a 4 because it is technically implementable but requires a multi-year construction season and the dredge plan conflicts with planned land uses. Alternatives 3 and 4 would require substantial investments in shoreline infrastructure that conflict with land owner objectives and land-use plans. | Score = 3<br>This is ranked at 3 because of the logistical complexity of the project; the need for extensive multi-year dredge seasons and shoreline stabilization requirements; and dredging conflicts with planned land uses. |

| Criteria | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| **Consideration of public concerns** | Score = 7<br>Alternative 1 is relatively responsive to community concerns that have been raised. The alternative generally makes significant use of removal, treatment, and upland disposal technologies for management of contaminated sediment. The alternative is consistent with land-owner objectives and land-use plans. Alternative 1 also preserves the flexibility for continued deep draft navigation uses at the shipping terminal. | Score = 8<br>Alternative 2 is responsive to public concerns that have been raised during public involvement activities for the site. Alternative 2 receives a higher ranking than Alternative 1 and the highest overall score in this category, because it allows for greater deep draft shipping which was a public concern. | Score = 5<br>Although the alternative includes a greater degree of dredging and upland disposal than Alternative 1 or Alternative 2, non-cleanup related factors result in other conflicts and received unfavorable comments relating to: 1) the destruction of habitat, and 2) concerns about the conflicts between the shoreline infrastructure requirements of this alternative and the planned land uses, navigation patterns, and habitat enhancement objectives. | Score = 4<br>This alternative received favorable remarks from commenters who wanted the site cleanup to maximize the use of dredging and upland disposal, and minimize the use of other technologies, and who were less concerned about costs, land-use impacts, short-term environmental affects, or habitat impacts of the alternative. However, with the exception of habitat and land-use preferences, each of these issues was considered in the other categories above. The alternative received unfavorable comments relating to 1) the destruction of habitat, and 2) concerns about the conflicts between the shoreline infrastructure requirements of this alternative, as well as the planned land uses, navigation patterns, and habitat enhancement objectives. |

**Appendix H: Table H-7.** Case Study #2. Summary of the alternatives evaluation and ranking.

| Criteria | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| Compliance with minimum requirements | Yes | Yes | Yes | Yes |
| **Overall weighted benefit scores** | **6.2** | **6.9** | **6.8** | **7.2** |
| **Disproportionate Cost Analysis** | | | | |
| Estimated cost of alternative | $42 M | $44 M | $74 M | $146 M |
| Ratio of cost to benefits | $6.7 M per benefit | $6.3 M per benefit | $10.9 M per benefit | $21.2 M per benefit |
| Cost disproportionate to incremental benefits | No | No | Yes | Yes |
| Alternative permanent to the maximum extent practicable | Yes | Yes | Yes | Yes |
| Practicability of remedy | Practicable | Practicable | No | No |
| **Overall Alternative Ranking** | **2nd** | **1st** | **3rd** | **4th** |




**Appendix H: Figure H-1.** Case Study #3. Relative ratio of the overall post-remediation and long-term risk reduction at the site relative to costs.

# Appendix I
# Natural Background Data

## I.1 Introduction

This appendix includes data that Ecology will use to support the calculation of natural background for Puget Sound, marine areas, or select areas within Puget Sound (Chapter 10). The following data sets were used to calculate the 90/90 Upper Tolerance Limits (UTLs) for the parameters in Chapter 10 Table 10-1.

- OSV Bold survey from the sampling event conducted in 2008 (DMMP 2009). These data are available in several ways:
    - As Excel spreadsheets available to Ecology site managers. They can be downloaded from: X:\\SCUM.
    - By downloading from Ecology's Environmental Information Management (EIM) database for external users. The EIM database can be accessed under Study ID = BOLD 2008 at: http://www.ecy.wa.gov/eim/index.htm
    - By accessing the data report at: http://www.ecy.wa.gov/eim/.

- Ecology-approved Puget Sound reference sites and other areas in the Puget Sound area. These are areas that Ecology has determined appropriately similar to reference sites in terms of anthropogenic impact. The data are available here:
    - Appendix I: Table I-1: Ecology-approved data for organics.
    - Appendix I: Table I-2: Ecology-approved data for metals.
    - Appendix I: Table I-3: Ecology-approved data for dioxin.
    - Appendix I: Table I-4: Environmental Information System data qualifiers.

This appendix will be updated as more information becomes available for both Puget Sound and other areas of the state.

# I.2 Calculation of Natural Background Threshold Values

This section contains the statistical process used to calculate natural background for select chemicals. The TEQ sums for dioxins/furans, PCBs, and cPAHs were calculated using the process in Chapter 6 which includes the Kaplan-Meier (KM) method for calculating a sum when some of the congeners in a sample were below detection (Helsel 2010 and 2012). In the KM calculation, Efron's bias correction was used (Klein and Moeschberger 2003), and qualifiers were assigned to samples with high, or an excessive proportion of, non-detected values (see Appendix F Section F.1.2). The upper bound TEQ sums bearing qualifiers were treated as censored values in the following analyses, unless otherwise indicated.

When all the data were detected, the large sample sizes available for these natural background data sets (i.e., n = 76 to 101) should result in fairly robust bootstrap estimates of the 90/90 UTL. If a parametric distribution (i.e., normal, lognormal, or gamma) was a good fit to the data, then the non-parametric BCA (bias-corrected and accelerated) bootstrap estimate of the 90/90 UTL should approximate the parametric estimate for the best-fitting distribution. When the data were found to be adequately described by a parametric distribution, both parametric and non-parametric estimates were calculated. However, due to the large sample sizes and the potential for strong influence on the parametric results by one or more individual high values, preference was given to the non-parametric results.

When the datasets were partially censored, the distribution of the detected portion of the data set was reviewed to determine if a parametric UTL using KM estimates of the mean and variance may be appropriate. If the censored proportion of the data set was greater than approximately 50%, a non-parametric UTL based on order statistics was preferred regardless of the distribution of the uncensored data. All computations were done in either ProUCL 5.0 (USEPA 2013), or R (R Core Team 2014) using the *base*, *stats*, and *tolerance* packages.

## I.2.1 Dioxin/Furan TEQs

The Bold dataset plus 21 additional samples resulted in a total of 91 data points that were used to calculate natural background threshold values for the dioxin/furan TEQ sum. KM-based TEQ sums for this dataset resulted in 40 uncensored values out of 91 data points (56% censored, Appendix I: Table I-5). The data distribution was skewed (i.e., non-normal), with the uncensored data significantly different from both the gamma and lognormal distributions by the Anderson-Darling and Shapiro-Wilks tests ($\alpha = 0.05$), respectively. Non-parametric order statistics were used to estimate the 90/90 UTL on the full data set, resulting in a value of 4.5 ng/kg TEQ.

A formal outlier test was not performed because the full data set did not fit a parametric distribution. However, the highest value (12 ng/kg TEQ) was nearly 50% higher than the next highest value (8.3 ng/kg TEQ), so the influence of this single value on the UTL was investigated.

Excluding the highest value, the uncensored data were not significantly different from a lognormal distribution (Shapiro-Wilks test, p=0.09), and the 90/90 UTL assuming a lognormal distribution and using KM estimates of the mean and variance was 3.5 ng/kg TEQ. However, because of the large number of censored data points (57%), the 90/90 UTL using non-parametric order statistics was preferred, resulting in a value of 4.4 ng/kg TEQ. Both non-parametric UTL estimates round to 4 ng/kg TEQ (for one significant figure).

## I.2.2 PCB TEQ

No additional PCB congener data were available to add to the Bold dataset to calculate natural background threshold values for the PCB TEQ sum. KM-based TEQ sums of the Bold PCB dataset resulted in only one unqualified data point out of 70 values (Appendix I: Table I-5). Fifteen of the samples had the highest contributing congener reported as non-detect (L-qualified, see Appendix F). These values are typically treated as censored. However, due to the lack of uncensored data, they were treated as uncensored to allow calculation of a 90/90 UTL with the understanding that it may be biased high. The data distribution was skewed (i.e., non-normal), with the 16 uncensored data points adequately described by both the gamma and the lognormal distribution (Anderson-Darling and Shapiro-Wilks tests p-values > 0.05, respectively). The lognormal distribution was a better fit, having the highest QQ-Plot correlation coefficient at a value of 0.984 for the uncensored data points. However, because there were so many censored data points (77%), the non-parametric 90/90 UTL estimate based on order statistics was preferred, which resulted in a value of 0.22 ng/kg TEQ.

A formal outlier test was not performed because the full data set did not fit a parametric distribution. However, the highest value (0.41 ng/kg TEQ) was nearly twice as high as the next highest value (0.23 ng/kg TEQ), so the influence of this single value on the UTL was investigated. Because of the large number of censored data points (78%), the 90/90 UTL using non-parametric order statistics was preferred, resulting in a value of 0.20 ng/kg TEQ. Both non-parametric UTL estimates round to 0.2 ng/kg TEQ (for one significant figure).

## I.2.3 cPAH TEQ

The Bold data set, plus six additional samples with cPAH congener data, resulted in a total of 76 data points to calculate natural background for cPAH TEQs. KM estimates of the cPAH TEQ sums were calculated, resulting in 39 uncensored values (51% uncensored, Appendix I: Table I-5). The data distribution was skewed (i.e., non-normal), with the uncensored data adequately described by the lognormal distribution (Shapiro-Wilks test p-value = 0.31, QQ-plot correlation coefficient of 0.982). Using a lognormal distribution with KM estimates of the mean and standard deviation for the logged TEQ values, the 90/90 UTL was 16 µg/kg cPAH TEQ.

The highest value (57 µg/kg TEQ) was more than 50% higher than the next highest value (37 mg/kg TEQ), and although it was not a statistical outlier, the influence of this single value on the UTL was investigated. Excluding this highest value, the uncensored data were not significantly

different from a lognormal distribution (Shapiro-Wilks test, p=0.80). The 90/90 UTL, assuming a lognormal distribution and using KM estimates of the mean and variance, was 14 µg/kg TEQ.

For these cPAH results, the large number of censored data points (49%) results in a large amount of uncertainty regarding the true distribution of the full data set. Non-parametric estimates of the UTL are robust for this sample size, so the 90/90 UTL based on non-parametric order statistics for the full data set was preferred, which resulted in an estimate of 21 µg/kg TEQ using all data.

## I.2.4 Metals

There were varying numbers of additional data that were added to the Bold dataset, depending on the metal. Results for each metal are presented below.

### I.2.4.1 Arsenic

Arsenic had a total of 96 data points, all of which were detected. The data distribution was skewed (i.e., non-normal), and was best described by a lognormal distribution (Shapiro-Wilks test p-value = 0.22, QQ-Plot correlation coefficient = 0.99). The two highest values (i.e., 21 and 17.8 mg/kg) that appear to be influential on the original scale were not statistical outliers for the lognormal distribution (Rosner's test for up to two outliers was not rejected at $\alpha = 0.05$). These values did, however, influence the mean and variance for the best-fitting lognormal distribution. The parametric estimate of the 90/90 UTL based on the lognormal distribution was 12.6 mg/kg, but this estimate may be unduly influenced by the two highest values. Non-parametric estimates of the UTL are robust for this sample size, so the BCA bootstrap estimate using all the data was preferred, which resulted in a value of 11 mg/kg.

### I.2.4.2 Cadmium

Cadmium had a total of 96 data points, all of which were detected. The data distribution was skewed (i.e., non-normal), and was best described by a lognormal distribution (Shapiro-Wilks test p-value = 0.15, QQ-Plot correlation coefficient = 0.989). The four high values (i.e., 1.2, 1.3, 2.3, 2.8 mg/kg) that appear to be influential on the original scale were not statistical outliers for the lognormal distribution (Rosner's test for up to four outliers was not rejected at $\alpha = 0.05$). These values do, however, have a strong influence on the estimates of mean and variance for the best-fitting lognormal distribution. The parametric estimate of the 90/90 UTL based on the lognormal distribution was 0.88 mg/kg, but this estimate may be unduly influenced by the four highest values. Non-parametric estimates of the UTL are robust for this sample size, so the BCA bootstrap estimate using all the data was preferred, which resulted in a value of 0.79 mg/kg, which rounds to 0.8 mg/kg (one significant figure).

### I.2.4.3 Chromium

Chromium had a total of 101 data points, all of which were detected. The data distribution was skewed (i.e., non-normal), and was best described by a lognormal distribution (Shapiro-Wilks test p-value = 0.48, QQ-Plot correlation coefficient = 0.994). The two high values (i.e., 97.1 and 105 mg/kg) that appear to be influential on the original scale were not statistical outliers for the lognormal distribution (Rosner's test for up to two outliers was not rejected at $\alpha = 0.05$). These values have a moderate influence on the estimates of mean and variance for the best-fitting lognormal distribution. The parametric estimate of the 90/90 UTL based on the lognormal distribution was 57 mg/kg using all the data, and 53 mg/kg excluding the two highest values. Non-parametric estimates of the UTL are robust for this sample size, so the BCA bootstrap estimate was preferred, which resulted in a value of 62 mg/kg.

### I.2.4.4 Copper

Copper had a total of 76 data points, all of which were detected. The data distribution was skewed (i.e., non-normal) and was best described by a gamma distribution (Anderson-Darling test p-value > 0.05, QQ-Plot correlation coefficient = 0.99). The highest data point (i.e., 91.2 mg/kg) which appears to be influential on the original scale is not an outlier for the gamma distribution (using the fourth-root transformation to approximate the normal distribution and applying Rosner's test, with $\alpha = 0.05$). This value does have a moderate influence on the estimate of shape and scale for the best-fitting gamma distribution. The parametric estimate of the 90/90 UTL based on the gamma distribution was 48 mg/kg using all the data, and 45 mg/kg excluding the highest value. Non-parametric estimates of the UTL are robust for this sample size, so the BCA bootstrap estimate on all the data was preferred, which resulted in a value of 45 mg/kg.

### I.2.4.5 Lead

Lead had a total of 96 data points, all of which were detected. The data distribution was skewed (i.e., non-normal) and was best described by a gamma distribution (Anderson-Darling test p-value > 0.05, QQ-Plot correlation coefficient = 0.98). The highest data point (i.e., 27.5 mg/kg) is not an outlier for the gamma distribution (using the fourth-root transformation to approximate the normal distribution and applying Rosner's test, with $\alpha = 0.05$). Using all data, the 90/90 UTL based on the gamma distribution (reporting the average of the two approximation methods provided by ProUCL) was 21 mg/kg. The non-parametric BCA bootstrap estimate on all the data was also 21 mg/kg.

### I.2.4.6. Mercury

Mercury had a total of 96 data points, with 29 non-detected values (70% detected). The detected data did not follow a discernible distribution, and there were no extreme or influential data points. A non-parametric 90/90 UTL based on order statistics was the only option for this censored

dataset, which resulted in a value of 0.17 mg/kg, which rounds to 0.2 mg/kg (one significant figure).

### I.2.4.7 Nickel

Nickel had a total of 93 data points, all of which were detected. The data distribution was skewed (i.e., non-normal) and was best described by a lognormal distribution (Shapiro-Wilks test p-value = 0.104, QQ-Plot correlation coefficient = 0.985). When a lognormal distribution was assumed for the full data set, the highest value (94.7 mg/kg) was a statistical outlier (identified by Rosner's test on the log-transformed data, $\alpha = 0.05$). The 90/90 UTL based on the lognormal distribution was 50 mg/kg using all the data, or 48 mg/kg excluding the highest value. Non-parametric estimates of the UTL are robust for this sample size, so the BCA bootstrap estimate was preferred on all the data, which resulted in a value of 50 mg/kg.

### I.2.4.8 Silver

Silver had a total of 96 data points, with 18 non-detected values (81% detected). The detected data did not follow a discernible distribution, and there were no extreme or influential data points. A non-parametric 90/90 UTL based on order statistics was the only option for this censored dataset, which resulted in a value of 0.24 mg/kg.

### I.2.4.9 Zinc

Zinc had a total of 76 data points, all of which were detected. The data distribution was slightly skewed (i.e., non-normal), but there were no extreme or influential data points. Neither the lognormal nor the gamma distributions were rejected for these data (Shapiro-Wilks and Anderson-Darling tests, respectively, with $p > 0.05$). However, the observed distribution tended to have fewer high values than expected under these skewed parametric distributions. Non-parametric estimates of the UTL are robust for this sample size, and are preferred when the parametric distributions do not provide a good fit to the data, particularly of the upper tail. The non-parametric BCA bootstrap estimate of the 90/90 UTL on all the data resulted in a value of 93 mg/kg.

**Appendix I: Table I-1.** Ecology-approved organics data.

| Chemical | | Benz[a] anthracene | Benzo(a) anthracene | Benzo(a) pyrene | Benzo(b) fluoranthene | Benzo(k) fluoranthene | Benzo fluor anthenes | Chrysene | Dibenzo(a,h) anthracene | Indeno (1,2,3-c,d) pyrene | p,p'-DDD | 4,4'-DDD | 4,4'-DDE | p,p'-DDE | 4,4'-DDT | p,p'-DDT | TBT | TBT ion (bulk) | TBT ion (pore-water) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Units | | ppb | ppb | ppb | ppb | ppb | ppb | ppb | ppb | ppb | ppb | ppb | ppb | ppb | ppb | ppb | ppb | ug/Kg | ug/L |
| Study ID | Study Location | | | | | | | | | | | | | | | | | | |
| MONAK4DF227 | AKB02 | | 4.3 U | 3.9 U | | | 6.2 | 5.5U | 3.9 | 5.4 | 1 U | | | 0.8 U | | 1.3 U | | 0.11 U | 0.0006 U |
| MONAK4DF227 | AKB02 | | 4.3 U | 3.9 U | | | 6.2 | 5.5U | 3.9 | 5.4 | 1 U | | | 0.81 U | | 1.3 U | | | |
| MONAK4DF227 | AKB02 | | 4.3 U | 3.8 U | | | 6 | 5.4U | 3.8 | 5.3 | 1 U | | | 0.79 U | | 1.3 U | | | |
| MONAK4DF227 | AKB03 | | 4.3 U | 3.8 U | | | 6.1 | 5.4 U | 3.9 | 5.3 | 0.99 U | | | 0.78 U | | 1.3 U | | 0.11 U | 0.0012 J |
| MONAK4DF227 | AKB03 | | 4.3 U | 3.8 U | | | 6.1 | 5.4 U | 3.9 | 5.3 | 1 U | | | 0.79 U | | 1.3 U | | | |
| MONAK4DF227 | AKB03 | | 4.3 U | 3.8 U | | | 6.1 | 5.4 U | 3.9 | 5.3 | 1 U | | | 0.8 U | | 1.3 U | | | |
| MONAK4DF227 | AKP01 | | 4.3 U | 3.8 U | | | 6.1 | 5.4 U | 3.9 | 5.3 | 1 U | | | 0.8 U | | 1.3 U | | 0.69 JP | 0.0015 J |
| MONAK4DF227 | AKP01 | | 4.3 U | 3.8 U | | | 6.1 | 5.4 U | 3.9 | 5.3 | 1 U | | | 0.8 U | | 1.3 U | | | |
| MONAK4DF227 | AKP01 | | 4.3 U | 3.9 U | | | 6.1 | 5.5 U | 3.9 | 5.4 | 1 U | | | 0.8 U | | 1.3 U | | | |
| MONAK4DF227 | AKP02 | | 4.3 U | 3.8 U | | | 23 | 20 | 3.9 | 5.3 | 1 U | | | 0.8 U | | 1.3 U | | 0.11 U | 0.0011 J |
| MONAK4DF227 | AKP02 | | 4.3 U | 3.8 U | | | 6 | 5.3 U | 3.8 | 5.2 | 0.99 U | | | 0.78 U | | 1.3 U | | | |
| MONAK4DF227 | AKP02 | | 4.3 U | 3.9 U | | | 6.1 | 5.5 U | 3.9 | 5.4 | 1 U | | | 0.8 U | | 1.3 U | | | |
| MONAK4DF227 | AKP03 | | 4.3 U | 20 | | | 34 | 24 | 3.9 | 5.4 | 1 U | | | 0.81 U | | 1.3 U | | 0.16 U | 0.0017 J |
| MONAK4DF227 | AKP03 | | 4.3 U | 3.8 U | | | 30 | 23 | 3.8 | 5.3 | 1 U | | | 0.79 U | | 1.3 U | | | |
| MONAK4DF227 | AKP03 | | 4.3 U | 23 | | | 54 | 27 | 3.8 | 5.3 | 1 U | | | 0.8 U | | 1.3 U | | | |
| MONAK4DF227 | AKP04 | | 4.3 U | 3.8 U | | | 29 | 21 | 3.8 | 5.3 | 1 U | | | 0.8 U | | 1.3 U | | 0.14 U | 0.0011 J |
| MONAK4DF227 | AKP04 | | 4.3 U | 22 | | | 32 | 21 | 3.8 | 5.3 | 1 U | | | 0.8 U | | 1.3 U | | | |
| MONAK4DF227 | AKP04 | | 4.3 U | 3.9 U | | | 25 | 5.5 U | 3.9 | 5.4 | 1 U | | | 0.81 U | | 1.3 U | | | |
| PASED08 | PA_RF01A | 15 U | | 20 U | 24 U | 23 | | 17 U | 21 | 22 | | 0.31 U | 0.27 U | | 0.31 U | | 1.6 U | | |
| PASED08 | PA_RF02A | 5.7 U | | 7.9 U | 9.2 U | 9 | | 6.4 U | 8.3 | 8.3 | | 0.32 U | 0.28 U | | 0.32 U | | 1.7 U | | |
| PASED08 | PA_RF03A | 5.9 U | | 8.1 U | 9.5 | 9.2 | | 6.6 U | 8.5 | 8.6 | | 0.48 U | 0.41 U | | 0.47 U | | 1.7 U | | |
| RAYONR05 | RAYONR05 SB-01 | 1.9 U | | 2.1 U | 24 U | 3.3 | | 2 T | 2.9 | 2.5 | | 0.2 U | 0.32 U | | 0.22 U | | | | |
| RAYONR05 | RAYONR05 SB-02 | 3.6 T | | 3.9 T | 9.2 U | 4.9 | | 5 T | 4.4 | 3.8 | | 0.3 U | 0.48 U | | 0.34 U | | | | |
| RAYONR05 | RAYONR05 SB-03 | 9.1 T | | 8.8 T | 9.5 | 11 | | 15 T | 9.5 | 8.2 | | 0.66 U | 1.1 U | | 0.73 U | | | | |

**Appendix I: Table I-2.** Ecology-approved data for metals.

| Chemical | | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Mercury | Nickel | Selenium | Silver | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Units | | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm |
| Study ID | Study Location | | | | | | | | | | | |
| MONAK4DF227 | AKB02 | 0.47 NE | 6.39 | 0.274 | 17.6 | 22.1 | 12.4 | 0.073 | 16 | 0.6 B | 0.108 | 40.6 |
| MONAK4DF227 | AKB02 | 0.34 NE | 5.84 | 0.275 | 14.8 | 21.1 | 11.9 | 0.073 | 15.4 | 0.8 B | 0.118 | 39.7 |
| MONAK4DF227 | AKB02 | 0.4 NE | 5.42 | 0.258 | 16.2 | 20.6 | 11.3 | 0.075 | 15.1 | 0.7 B | 0.11 | 38.2 |
| MONAK4DF227 | AKB03 | 0.19 NE | 5.33 | 0.282 | 14.4 | 21.9 | 10.6 | 0.078 | 13.1 | 0.8 B | 0.114 | 38.6 |
| MONAK4DF227 | AKB03 | 0.19 NE | 5.4 | 0.284 | 11.6 | 20.9 | 10.6 | 0.082 | 12.2 | 1 B | 0.125 | 35.7 |
| MONAK4DF227 | AKB03 | 0.23 NE | 5.61 | 0.294 | 12.3 | 21.2 | 10.5 | 0.071 | 12.5 | 1 B | 0.127 | 37.5 |
| MONAK4DF227 | AKP01 | 0.67 NE | 10.1 | 0.431 | 20.5 | 32.7 | 21.6 | 0.089 | 23.7 | 1.5 B | 0.217 | 54.9 |
| MONAK4DF227 | AKP01 | 0.41 NE | 8.22 | 0.379 | 16.3 | 28 | 21.8 | 0.137 | 19.9 | 1.4 B | 0.196 | 47.2 |
| MONAK4DF227 | AKP01 | 0.52 NE | 8.92 | 0.431 | 20.2 | 30.9 | 20.5 | 0.087 | 23.5 | 1.4 B | 0.188 | 54.2 |
| MONAK4DF227 | AKP02 | 0.32 NE | 5.83 | 0.314 | 17.2 | 25 | 12.4 | 0.077 | 15.6 | 0.9 B | 0.124 | 45.2 |
| MONAK4DF227 | AKP02 | 0.37 NE | 6.33 | 0.307 | 17.5 | 24.7 | 12.8 | 0.07 | 15.4 | 0.8 B | 0.137 | 44.1 |
| MONAK4DF227 | AKP02 | 0.26 NE | 6.24 | 0.301 | 15.4 | 23.4 | 12.7 | 0.092 | 15 | 0.8 B | 0.128 | 43.2 |
| MONAK4DF227 | AKP03 | 0.56 NE | 8.46 | 0.388 | 20.4 | 33.2 | 19.4 | 0.122 | 22.6 | 1.8 B | 0.213 | 56.3 |
| MONAK4DF227 | AKP03 | 0.65 NE | 9.06 | 0.413 | 21.1 | 33 | 20.5 | 0.115 | 23 | 1.7 B | 0.209 | 59.4 |
| MONAK4DF227 | AKP03 | 0.5 NE | 9.55 | 0.435 | 22.7 | 34.2 | 21.6 | 0.113 | 24 | 1.7 B | 0.21 | 61.5 |
| MONAK4DF227 | AKP04 | 0.66 NE | 9.16 | 0.4 | 23.5 | 28.2 | 18.3 | 0.107 E | 24.4 | 1.2 B | 0.163 | 57.5 |
| MONAK4DF227 | AKP04 | 0.74 NE | 9.16 | 0.419 | 22.9 | 28.6 | 18.4 | 0.093 | 25.8 | 1.3 B | 0.161 | 58.7 |
| MONAK4DF227 | AKP04 | 0.68 NE | 6.42 | 0.256 | 23.3 | 17.6 | 10.4 | 0.09 | 29.7 | 0.6 B | 0.166 | 44.3 |
| PASED08 | PA_RF01A | 0.1 JT | 7.1 | 0.14 JT | 37 | 34 | 4.3 | 0.012 JT | 45 | | 0.035 JT | 55 |
| PASED08 | PA_RF02A | 0.11 JT | 3.5 | 0.12 JT | 30 | 16 | 3.5 | 0.013 JT | 33 | | 0.029 JT | 52 |
| PASED08 | PA_RF03A | 0.2 JT | 6.9 | 0.39 | 41 | 31 | 8.3 | 0.077 | 40 | | 0.13 JT | 70 |
| RAYONR05 | RAYONR05SB-01 | | 2.7 | 0.218 | 21.4 | 6.9 | 2.2 | 0.02 | | 0.5 T | 0.084 E | 24.9 |
| RAYONR05 | RAYONR05SB-02 | | 6.03 | 0.678 | 30.9 | 16.4 | 5.7 | 0.04 | | 1.1 T | 0.218 E | 45.4 |
| RAYONR05 | RAYONR05SB-03 | | 7.5 | 1.3 | 36.2 | 28.6 | 9.03 | 0.07 | | 2.1 T | 0.341 E | 66.7 |

**Appendix I: Table I-3.** Ecology approved data for dioxins/furans.

| | Dioxins/Furans | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2,3,7,8-TCDD** | **1,2,3,7,8-PECDD** | **1,2,3,4,7,8-HXCDD** | **1,2,3,6,7,8-HXCDD** | **1,2,3,7,8,9-HXCDD** | **1,2,3,4,6,7,8-HPCDD** | **OCDD** | **2,3,7,8-TCDF** | **1,2,3,7,8-PECDF** | **2,3,4,7,8-PECDF** | **1,2,3,4,7,8-HXCDF** | **1,2,3,6,7,8-HXCDF** | **1,2,3,7,8,9-HXCDF** | **2,3,4,6,7,8-HXCDF** | **1,2,3,4,6,7,8-HPCDF** | **1,2,3,4,7,8,9-HPCDF** | **OCDF** |
| **TEF** | **1** | **1** | **0.1** | **0.1** | **0.1** | **0.01** | **0.0003** | **0.1** | **0.03** | **0.3** | **0.1** | **0.1** | **0.1** | **0.1** | **0.01** | **0.01** | **0.0003** |
| **Study ID** | | | | | | | | | | | | | | | | | |
| **CR02** | 0.0499 KJU | 0.533 J | 0.749 J | 2.89 J | 2.32 J | 43.9 | 320 | 0.859 J | 0.416 J | 0.612 J | 1.26 J | 0.453J | 0.0927 U | 0.457 J | 8.56 | 0.566 J | 20 |
| **CR23** | 0.0503 U | 0.227 J | 0.32 J | 0.977 J | 0.171 KJU | 13.3 | 96.1 | 0.0503 KJU | 0.0956 KJU | 0.22 J | 0.455 J | 0.169 J | 0.0936 U | 0.18 J | 3.15 J | 0.215 J | 7.64 J |
| **CR23W** | 0.07 KJ | 0.124 U | 0.181 U | 0.582 J | 0.406 J | 7.75 | 49.7 | 0.166 BJ | 0.105 J | 0.175 J | 0.246 J | 0.126 J | 0.0887 U | 0.129 J | 1.78 J | 0.107 J | 3.46 J |
| **CR24** | 0.077 KJ | 0.193 J | 0.185 U | 0.902 J | 0.683 J | 12.8 | 89.4 | 0.25 BJ | 0.146 J | 0.214 J | 0.324 J | 0.162 J | 0.905 U | 0.148 J | 2.69 J | 0.139 J | 5.66 J |
| **MSMP-43** | 0.0512 U | 0.131 U | 0.192 U | 0.308 J | 0.294 J | 3.95 J | 26.6 | 0.0505 KJU | 0.0959 U | 0.0969 KJU | 0.182 J | 0.121 U | 0.0938 U | 0.121 U | 1.09 J | 0.09 J | 2.29 J |
| **Samish Reference** | 0.23 J | 0.76 J | 0.61 I | 3.7 J | 2.2 J | 25 | 150 | 0.81 J | 0.39 J | 0.63 J | 0.55 J | 0.41 J | 0.53 J | 0.18 I | 4.8 J | 0.32 I | 10 |
| **PASED08-RF01A** | 0.0238 U | 0.0238 U | 0.0324 U | 0.057 JT | 0.034 JT | 0.177 JT | 0.839 JT | 0.06 JT | 0.0238 U | 0.034 JT | 0.033 JT | 0.024 JT | 0.0238 U | 0.0238 U | 0.069 JT | 0.0238 U | 1.13 U |
| **PASED08-RF02A** | 0.0241 U | 0.0241 U | 0.032 JT | 0.075 JT | 0.067 JT | 0.346 JT | 1.62 | 0.11 JT | 0.0241 U | 0.029 JT | 0.569 U | 0.0241 U | 0.0241 U | 0.0241 U | 0.53 U | 0.0241 U | 1.15 U |
| **PASED08 RF03A** | 0.116 JT | 0.236 JT | 0.191 JT | 1.01 | 0.82 | 8.06 | 53.7 | 0.779 | 0.106 JT | 0.188 JT | 0.224 JT | 0.128 JT | 0.0256 U | 0.125 JT | 1.82 | 0.111 JT | 3.02 |
| **RAYONR05SB-01** | 0.197 UJ | 0.089 U | 0.081 U | 0.098 U | 0.088 U | 1.947 JT | 13.069 B | 0.197 UJ | 0.06 U | 0.065 U | 0.065 U | 0.063 U | 0.095 U | 0.072 U | 0.364 JT | 0.275 U | 0.581 JT |
| **RAYONR05SB-02** | 0.058 U | 0.068 U | 0.051 U | 0.329 JT | 0.055 U | 2.865 JT | 20.364 B | 0.128703 | 0.044 U | 0.048 U | 0.059 U | 0.055 U | 0.096 U | 0.065 U | 0.921 JT | 0.236 U | 0.879 JT |
| **RAYONR05SB-03** | 0.547 U | 0.181 U | 0.175 U | 0.209 U | 0.188 U | 6.796 | 48.381 B | 0.547 U | 0.138 U | 0.147 U | 0.132 U | 0.128 U | 0.197 U | 0.143 U | 1.197 JT | 0.446 U | 2.446 JT |
| **GRAYS_OM90 West Beach** | 2.3 U | 0.64 U | 0.52 U | 0.83 U | 1.3 U | 2.4 | 19 | 2.6 U | 0.68 U | 0.69 U | 0.7 U | 0.51 U | 0.73 U | 0.75 U | 2 U | 0.95 U | 4.5 U |
| **GRAYS_OM90 Sequim** | 2.6 U | 0.95 | 1 | 3.1 | 2.1 | 36 | 230 | 1.9 | 1.1 U | 0.72 | 0.97 | 0.86 U | 0.97 | 0.88 U | 5.2 | 1.4 U | 13 |
| **AKB02** | 0.207 U | 0.42 J | 0.835 U | 1.70 J | 0.913 J | 23.4 | 179 | 0.987 | 0.415 U | 0.723 J | 0.979 J | 0.335 J | 0.544 J | 0.226 U | 5.58 | 0.3661 J | 13.3 |
| **AKB03** | 0.154 U | 0.565 J | 1.17 U | 2.79 | 1.58 J | 41.3 | 318 | 1.14 | 0.687 J | 1.23 J | 1.77 J | 0.684 J | 0.755 J | 0.345 J | 12.1 | 0.773 J | 29.7 |
| **AKP01** | 0.375 J | 1.42 J | 1.57 J | 7.22 | 4.11 | 97.8 | 695 | 3.43 | 2.11 J | 3 | 4.75 | 1.76 J | 1.83 J | 0.983 J | 24.5 | 1.78 J | 69.6 |
| **AKP02** | 0.211 J | 0.449 J | 0.987 U | 3.04 | 1.62 J | 44 | 287 | 1.21 | 0.646 J | 1.02 J | 1.46 J | 0.571 J | 0.666 J | 0.427 U | 9.52 | 0.651 J | 23.2 |
| **AKP03** | 0.286 J | 0.959 J | 1.46 U | 4.3 | 2.46 J | 53.1 | 344 | 2.65 | 1.65 J | 2.28 J | 3.15 | 1.10 J | 1.27 J | 0.644 J | 13.1 | 1.05 J | 37.8 |
| **AKP04** | 0.325 U | 0.795 J | 1.55 U | 3.8 | 2.14 J | 52.3 | 390 | 1.99 | 2.52 J | 2.28 J | 6.61 | 2.32 J | 1.28 J | 0.997 J | 14.3 | 1.41 J | 33.7 |
| **AKT01** | 0.356 U | 5.92 J | 1.13 U | 3.25 | 1.69 J | 47.4 | 304 | 1.67 | 0.887 J | 1.41 J | 1.88 J | 0.742 J | 0.689 J | 0.393 J | 8.4 | .864 J | 22.2 |

*This page intentionally left blank*

**Appendix I: Table I-4.** EIM data qualifier codes and descriptions.

| EIM Data Qualifier Code | EIM Data Qualifier Code Description |
|---|---|
| B | Analyte detected in sample and method blank. Reported result is sample concentration without blank correction or associated quantitation limit. |
| E | Reported result is an estimate because it exceeds the calibration range. |
| J | Analyte was positively identified. The reported result is an estimate. |
| JT | Analyte was positively identified. Reported result is an estimate below the associated quantitation limit but above the MDL. |
| K | Reported result with unknown bias. |
| N | There is evidence the analyte is present in the sample. Tentatively identified analyte. |
| T | Reported result below associated quantitation limit but above MDL. |
| U | Analyte was not detected at or above the reported result. |
| UJ | Analyte was not detected at or above the reported estimate. |
| UJK | Analyte was not detected at or above the reported estimate with unknown bias. |

**Appendix I: Table I-5.** Kaplan-Meier-based TEQ Sums for dioxin/furans, PCBs, and cPAHs.

| Data Group | Sample ID | Dioxin/ Furan TEQ (KM)[1] | Qualifier[2] | PCB TEQ (KM)[1] | Qualifier[2] | cPAH TEQ (KM)[1] | Qualifier[2] |
|---|---|---|---|---|---|---|---|
| BoldData | AI_1 | 0.61 | L | 0.051 | *7 | 2.6 | *5 |
| BoldData | AI_11_C | 0.19 | *13 | 0.031 | *10 | 2.6 | *6 |
| BoldData | AI_13_C | 0.6 | L | 0.12 | *7 | 2.5 | *5 |
| BoldData | AI_20_C_GS | 0.62 | | 0.038 | *6 | 3.1 | L |
| BoldData | AI_5_C | 0.56 | L | 0.044 | L | 2.6 | *5 |
| BoldData | CPS_0 | 1.9 | | 0.41 | L | 19 | |
| BoldData | CPS_1 | 2.2 | | 0.12 | L | 15 | |
| BoldData | CPS_3 | 1.3 | | 0.075 | L | 18 | |
| BoldData | CPS_4 | 0.95 | | 0.1 | *6 | 3.9 | |
| BoldData | CPS_5 | 0.79 | L | 0.17 | | 6.6 | |
| BoldData | HC_0 | 0.89 | | 0.23 | L | 6.3 | *4 |
| BoldData | HC_1 | 0.8 | | 0.074 | *6 | 2.7 | *5 |
| BoldData | HC_2 | 1.2 | L | 0.14 | *7 | 5.1 | *5 |
| BoldData | HC_3 | 0.65 | L | 0.22 | L | 4.6 | |
| BoldData | HC_6 | 0.77 | L | 0.22 | L | 7.9 | |
| BoldData | NCPS_0 | 0.83 | L | 0.15 | L | 6.2 | |
| BoldData | NCPS_1 | 0.21 | *14 | 0.096 | *9 | 1.8 | *7 |
| BoldData | NCPS_2 | 1.4 | L | 0.21 | L | 6.7 | |
| BoldData | NCPS_3 | 0.68 | | 0.11 | *6 | 21 | |
| BoldData | NCPS_4 | 0.48 | *9 | 0.039 | *6 | 3.5 | |
| BoldData | PSPS_1 | 2.4 | L | 0.081 | L | 3.0 | *7 |
| BoldData | PSPS_2 | 3.3 | L | 0.059 | *6 | 4.2 | |
| BoldData | PSPS_3 | 1.2 | L | 0.051 | *8 | 23 | |
| BoldData | PSPS_8 | 0.27 | *13 | 0.033 | *8 | 3.6 | *6 |
| BoldData | PSPS_9 | 1.9 | L | 0.083 | *7 | 2.7 | *6 |
| BoldData | R_CAR_0 | 0.84 | L | 0.034 | *7 | 2.2 | *7 |
| BoldData | R_CAR_1 | 1.3 | L | 0.022 | *7 | 2.6 | *5 |
| BoldData | R_CAR_4 | 1.1 | L | 0.065 | *6 | 6.5 | |
| BoldData | R_CAR_5 | 5.1 | | 0.082 | L | 8.8 | |
| BoldData | R_CAR_6_C | 0.48 | *11 | 0.055 | *6 | 1.9 | *7 |
| BoldData | R_DAB_0 | 0.54 | *11 | 0.048 | *7 | 2.0 | *7 |
| BoldData | R_DAB_1 | 1.6 | | 0.09 | *7 | 4.6 | *5 |
| BoldData | R_DAB_2 | 2 | L | 0.089 | *8 | 4.8 | |
| BoldData | R_DAB_5 | 2.1 | L | 0.093 | L | 8.8 | |
| BoldData | R_DAB_7_C | 1.2 | | 0.075 | L | 5.8 | |

| Data Group | Sample ID | Dioxin/ Furan TEQ (KM)[1] | Qualifier[2] | PCB TEQ (KM)[1] | Qualifier[2] | cPAH TEQ (KM)[1] | Qualifier[2] |
|---|---|---|---|---|---|---|---|
| BoldData | R_HOL_0 | 0.28 | *10 | 0.023 | *7 | 3.8 | *6 |
| BoldData | R_HOL_1 | 0.44 | L | 0.034 | *8 | 2.7 | *5 |
| BoldData | R_HOL_3 | 0.21 | *11 | 0.028 | *6 | 3.3 | *6 |
| BoldData | R_HOL_4 | 1.5 | L | 0.11 | *6 | 13 | |
| BoldData | R_HOL_7 | 0.86 | | 0.079 | *6 | 10 | |
| BoldData | R_SAM_0 | 1.3 | | 0.1 | *10 | 2.9 | L |
| BoldData | R_SAM_1 | 1.6 | | 0.046 | *7 | 6.8 | |
| BoldData | R_SAM_3 | 1.3 | | 0.066 | *8 | 5.5 | L |
| BoldData | R_SAM_4 | 0.88 | | 0.083 | *7 | 3.8 | |
| BoldData | R_SAM_5 | 1.8 | | 0.1 | *7 | 4.1 | |
| BoldData | SCPS_1 | 3.4 | | 0.12 | *8 | 37 | |
| BoldData | SCPS_10_C | 1.1 | | 0.044 | L | 4.9 | |
| BoldData | SCPS_2 | 0.61 | L | 0.048 | *6 | 2.4 | *5 |
| BoldData | SCPS_3 | 0.32 | *10 | 0.042 | *7 | 1.7 | *7 |
| BoldData | SCPS_5 | 3.6 | | 0.13 | *7 | 57 | |
| BoldData | SJF_10_C | 0.46 | *9 | 0.043 | *10 | 2.3 | L |
| BoldData | SJF_12_C_GS | 1.7 | | 0.11 | *8 | 4.8 | |
| BoldData | SJF_2 | 0.48 | *10 | 0.031 | *9 | 2.7 | L |
| BoldData | SJF_3 | 0.34 | *12 | 0.027 | L | 2.3 | L |
| BoldData | SJF_9_C | 0.82 | *10 | 0.041 | *6 | 2.5 | *5 |
| BoldData | SJI_0 | 1 | *9 | 0.066 | *6 | 8.6 | |
| BoldData | SJI_1 | 0.83 | | 0.026 | *8 | 2.1 | |
| BoldData | SJI_20_C_GS | 1.5 | L | 0.058 | *9 | 9.5 | |
| BoldData | SJI_3 | 0.68 | *10 | 0.04 | *9 | 2.0 | *6 |
| BoldData | SJI_8_C | 0.75 | L | 0.049 | *6 | 1.9 | *7 |
| BoldData | SPSB_0 | 1.5 | | 0.071 | *7 | 13 | |
| BoldData | SPSB_1 | 1.3 | | 0.12 | *7 | 9.6 | |
| BoldData | SPSB_2 | 2.1 | | 0.15 | *8 | 6.8 | |
| BoldData | SPSB_3 | 0.39 | *11 | 0.038 | *8 | 2.0 | *7 |
| BoldData | SPSB_8_C | 0.25 | *13 | 0.02 | *9 | 2.3 | |
| BoldData | SS_0 | 8.3 | | 0.11 | *8 | 5.8 | L |
| BoldData | SS_1 | 0.55 | L | 0.019 | *11 | 1.5 | *7 |
| BoldData | SS_2 | 1.3 | | 0.076 | *6 | 5.5 | |
| BoldData | SS_8_C | 1.3 | L | 0.062 | *6 | 5.9 | |
| BoldData | SS_9_C | 12 | | 0.13 | *7 | 14 | |
| PlusData | CR02 | 2.3 | | | | | |

| Data Group | Sample ID | Dioxin/Furan TEQ (KM)[1] | Qualifier[2] | PCB TEQ (KM)[1] | Qualifier[2] | cPAH TEQ (KM)[1] | Qualifier[2] |
|---|---|---|---|---|---|---|---|
| PlusData | CR23 | 0.73 | | | | | |
| PlusData | MSMP43 | 0.3 | *9 | | | | |
| PlusData | CR23W | 0.54 | L | | | | |
| PlusData | CR24 | 0.78 | | | | | |
| PlusData | samish.ref | 2.4 | | | | | |
| PlusData | PASED08RF01A | 0.084 | L | | | 21 | *7 |
| PlusData | PASED08RF02A | 0.11 | *10 | | | 8.3 | *7 |
| PlusData | PASED08RF03A | 0.86 | | | | 8.5 | *7 |
| PlusData | RAYONR05SB01 | 0.14 | *13 | | | 2.2 | *6 |
| PlusData | RAYONR05SB02 | 0.17 | *11 | | | 5.6 | |
| PlusData | RAYONR05SB03 | 0.33 | *13 | | | 12 | |
| PlusData | GRAYSOM90.WestBeach | 2.4 | *15 | | | | |
| PlusData | GRAYSOM90.SequimBay | 5.3 | L | | | | |
| PlusData | AKT01 | 2.9 | | | | | |
| PlusData | AKP01 | 6.8 | | | | | |
| PlusData | AKP02 | 2.4 | | | | | |
| PlusData | AKP03 | 4.4 | | | | | |
| PlusData | AKP04 | 4.5 | | | | | |
| PlusData | AKB02 | 1.6 | | | | | |
| PlusData | AKB03 | 2.6 | | | | | |

1, All TEQs were rounded to 2 significant figures after KM calculations were performed.

2, Qualifiers assigned to the KM-based TEQ sums:

“L" qualifier assigned when the highest non-detect TEC exceeded all detected TECs. Substitution at the DL was used, and the TEC was treated as uncensored in the KM calculation. TEQ sum is considered an upper bound.

"*n" qualifier assigned when the proportion of detected congeners in a sample is less than approximately 50%. The 'n' indicates the number of censored congeners (including the highest and lowest). TEQ sum is considered a biased high estimate.

# Appendix J
# Determining Toxicity of Naturally Occurring Chemicals

## J.1 Introduction

Sediment can be contaminated by natural chemicals (such as ammonia and sulfide) that derive from either natural or anthropogenic sources, and evaluation and assessment of sediment toxicity may need to be conducted differently. This includes the occurrence and interpretation of natural chemicals at several PSEP-recognized reference stations across Puget Sound, or at reference stations established for freshwater sites.

## J.2 Approaches to Toxicity Test Exposures

The origins of the sediment toxicity evaluations described in the DMMP guidelines and the SMS rule are from the PSEP protocols (PSEP, 1995). These protocols were developed for evaluating dredged sediment for navigation and commerce purposes, with the assumption that most dredged sediment would be placed in deep, open-water disposal sites. The protocols were therefore intended for the act of disposal (e.g., they allowed for some reduction of semi-volatile compounds during settling). Laboratory test conditions for DMMP purposes were designed to simulate exposure conditions experienced during the disposal process or at the disposal sites. For example, sediment samples are mixed and allowed to settle in test chambers or sediment is purged before test organisms are introduced.

For cleanup under the SMS rule, the DMMP testing approach can be problematic as it does not represent *in situ* sediment conditions because:

> 1) -The DMMP test protocols include mixing or purging which can result in the release of volatile chemicals present in *in situ* sediment. Therefore, these test conditions would not represent *in situ* sediment conditions at a cleanup site or for the sample being evaluated from a cleanup site.
>
> 2) Unlike the PSEP protocols, the SMS/SCUM sediment chemical and biological protocols are designed to simulate *in situ* sediment conditions to determine the horizontal and vertical extent of the sediment chemistry and biological effects of undisturbed sediment remaining in place. Sampling is focused primarily on the biologically active zone where chemicals pose the greatest risk to human health and the environment. If

PSEP is used, additional evaluation of the underlying sediment is often necessary to determine human health and ecological risks that may remain after any dredging occurs.

For purposes of cleanup, mixing or purging of sediment samples prior to analysis should not be done to determine nature and extent of contamination or impacts (i.e., *in situ* conditions). However, mixing or purging of sediment samples prior to analysis can be done to determine if certain remedies are appropriate. This protocol should include evaluation of both purged/unpurged and/or mixed/unmixed sediment samples.

## J.3 Natural versus Anthropogenic Sources of Chemicals

A natural chemical (e.g., ammonia or sulfide) in sediment can occur with or without anthropogenic influence. For example ammonia can occur in marine sediment as a result of the nitrogen cycle (i.e., occurs naturally) or as a result of the accumulation and subsequent breakdown of wood waste, stormwater, fertilizers, etc. (i.e., anthropogenic influence) (Ecology, 2013a). Ammonia and sulfides have numerous natural and anthropogenic sources. Sulfides are a particular concern in areas impacted by woodwaste. For example, in Puget Sound a substantial portion of shorelines were built with fill containing woodwaste which can result in high sulfide concentrations in groundwater and sediment.

Most benthic organisms are adapted to a range of concentrations of naturally occurring chemicals, due in part to their differing tolerance and divergent habitat preferences. Relatively short exposures to natural chemicals at the higher end of the normal range can be tolerated with little effect at the population level beyond natural seasonal fluctuations. However, when levels of natural chemicals exceed the normal concentration range threshold, significant toxicity to the benthic community may occur. When sediment is impacted by even more combinations of natural chemicals, it can result in increased acute (mortality) or chronic (reduced reproduction) effects.

### J.3.1 Ammonia as a natural chemical

Ammonia is a by-product of bacterial degradation of nitrogen-rich compounds in sediment. Sources of nitrogen can be natural (such as animals or organic-rich plants) or anthropogenic (such as synthetic amines and amides). Nitrogen loading to sediment can be significantly augmented by anthropogenic sources or activities such as:

- Processing and handling of plant material for manufacturing paper and wood products
- Food processing such fish, shellfish or meat rendering
- Human sewage

- Run-off due to erosion-enhancing activities such as road construction, mining, and logging near stream beds
- Agricultural and residential application of natural and chemical fertilizers
- Animal waste from livestock production

Therefore, *in situ* sediment evaluations should consider ammonia and many other compounds and conditions (such as sulfides, heavy metals, dissolved, temperature), then compare them to reference sediment.

### J.3.2 Ammonia in reference sediment

The SMS requires site sediment to be compared to reference sediment to determine if benthic biological criteria have been exceeded. Reference sediment should reflect natural sediment conditions in the absence of anthropogenic influences. Several suitable sediment reference sites in Puget Sound have been identified for this purpose (PSEP, 1991). Freshwater sediment reference sites must be determined on a case-by-case basis. Ammonia may cause an exceedance of the biological criteria, either solely or in combination with other chemicals. Therefore, purging or other manipulation of surface sediment to remove ammonia from test samples would not be representative of *in situ* sediment conditions and potential toxicity. However, evaluation of purged or manipulated sediment samples may be appropriate for determining the cleanup alternative (capping, dredging, etc.).

## J.4 Summary

Evaluation of sediment toxicity for compliance with the SMS requires comparison of site sediment to reference sediment. It is assumed that reference sediment represents *in situ* sediment conditions unaltered by anthropogenic activities. Reference sediment contains naturally occurring chemicals that may cause toxicity if found in concentrations above normal "background" reference sediment conditions. Augmentation of these compounds by anthropogenic sources may exceed the natural tolerance range of the benthic community or bioassay test organisms and cause significant toxic effects. PLPs responsible for direct or indirect augmentation of natural chemicals that result in toxicity to biological resources and exceed the SMS criteria may be required to conduct cleanup.

*This page left intentionally blank.*

# Appendix K
# Spreadsheets for Calculating Risk-Based Concentrations for Sediment and Tissue

## K.1 Introduction

This appendix contains spreadsheets to use as a resource for calculating risk-based concentrations for:

- Sediment. To calculate risk-based sediment concentrations protective of human health and higher trophic levels using site-specific BSAFs (Chapter 9, Option 2 and Figure 9-3).

- Sediment. To calculate risk-based sediment concentrations protective of human health using the incidental sediment ingestion and dermal contact exposure pathways (Chapter 9, Options 1 and 2).

- Tissue. To calculate risk-based tissue concentrations protective of human health and higher trophic levels using the consumption of fish and shellfish exposure pathway (Chapter 9, Option 2).

These spreadsheets were used in conjunction with the recommended exposure parameters in Chapter 9 (Table 9-1 and Table 9-3) to calculate the risk-based values for sediments and tissues presented in Chapter 9 (Table 9-2 and Table 9-4). The values in Tables 9-2 and 9-4 for each exposure parameter can be modified to calculate site-specific values upon approval by Ecology, as discussed in Appendix E. In addition, the spreadsheet can be used to conduct a sensitivity analysis to determine the effect that varying specific parameters would have on the resulting tissue and sediment concentrations. Such an evaluation would be useful, for example, to determine whether risk-based sediment concentrations would be below background regardless of how a particular parameter is modified (assuming a reasonable range).

The spreadsheets can be accessed here:
https://fortress.wa.gov/ecy/publications/SummaryPages/1209057.html

*This page left intentionally blank.*

# Appendix L
# False Positive and False Negative Error Rates Associated with Simulated Compliance Scenarios

This appendix provides further detail on the recommended approach to determine compliance for a remediated site, described in Chapter 13. The simulations in this appendix were performed to estimate the false positive and false negative error rates (Type I and II errors) that are associated with the two compliance testing approaches described in Chapter 13 (Options A and B). They also describe error rates associated with one alternative approach suggested in the public comments. These approaches involve the following comparisons to the site-specific sediment cleanup level:

- **Option A**: Point-by-point comparison of each value
- **Option B**: Comparison of the mean (arithmetic or area-weighted)
- **Alternative**: Comparison of the 95$^{th}$ upper confidence limit (95UCL) of the mean

In these simulations, the cleanup level is a bright line threshold, and it is considered as such during compliance monitoring. The cleanup level could be the SCO, CSL, or some level in between. It may be based on background, risk, or the practical quantitation limit (PQL). See Chapter 7 for more detail on how the SCO, CSL, and cleanup levels are established. What the cleanup level is based upon (background, risk, or PQL) does not affect the outcome of the simulations, but may be important for interpreting the ecological, chemical, and biological relevance of these outcomes. Those issues are explored in the discussion (Section L.3).

In these simulations, multiple site scenarios were explored that involved a range of sample sizes, site mean values, variability, and skewness. The site scenarios and methods are described in Section L.1, results are presented graphically in Section L.2, and discussion and conclusions are presented in Section L.3.

## L.1 Methods

Monte Carlo simulations were used to evaluate 14 different scenarios to describe possible site conditions, where theoretical ("true") site means ranged from 50% below the cleanup level to 30% above the cleanup level. The 14 scenarios can be grouped into two general categories: those used to assess false positive error rates (Scenarios 1–9, Appendix L: Table L-1) and those used to assess false negative error rates (Scenarios 10–14, Table L-1). Each simulated draw is a

random sample from an independent, simulated site. Therefore, these error rates can be collectively thought of as programmatic error rates, rather than the probability of failure at a specific site. The assumption in each of these scenarios is that the site has already been cleaned up and is in the compliance monitoring phase.

## L.1.1. False positive error rate scenarios

The false positive error rate is the rate at which a clean site (i.e., a site with a true mean below the cleanup level) will fail the compliance monitoring test.

For the assessment of false positive error rates, nine different distributions were considered for the theoretical (true) distribution of sediment chemical concentrations in the compliance monitoring data set. The simulated true site means ranged from 50 - 10 % below the cleanup level (Scenarios 1–9 in Appendix L: Table L-1 and Appendix L: Figure L-1).

Scenarios 1 and 2 represent skewed (lognormal) distributions where the means are well below the cleanup level (i.e., true mean to cleanup level ratios of 0.5 and 0.7). The higher variability (coefficients of variation [CV] of 1.3) and right-skew of these distributions means that both the frequency of samples exceeding the cleanup level, as well as the magnitude of exceedance, is higher than for the symmetric distributions with similar means. These scenarios were chosen to represent sites that have mostly low concentrations but exhibit some higher concentration areas or stations.

Scenarios 3 through 9 represent symmetric (normal) distributions with means increasingly closer to the cleanup level (i.e., true mean to cleanup level ratios ranging from 0.5 to 0.9) and constant CV (CV = sd/mean) of either 0.5 or 1.0. These symmetric distributions are representative of sites that have been uniformly cleaned up, with the variability in concentrations driven by natural processes. Many of the concentration distributions for the regional background studies completed to date have exhibited symmetric or slightly skewed distributions with CVs of 0.6 or less.

## L.1.2 False negative error rate scenarios

The false negative error rate is the rate at which a “contaminated site” (i.e., a site with a true mean above the cleanup level) will pass the compliance monitoring test.

For the assessment of false negative error rates, five different distributions were considered for the theoretical (true) distribution of sediment chemical concentrations at the site. Scenarios 10 through 14 are symmetric (normal) distributions with true site means exceeding the cleanup level (i.e., true mean to cleanup level ratios ranging from 1.1 to 1.3, Table L-1, and Appendix L:

Figure L-2). The frequency of samples exceeding the cleanup level is greater than 50% in each distribution. These symmetric distributions are indicative of sites that may have undergone active cleanup but either a) used a capping material with elevated concentrations; b) did not adequately address source control and the site was recontaminated; or c) are in a monitored natural recovery process and may not yet have achieved the cleanup standards. Skewed distributions were not assessed because they would be expected to have a higher failure rate and thus a lower false negative rate than the normal distributions.

## L.1.3. Error rate calculation

For each scenario, a random sample of *n* observations was drawn from the true site distribution using six different sample sizes for the compliance monitoring data set: *n* = 6, 8, 10, 15, 20, and 30.

The error rates were evaluated using the three different compliance tests described above:

- **Chapter 13, Option A**: Point-by-point comparison of each value to the cleanup level.
- **Chapter 13, Option B**: Comparison of the mean (arithmetic or area-weighted) to the cleanup level.
- **Alternative**: Comparison of the 95$^{th}$ upper confidence limit (95UCL) of the mean to the cleanup level.

For each scenario assuming possible distributions (i.e., shape, mean, and standard deviation) and sample sizes (*n*) for the compliance monitoring data set, the following steps were performed:

1. Simulate a random sample of size *n* from the theoretical distribution with the specified shape, mean ($\mu$), and standard deviation ($\sigma$).
2. Compare the arithmetic mean, the 95UCL of the mean, and all individual observations to the cleanup level (set at 60 for these simulations).
3. Repeat Steps 1 and 2 10,000 times and count the number of false positives and false negatives for each of the summary statistics in Step 2.

# L.2 Results

Results for the nine scenarios used to evaluate false positive error rates and the five scenarios used to evaluate false negative error rates are shown in Appendix L: Figure L-3 through Figure L-6. These are discussed below, organized by approach.

## L.2.1 Point-by-point comparison to the cleanup level (Option A)

The false positive rates associated with a compliance test that counts the number of individual samples exceeding the cleanup level are shown in Figure L-3 for the nine scenarios described in Table L-1 and Appendix L: Figure L-1. Results are shown for when *m* or more individual samples within a data set exceed the cleanup level, for *m* = 1, 2, and 3.

- One or more samples exceeding the cleanup level was least likely for Scenario 3, which had false positive error rates ranging from 13 to 50% for all sample sizes. For all other scenarios, false positives occurred at a rate of greater than 60%.

- Two or more samples exceeding the cleanup level was least likely for Scenario 3, which had false positive error rates of less than 16% for all sample sizes. For all other scenarios, false positives occurred at a rate of greater than 24%.

- Three or more samples exceeding the cleanup level was least likely for Scenario 3, which had false positive rates of less than 4% for all sample sizes. For all other scenarios, and sample sizes of 10 or more, false positives occurred at a rate of greater than 20%.

Only the scenario with a symmetric distribution and a mean concentration of 50% of the cleanup level had reasonably low false positive error rates that would have a high likelihood of meeting the compliance test (less than three samples above the cleanup level). Because Option A is designed for compliance with benthic criteria, which are relatively high compared to background, PQL, or human health risk-based criteria, a compliance monitoring data set with concentrations this low relative to the cleanup level should be achievable.

The false negative rates associated with a compliance test that counts the number of individual samples exceeding the cleanup level are shown in Appendix L: Figure L-4 for the five scenarios described in Table L-1 and Figure L-2.

- When no samples exceeded the cleanup level, sample sizes of 6 had false negative error rates of 1% or less for all scenarios. All scenarios with sample sizes greater than 6 had false negative rates that were effectively zero.

- When one sample exceeded the cleanup level, sample sizes of 6 or 8 had false negative error rates of less than 8% for all scenarios. All scenarios with sample sizes of 10 or more had false negative rates that were effectively zero.

- When two samples exceeded the cleanup level, sample sizes of 6 – 10 had false negative rates less than 27% for all scenarios. False negative rates were higher for scenarios with true means closer to the cleanup level (i.e., as high as 27% for Scenario 10 and as low as 9% for Scenario 13). All scenarios with samples sizes of 15 or more had false negative rates that were effectively zero.

Similar to false positives:

a) when sample sizes are small (i.e., $n \leq 10$), and

b) if the mean is close to the cleanup level, then

c) false negative error rates are also high (i.e., between 10 – 30%) for the compliance test in Option A (no more than two samples above the cleanup level).

When sample sizes are large ($n$ = 15 or more), false negatives are effectively zero. Thus, for both false positives and false negatives, if the mean of the compliance data set is expected to be near the cleanup level, a minimum of 15 – 20 samples is recommended to improve the accuracy of the compliance determination under Option A.

## L.2.2 Comparison of the arithmetic mean to the cleanup level (Option B)

The false positive rates associated with <u>a compliance test that compares the arithmetic mean to the cleanup level</u> are shown in Appendix L: Figure L-5 for the nine scenarios described in Table L-1 and Figure L-1.

- Scenarios 1 and 2 represent skewed distributions with means of 0.5 and 0.7 of the cleanup level, respectively. Skew increases the probability of exceeding the cleanup level at very high magnitudes, which increases the false positive rate for this compliance test. The false positive error rate exceeds 50% for Scenario 2, and exceeds 19% for sample sizes of 20 or less for Scenario 1.

- Scenarios 3 through 5 represent symmetric distributions with means from 0.5 to 0.7 of the cleanup level, and variances such that 20% or less of the distributions is expected to exceed the cleanup level. For these scenarios, the false positive rate is very low (2% or less).

- Scenarios 6 and 7 represent symmetric distributions with means from 0.7 to 0.8 of the cleanup level and approximately 30% of the samples from these distributions expected to exceed the cleanup level. For these scenarios, the false positive rate is less than 20% for all sample sizes.

- Scenarios 8 and 9 represent symmetric distributions with means from 0.8 to 0.9 of the cleanup level and more than 40% of the samples from these distributions expected to exceed the cleanup level. The false positive error rate is approximately 20% or higher for all sample sizes considered for Scenario 8, and approximately 50% or higher for Scenario 9.

Based on these results, skewness in the distribution (i.e., samples or areas with higher concentrations) increases false positives to substantially higher levels than are present in normal distributions (more evenly distributed concentrations). Therefore, the chances of failure will be much greater if some areas are experiencing recontamination, have not fully recovered, or the remedy has failed. This result supports program goals in allowing Ecology to detect sites that may have remaining problem areas. However, in such cases, it may be appropriate to separate areas contributing to the skewness from the remainder of the site for compliance purposes.

If most of the distribution is well below the cleanup level, (e.g., if the site distribution is comparable to a regional background distribution used to set a 90/90 UTL as the cleanup level, like Scenario 3), false positive error rates are negligible. If the mean of the compliance monitoring data set is 70 – 80% of the cleanup level, even with fairly wide variability (CV = 1), even small sample sizes ($n$ = 6) will constrain programmatic false positive error rates to 20% or less, while sample sizes of 15 or more will increase the chances of compliance at individual sites. If the mean of the compliance data set is within 20% of the cleanup level, false positive error rates are high (i.e., greater than 20 %).

The false negative rates associated with <u>a compliance test that compares the arithmetic mean to the cleanup level</u> are shown in Appendix L: Figure L-6 for the five scenarios described in Table L-1 and Figure L-2.

- Scenario 10 represents a symmetric distribution with a mean 1.1 times the cleanup level and 54% of the distribution expected to exceed the cleanup level. The false negative rate falls below 20% only at sample sizes greater than 20.

- Scenarios 11–14 represent symmetric distributions with true means 1.2 to 1.3 times the cleanup level and 56% or more of the distributions expected to exceed the cleanup level. The false negative rate is below 20% for all sample sizes (Scenarios 11, 13, and 14), for 8 or more samples (Scenario 12), and for 15 or more samples (Scenario 10).

Similar to false positives, if the mean is close to the cleanup level and variability is high (CV ≥ 1), false negative error rates are also high (i.e., greater than 10 – 20%). If the mean is 20–30% above the cleanup level, false negative error rates may still be high (i.e., greater than 10 – 20%) unless variability is low (CV ≤ 0.5) and/or sample sizes are large (*n* = 15–20 or more). Thus, for both false positives and false negatives, if the mean of the compliance data set is expected to be near the cleanup level, a minimum of 15–20 samples is recommended to improve the accuracy of the compliance determination.

## L.2.3 Alternate approach: Comparison of the 95$^{th}$ UCL of the mean to the cleanup level

The false positive rates associated with a compliance test that compares the 95UCL of the arithmetic mean to the cleanup level are shown in Appendix L: Figure L-7 for the nine scenarios described in Table L-1 and Figure L-1. The width of the confidence limit becomes narrower for larger sample sizes, resulting in a decrease in the false positive error rates for higher *n*, as long as the true mean is sufficiently below the cleanup level.

- Scenario 3 represents a distribution with a very low frequency of samples exceeding the cleanup level (i.e., 2%). The false positive rate is zero at all sample sizes.

- Scenarios 4 and 5 represent symmetric distributions with means from 0.5 to 0.7 of the cleanup level and approximately 20% of the samples from these distributions expected to exceed the cleanup level. For these scenarios, the false positive rate is less than 20% for a sample size of 8 or more (Scenario 4), or 10 or more (Scenario 5).

- Scenarios 1, 2, and 6 – 9 all have high false positive error rates (i.e., greater than approximately 20% for all sample sizes).

If most of the distribution is well below the cleanup level, (e.g., if the site distribution is comparable to the regional background distribution whose 90/90 UTL set the cleanup level, like Scenario 3), then false positive error rates are negligible. If concentration ranges are low relative to the cleanup level, sample sizes of 8 – 10 or more will constrain programmatic false positive error rates to acceptable levels (i.e., 20% or less). Sample sizes of 15 or more will increase the chance of compliance at individual sites. If concentration ranges are moderate relative to the cleanup level and/or variability is high and/or the distribution is skewed, false positive error rates are unacceptably high (i.e., 20% or more).

The false negative rates associated with a compliance test that compares the 95UCL of the arithmetic mean to the cleanup level are shown in Appendix L: Figure L-8 for the five scenarios described in Table L-1 and Figure L-2.

- Small sample sizes ($n < 10$) have the highest false negative error rates, which ranged from less than 1 to 4% (Scenario 10).

- Sample sizes of 10 or more have false negative rates of 2% or less for all scenarios.

The built-in conservatism of this alternative testing approach results in false negative error rates of less than 4% for all sample sizes, for scenarios with site means between 10 and 30% of the cleanup level.

## L.3 Discussion

### L.3.1 Option A – Point-by-point comparison to the cleanup level

For benthic criteria, the previous compliance test required that every sample be below the cleanup level, regardless of the number of samples collected. For large sites with many compliance monitoring samples, the chances of at least one sample exceeding the cleanup level were relatively high, just due to random chance. Thus, the current compliance test is similar to that used to identify a site – no more than two samples may exceed the cleanup level. The results of these simulations suggest that cleanups should aim for concentrations of 50% or less of the applicable benthic cleanup level (e.g., Scenario 3) to ensure a high likelihood that fewer than three stations exceed the cleanup level even with larger sample sizes (i.e., 15 or more). At these larger sample sizes, the false negative error rates were effectively zero, even for sites with true means very close to the cleanup level. Ecology's 20-year program history of implementing these standards suggests that these cleanup levels along with the revised compliance monitoring test are achievable.

However, for bioaccumulation-based criteria, three or more individual exceedances are likely to occur at too high a frequency for Option A to be of use for compliance monitoring, since it is much less likely that the site-wide mean will be less than half the cleanup level. Option A may be useful in rare cases where most or all of the compliance data set is undetected and the PQL is lower than the cleanup level.

## L.3.2 Option B – Comparison of the mean to the cleanup level

The results of the simulations suggested several key points that have influenced Ecology's choice of the compliance monitoring test for Option B:

- If the cleanup level is based on the 90/90 UTL of a regional or natural background data set, and the cleanup is able to achieve a distribution similar to background through active or passive cleanup alternatives, false positives are expected to be quite low (i.e., 2% or less).

- When the cleanup level is based on another option (e.g., risk-based or PQL) and/or the compliance data set is expected to have a mean between 20 and 30% of the cleanup level, a minimum of 15–20 samples should provide both false positive and false negative error rates at reasonably low levels (less than 20%). The samples should also provide an adequate degree of confidence in the compliance decision for an individual site.

- If the compliance data set is skewed, it is much more likely to fail the cleanup level than a normally distributed data set with the same mean concentration. This may allow Ecology to identify sites where certain areas are not in compliance, while separating out and passing areas of the site where cleanup was successful.

- When the compliance data set is expected to have a mean within ±20% of the cleanup level, it is unlikely that false positives and false negatives can be reduced to reasonable levels. While it would be ideal to require cleanups to attempt to reach lower levels, with the very low cleanup standards required for bioaccumulative chemicals, Ecology recognizes that this may not be possible, especially when the cleanup level is based on natural background or the PQL. However, at this close to the cleanup level, the mean will be within analytical and/or field variability of the cleanup level and Ecology will consider such values in compliance with the cleanup level (see Section 13.6.1).

Because it is not always possible to know in advance which of the above cases will apply to any given site, Ecology recommends collecting a minimum of 15–20 samples for compliance purposes under Option B.

## L.3.3 Alternative approach – Comparison of the 95th UCL of the mean to the cleanup level

This approach employs the precautionary principle and inherently minimizes false negatives, resulting in false negative rates of 4% or less for all sample sizes. However, to reduce false positives to 20% or less using this approach, it would be necessary for the mean of the compliance monitoring data set to be at least 50 – 70% below the cleanup level, with low variability. While false positives could be reduced by increasing the size of the data set, the numbers of samples required (more than 30) would likely be prohibitive for data sets with means higher than 70% of the cleanup level, especially at smaller sites.

Because of the very low cleanup standards required for bioaccumulative chemicals—many of which may be based on background concentrations or PQLs—Ecology considers it unlikely that cleanups can achieve 50 – 70% or less of the cleanup level on a routine basis. As shown for Option B, it appears that error rates for comparison of the mean alone (without an upper confidence limit) are reasonable for concentration distributions that should be achievable in practice. Therefore, this alternative approach was not selected as the compliance monitoring test.

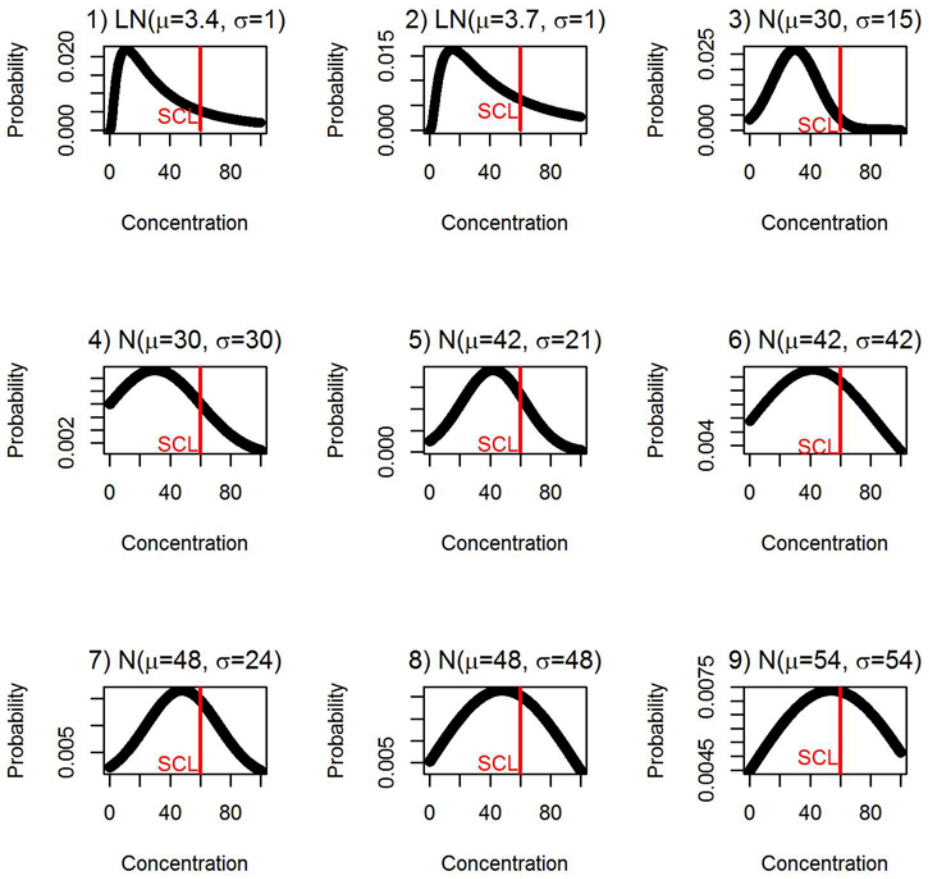
However, the error rate information in this appendix for Option B allowed Ecology to select an appropriate number of samples (at least 15 – 20) to ensure that the correct compliance decision is made <u>at least</u> 80% of the time. When a false negative does occur, the mean of the compliance monitoring data set will likely be very close to the cleanup level (i.e., within 20%, well within sampling variability), rather than substantially above it.

**Appendix L: Table L-1.** Description of the simulation scenarios used to assess false positive and false negative error rates associated with compliance monitoring tests.

| Scenario | Ratio of the true mean relative to the cleanup level | Shape (μ, σ) | Coefficient of variation | Pr(X > 60)[1] |
|---|---|---|---|---|
| **Distributions for Evaluating False Positive Errors** | | | | |
| **Skewed (lognormal) distributions[2]** | | | | |
| 1 | 0.5 | LN (3.4, 1) | 1.3 | 24% |
| 2 | 0.7 | LN (3.7, 1) | 1.3 | 35% |
| **Symmetric (normal) distributions** | | | | |
| 3 | 0.5 | N (30, 15) | 0.5 | 2% |
| 4 | 0.5 | N (30, 30) | 1.0 | 16% |
| 5 | 0.7 | N (42, 21) | 0.5 | 20% |
| 6 | 0.7 | N (42, 42) | 1.0 | 33% |
| 7 | 0.8 | N (48, 24) | 0.5 | 31% |
| 8 | 0.8 | N (48, 48) | 1.0 | 40% |
| 9 | 0.9 | N (54, 54) | 1.0 | 46% |
| **Distributions for Evaluating False Negative Errors** | | | | |
| **Symmetric (normal) distributions** | | | | |
| 10 | 1.1 | N (66, 66) | 1.0 | 54% |
| 11 | 1.2 | N (72, 36) | 0.5 | 63% |
| 12 | 1.2 | N (72, 72) | 1.0 | 56% |
| 13 | 1.3 | N (78, 39) | 0.5 | 68% |
| 14 | 1.3 | N (78, 78) | 1.0 | 59% |

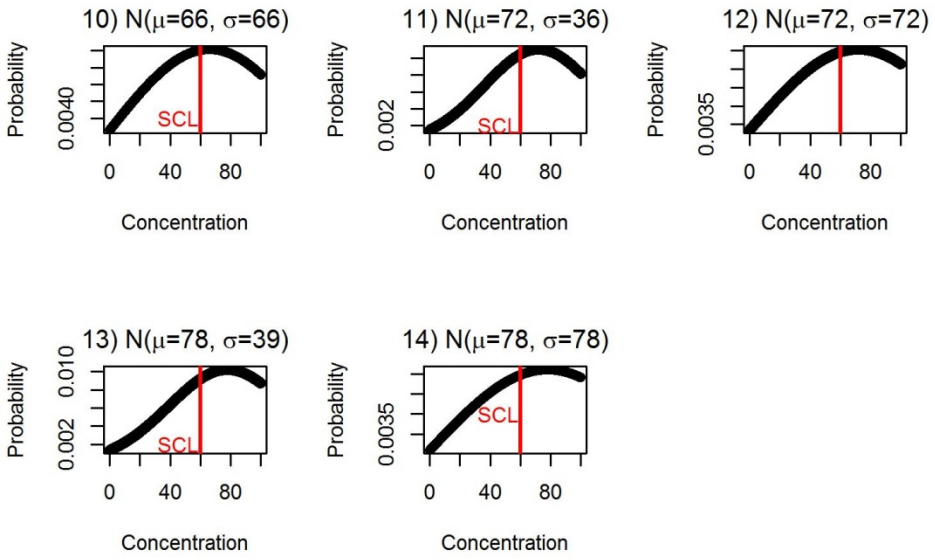
[1] The proportion of the specified distribution that exceeds the cleanup level of 60. It can also be thought of as the probability that an individual observation from the compliance monitoring data set will exceed the cleanup level.

[2] For the lognormal distributions, the mean (μ) and standard deviation (σ) are expressed on the natural log scale; the coefficient of variation is expressed on the natural (original) scale.



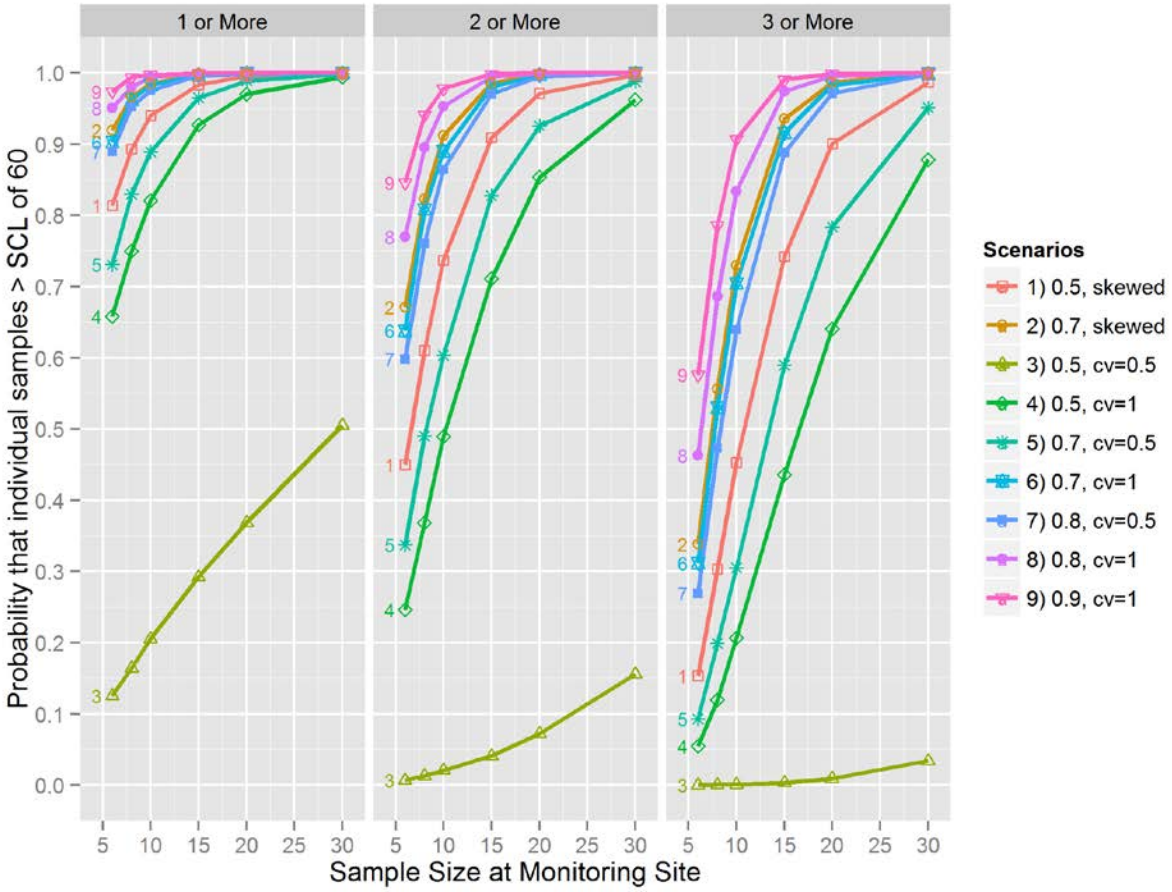

**Appendix L: Figure L-1.** Illustration of the simulated distributions used to estimate the false positive rates.

The means of these distributions are all below the cleanup level (Scenarios 1–9 in Table L-1).



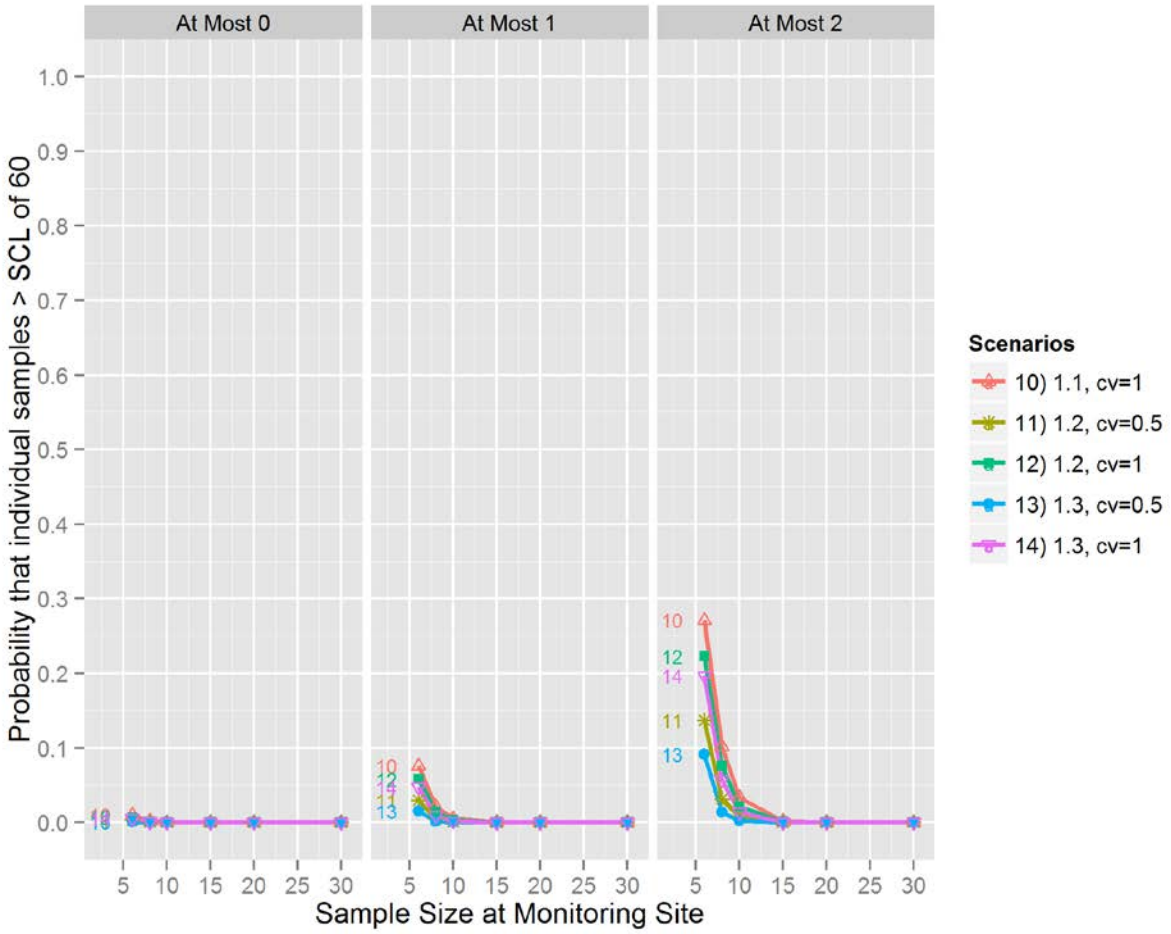

**Appendix L: Figure L-2.** Illustration of the simulated distributions used to estimate false negative rates.

The means of these distributions are all above the cleanup level (Scenarios 10–14 in Table L-1).



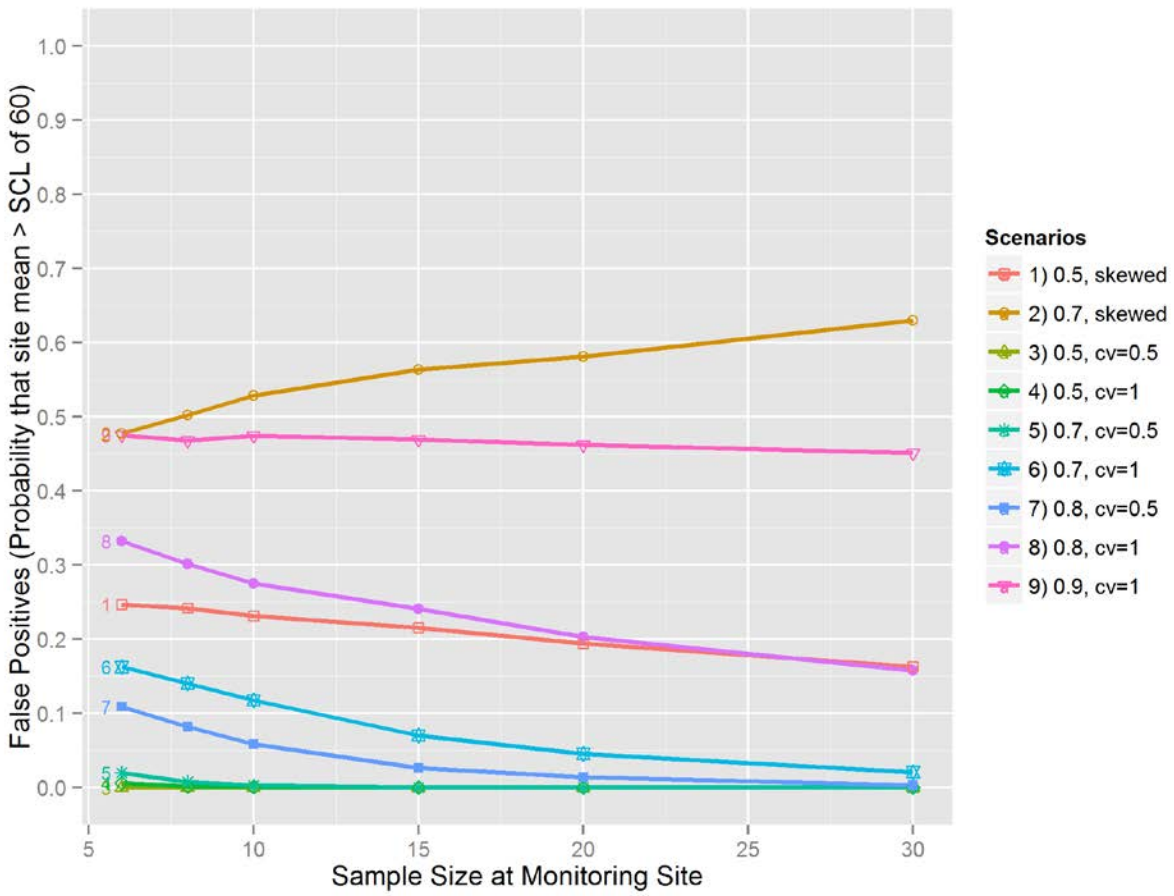

**Appendix L: Figure L-3.** False positive rates for Option A.

Frequency (from left to right) that one, two, or three or more individual samples from the compliance monitoring data set exceed the cleanup level when the true mean is below the cleanup level. Results based on 10,000 Monte Carlo simulations for nine different site scenarios with a true site mean below the cleanup level (see Table L-1 and Figure L-1). Sample sizes of *n* = 6, 8, 10, 15, 20, and 30 were evaluated.



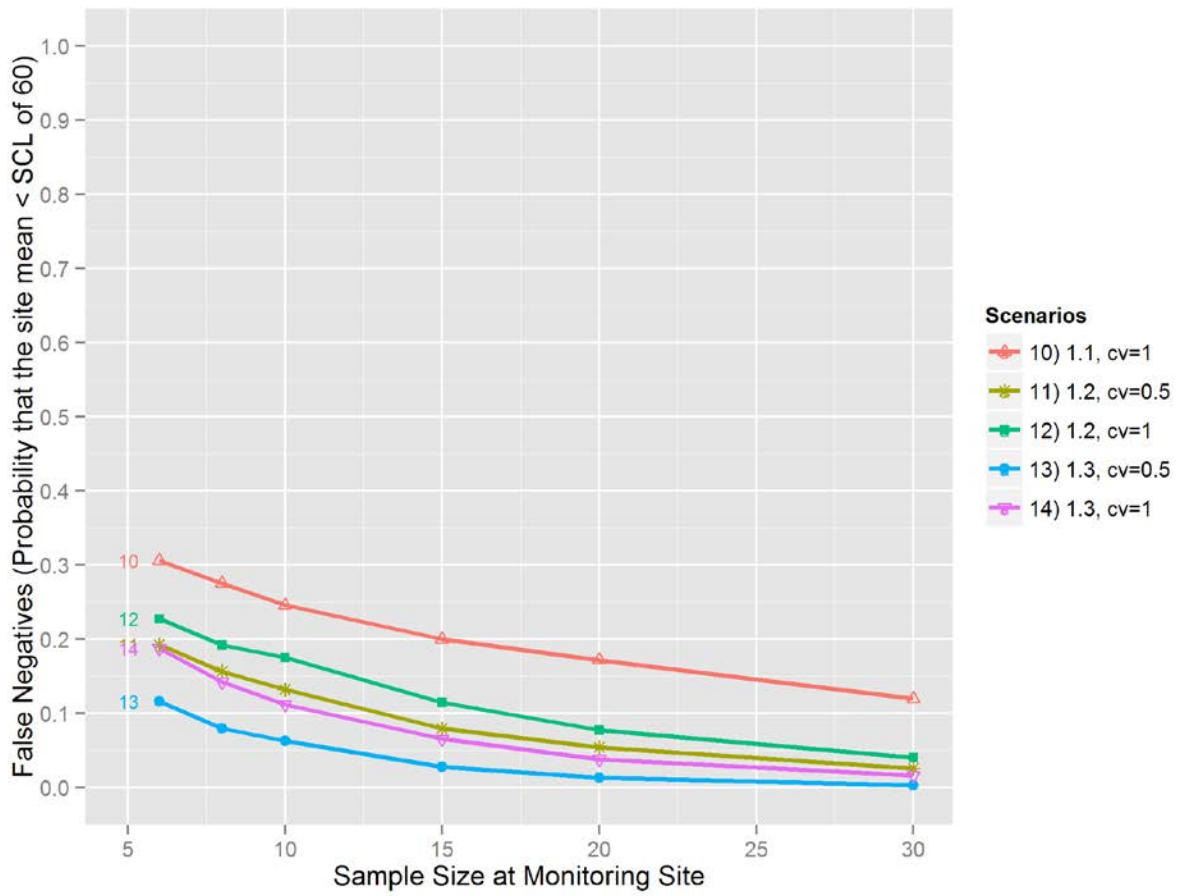

**Appendix L: Figure L-4.** False negative rates for Option A.

Frequency (from left to right) that not more than one, two, or three individual samples from the compliance monitoring data set exceed the cleanup level when the true mean exceeds the cleanup level. Results based on 10,000 Monte Carlo simulations for five different site scenarios with a true site mean above the cleanup level (see Table L-1 and Figure L-2). Sample sizes of $n$ = 6, 8, 10, 15, 20, and 30 were evaluated.



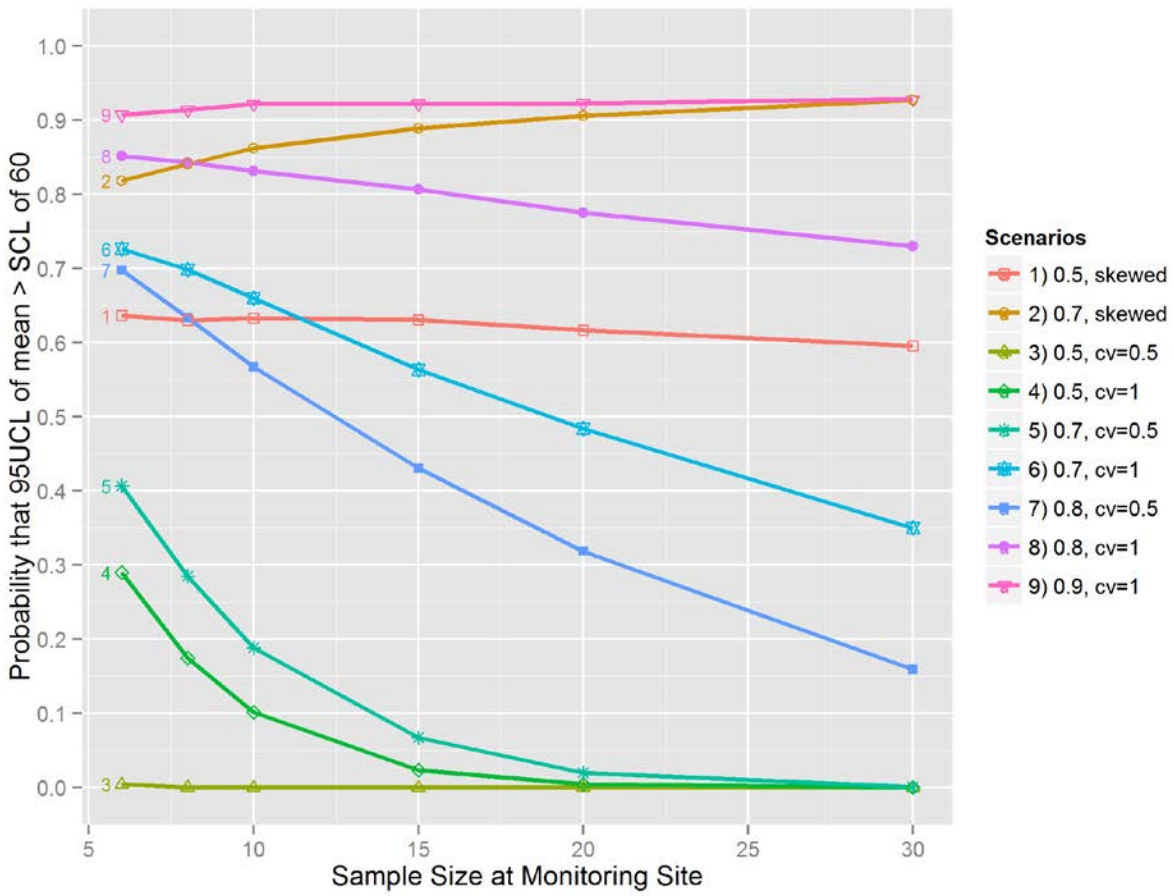

**Appendix L: Figure L-5.** False positive rates for Option B.

Frequency that the arithmetic mean of the compliance data set exceeds the cleanup level when the true mean is below the cleanup level. Results based on 10,000 Monte Carlo simulations for nine different site scenarios with a true site mean below the cleanup level (see Table L-1 and Figure L-1). Sample sizes of *n* = 6, 8, 10, 15, 20, and 30 were evaluated.



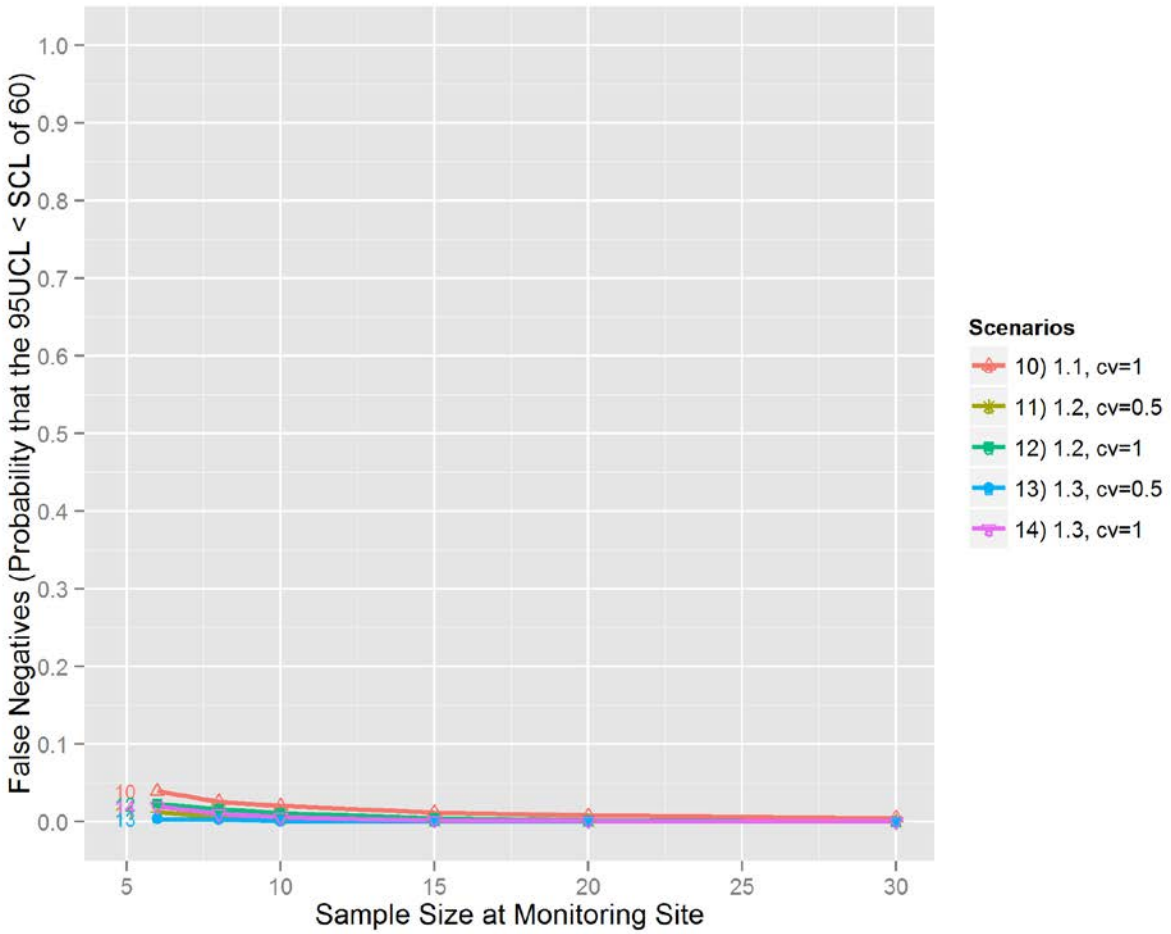

**Appendix L: Figure L-6.** False negative rates for Option B.

Frequency that the arithmetic mean of the compliance data set falls below the cleanup level when the true mean exceeds the cleanup level. Results based on 10,000 Monte Carlo simulations for five different site scenarios with a true site mean greater than the cleanup level (see Table L-1 and Figure L-2). Sample sizes of $n$ = 6, 8, 10, 15, 20, and 30 were evaluated.




**Appendix L: Figure L-7.** False positive rates for the alternative approach.

Frequency that the 95UCL of the mean of the compliance data set exceeds the cleanup level when the true mean is below the cleanup level. Results based on 10,000 Monte Carlo simulations for nine different site scenarios with a true site mean below the cleanup level (see Table L-1 and Figure L-1). Sample sizes of $n$ = 6, 8, 10, 15, 20, and 30 were evaluated.




**Appendix L: Figure L-8.** False negative rates for the alternative approach.

Frequency that the 95UCL of the mean of the compliance data set falls below the cleanup level when the true mean exceeds the cleanup level. Results based on 10,000 Monte Carlo simulations for five different site scenarios with a true site mean above the cleanup level (see Table L-1 and Figure L-2). Sample sizes of $n$ = 6, 8, 10, 15, 20, and 30 were evaluated.

*This page left intentionally blank.*

# Appendix M
# SCUM Revisions

## M.1 Introduction

This appendix is a record of when revisions were made and a brief summary of the topics addressed. SCUM is a living document and intended to accommodate substantial revisions as necessary on a biennial or as needed basis. The original publication date of this guidance was March 2015 and it has been revised in December 2017 and December 2019.

There will be a public process to update this guidance through the Sediment Management Annual Review Meeting (SMARM) held each May. Ecology will identify areas in this guidance that require updating and, depending on the type of updates, either update the public at SMARM or make proposed updates available for public review and comment through another appropriate process. In addition, members of the public may submit proposed changes for consideration to Ecology prior to SMARM, at SMARM, or during the public comment periods. Oral comments heard during the meeting and written comments received after the meeting will be considered before revisions to this document are finalized.

The most recent version of SCUM will be available online, with individual revisions recorded in this appendix as needed. If applicable, this appendix will cross-reference the specific SMARM issue or clarification paper in Appendix B that discusses the revisions in more detail

## M.2 Revisions Made for 2019 Version

| Chapter | Section/Table | Brief Summary of Revision(s) |
|---|---|---|
| 2 | 2.4 | Clarified how a site can be defined as "simple" vs "complex". |
| 4 | 4.2.2(5)(a)(iii) | Clarified that TOC outside the range of 0.5-3.5% could be considered unusual. |
| 4 | 4.2.3.1, Fig 4.1 | Corrected the appropriate amphipod species to use based interstitial salinity and % fines. |
| 4 | 4.3.2 and 4.3.3 | Revised timing and phasing of sampling specific to time of year, how to phase sampling for chemistry and bioassays if not taken at the same time, and added details on synoptic sampling. |
| 4 | 4.4.3 | Added added consistent language related to incremental sampling methodology consistent with Ch 13. |
| 4 | 4.5.4 | Added clarification to passive sampling and an EPA reference. |
| 5 & App J | 5.4.5.1/J.1-J.3 | Language clarified regarding protocols for analyzing sediment for sulfides and ammonia. |
| 5 | Table 5-1 | Corrected table e,f,g footnotes for benzofluoranthenes, 4 Methylphenol, Chlordane compounds |
| 6 | 6.3.1.1 | Corrected polar organics to non-polar organics and clarified steps to take with unusual TOC. |
| 6 | 6.3.3.1 | Clarified blank contamination results reporting above the Reporting Limit. |
| 6 | 6 | Corrected page #s for Chapter 6. |
| 6/App A | 6.3.1.2/A.7 | Added language that EIM data submittal required before Data Reports are approved |
| 7 | 7.2.3.2 | • Clarified in red text that Ecology could (but is not obligated to) adjust cleanup levels<br>• Clarified source control actions to address recontamination. |
| 7 | 7.3 | • Clarified that the point of compliance is based on the depth of species likely to be present. |
| 8 | Table 8-1<br><br>Table 8-2<br>8.3.1.2 | • Corrected DDD and DDT isomers (o to p).<br>• Added information about the preferred reference location of Carr Inlet.<br>• Corrected bivalve CSL interpretive criteria NT/NR > 0.70 should be NT/NR < 0.70.<br>• Included use of the Microtox bioassay test for freshwater sediment. |
| 2, 3, 6, 12 | 2, 3, 6, 12 | Incorporated climate change guidance (Publication No. 17-09-052) into appropriate sections: 2.3, 2.4, 3.1.2, 4.3.2, 3.3.1, 3.4.4, 6.2, 6.4.2, 6.5, 12.2, 12.4.3, 12.4.4, 12.4.5.1. |
| 9 | 9.3.2.1, 9.2.1, 9.2.2.1 | • Revised the list of bioaccumulative chemicals to be fluoranthene, not phenanthrene.<br>• Added policy for early life exposure for mutagens (cPAHs) when calculating risk-based values. |

| Chapter | Section/Table | Brief Summary of Revision(s) |
|---|---|---|
| 9/App E | Tables 9-1a, 9-1b, 9-2, 9-4, App E.2.1, E.2.3, | • Updated calculated values for cPAHs to reflect updated EPA cancer slope factor and early life exposure and EPA Exposure Factors Handbook, 2011.<br>• Clarified that PCBs were dioxin-like PCBs.<br>• Revised cancer averaging time from 75 to 70 years for subsistence fishers and updated body weights, dermal surface area.<br>• Corrected CPF to CPFo in Equation E-1.<br>• Updated table values to reflect changes in Appendix K (see next page for Appendix K changes) |
| 10 | 10.3.1, 10.3.2.3, Table 10-2 | Added information for South Puget Sound regional background |
| 10 | Table 10-1 | Clarified PCB TEQs for dioxin-like congeners should be used to establish cleanup levels. |
| 10 | Table 10-2 | Clarified that if regional background is not established or if regional background is actually lower than Puget Sound natural background then there is a default to natural background. Added South Puget Sound regional background values to Table 10-2. |
| 12 | 12.4.3.3 | Revised text on the use of activated carbon amendments |
| 12 | 12.4.5.2 | Clarified in red text that: when conducting the DCA for a site with an upland and sediment ~~unit~~, the DCA should be performed separately for each. |
| 3, 7, 13 | 3.3.6.2, 7.1, 13.4.2, 13.6.2 | Added use of porewater for compliance monitoring, that porewater for sediment is in biologically active zone, where the BAZ is, groundwater POC is under biologically active zone and is not porewater |
| 13 | 13.1-13.4 | Reordered text to harmonize with MTCA monitoring definitions. No substantive changes made. |
| 16 | | Added a new chapter to provide more e guidance on BMPs for removal of creosote pilings |
| 17 | | Changed Chapter # and updated RSET reference to 2016; added South Puget Sound RB report. |
| App A | A.1.2.3 | Clarified how to use freshwater sediment bioassays. |
| App D | D-2 | Clarified language on LLOQ and non-detected sample results reporting |
| App E | Table E-4 | Corrected Table E-4 references and changed body from 80kg to 75kg. |
| App G | Table G-1 | Added “for working in the intertidal area” to a BMP. |

| Chapter | Section | Brief Summary of Revision(s) |
|---|---|---|
| App K | | STEP 1<br>• Added non-cancer toxicity values for cPAHs<br>• Clarified that PCBs were dioxin-like PCBs<br>• Dioxin-like PCBs and dioxins/furans were assigned a Gastrointestinal (GI) Absorption Conversion Factor of 0.8.<br>• For GI values, changed "Dioxins/Furans" to "Dioxins/Furans/dioxin-like PCB"s.<br>• Clarified that Tributyltin is applied to TBT oxide, not other reported forms.<br>STEP 2:<br>• Updated Gastrointestinal absorption fraction and dermal absorption fraction based on EPA RAGS Part E<br>• Changed averaging time from 75 to 70 years<br>• Corrected exposure frequency from 65 to 41<br>• Corrected significant figures<br>• Updated fish consumption rates based on Ecology 2013 FCR Technical Report (90th percentile values Tulalip tribe 193 g/d; Suquamish tribe 489 g/d; Columbia River ITFC 130 g/d). The previous calculations were based on rates from the 2011 draft report.<br>STEP 3: Added early life exposure data fields and updated parameters based on Chapter 9<br>SHEET "Consumption_HH_Tissue": Added early life exposure column and hidden equations<br>SHEET "Consumption_Sediment"<br>• Added equation for correctly calculating sediment SLs for organics<br>• Added language clarifying that original equation for metals only<br>• Corrected calculation in spreadsheet:<br>$$Sediment\ SL = \frac{TSL * \left(\frac{\%TOC}{100}\right)}{SUF * BSAF * \left(\frac{\%lipid}{100}\right)}$$<br>SHEET "IngestionDermal_Sediment"<br>• Added early life exposure hidden calculations<br>• Title of table referenced Chapter 9 |

## M.3 Revisions Made for 2017 Version

| Chapter | Section | Brief Summary of Revision(s) |
|---|---|---|
| 1 | 1.4 | Updated section to reflect creation of new Appendix M. |
| 2 | 2.2.1 | Changed sentence: Sediment values above the SCO but at or below the CSL are expected to have minor adverse effects on the benthic community. |
| 3 | 3.3.6.2 | Added option of screening CoCs using combined dioxins/furans TEQs and dioxin-like PCB TEQs. |
| 4 | 4.2.2(4)(e)/(f) | Last sentence in subsection (f) removed and added to temperature subsection (e). |
| 4 | 4.2.2(5)(a)(ii) | Added the following: For TOC outside this range, compare sediment concentrations to both TOC normalized and dry weight AET values (Table 8-1). Any exceedances at the highest magnitude (SCO or CSL) are used for that station. If more than one CoC at a station is close to exceeding the SCO, bioassays may need to be conducted for that station. |
| 4 | 4.2.3.2 | Clarified freshwater bioassay requirements as three toxicity test endpoints. |
| 5 | Table 5-1 | PSEP 1997a changed to PSEP 1986 for solids, TVS, and grain size. PCB sum TEQ added as chemicals of special concern and recommended EPA Method 1668. Updated total sulfides method. |
| 5 | 5.1.1.4 | Added the concept of lower level of quantitation (LLOQ) to the PQL definition as an appropriate equivalent, per EPA SW-846 methods. Clarified that MDL must be reported per MTCA requirements. |
| 5 | 5.4.2 | Changed “recovery” to “measured concentration” in precision equation for clarification. |
| 5 | Table 5-3 | Revised corrective actions for matrix spikes. |
| 6 | 6.3.1 | • Added TOC normalization conversion equation.<br>• Clarified dry weight in TOC normalization process.<br>• Clarified PQL reporting to EIM. |
| 6 | 6.3.2 | • Added instructions to calculate derived variables in EIM and clarified how to evaluate PCB congeners.<br>• Included option to sum dioxins/furans and dioxin-like PCB TEQs as one CoC for dioxin-like carcinogenic effects. |

*(Continued next page)*

| Chapter | Section | **Brief Summary of Revision(s)** *(continued from previous page)* |
|---|---|---|
| 6 & 8 | 6.3.2<br>Table 8-1 | • Added option of using Total PCB congeners in place of PCB Aroclors for benthic criteria.<br>• Clarified when bioassays should be conducted if Total PCB congeners are used in place of Aroclors for assessing impacts to the benthic community and compliance with the benthic criteria. |
| 8 | Tables 8-2 & 8-4 | ▪ The > or < signs changed to ≥ or ≤ as appropriate consistent with the SMS rule, Part III criteria.<br>• *Neanthes* performance standard revised to reflect SMARM paper (ash free dry weight, 0.72 to 0.318).<br>• Performance standard for *Chironomus dilutus* growth endpoint corrected to 0.48 mg/individual AFDW and clarified the dry weight value in footnote d. |
| 9 | Equation | Simplified equations 9-1 and 9-2 by moving the UCF to the numerator, no significant change. |
| 9 | 9.2.1 | Added option of combining dioxins/furans and dioxin-like PCB TEQs. |
| 9 | 9.3.3<br>Table 9-1 | Throughout this section lipid-normalization and OC-normalization have been assumed, so there are minor fixes throughout to accommodate dry weight BSAFs:<br>1) Added units to the equation in the introduction<br>2) Edits to page 9-20<br>3) What to do with an OC-normalized value in the introduction and section 9.3.3.3.<br>4) Corrected App E references.<br>Relating to Appendix K, sections 9.3.3 and 9.3.3.1 have been modified. |
| 10 | Table 10-1 | • Added Total PCB congeners natural background value, but Ecology recommends use of dioxin-like TEQs.<br>• Clarified Puget Sound sediment includes marine sediment.<br>• Clarified TEQ is sum TEQ. |
| 10 | Table 10-2 | • Added a new table that summarizes the regional background values Ecology has established. |
| 10 | 10.1.2 | • Corrected an error by moving the sediment cleanup objective concept under regional background to natural background.<br>• Clarified what occurs when regional background has not been, or cannot be, established. |
| 10 | 10.1.1 & 10.1.2 | Reversed the order of sections 10.2.1 and 10.1.1. |
| 10 | 10.3.2 | Added new guidance on how to establish regional background using existing data based on the Lake Washington Area report. |

| Chapter | Section | **Brief Summary of Revision(s)** *(continued from previous page)* |
|---|---|---|
| 11 | Table 11-1 | Added tissue PQLs for dioxins/furans and mercury. |
| 11 | 11.3 | Remove fourth duplicative paragraph beginning "It is important to reach an…." |
| 12 | 12.3 | Clarified how sediment cleanup units can be defined. |
| App A | Table A-2 | • Corrected biological criteria consistent with the SMS rule and Chapter 8.<br>• Included adding SIZmax exceedances to the map.<br>• Corrected minor editing errors. |
| App C | C.3 | Added a new section explaining the concept of reference and control sediment samples for bioassays. |
| App D | D-5, Table D-2 | Added dioxins/furans and mercury tissue EIM data and explanatory language to show how PQLs were calculated. |
| App D | D.2 | Added the concept of lower level of quantitation (LLOQ) to the PQL section. |
| App E | E.2.2 | AD (adsorbed dose) should be AF (sediment to skin adherence factor) in Equations E-3 and E-4. |
| App E | E.2.1.2 | Updated this section on fish consumption rates to reflect the adoption of new water quality standards. |
| App E | Table E-1 | Corrected section number references. |
| App G | | Added EPA Best Management Practices guidance reference. |